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APPENDIX 3A- DESIGN ASSESSMENT REPORT

3A.1 GENERAL INFORMATION

3A.1.1 PURPOSE OF REPORT

The purpose of this Design Assessment Report is to present evidence that the Limerick Generating Station design margins are adequate if the plant should be subjected to the recently defined thermohydrodynamic loads that result from SRV operations and/or discharges during a LOCA in a GE boiling water reactor.

3A.1.2 BACKGROUND

The history of the recently defined Mark II thermohydrodynamic loading issue is based on two distinctive events. First, in April 1972, at the German AEG-Kraftwerk Union Wurgassen Nuclear Plant, a BWR SRV was opened during startup testing and failed to close. The reactor remained at full pressure, and the valve discharged reactor steam into the containment suppression chamber until the suppression pool water heated from just above ambient to almost 170°C (in approximately 30 minutes). Pulsating condensation developed and large impulsive forces with substantial underpressure amplitudes acted upon the containment, eventually causing leakage from the bottom liner plate. Therefore, concern was expressed that the structural integrity of other BWR pressure containment systems could be sensitive to SRV induced dynamic loads. The Nuclear Regulatory Commission issued Bulletin 74-14 to all BWR owners on November 14, 1974, to alert them to the potential problems of condensation instability (Wurgassen effect) due to SRV operation. The NRC requested verification that BWR suppression pools had been designed to withstand loads similar to those being experienced.

Secondly, in January 1975, GE-NEPD identified the dynamic loading conditions due to LOCA hydrodynamic phenomena that result from vent clearing and pool-swell. These loads had not been fully considered in the design criteria of Mark II BWR containments.

It became evident that a complex technical issue existed for all Mark II plants. PECo took part in the formation of a unified utility group to address the matter. A Mark II BWR containment owners group was formed in June 1975 to define the suppression pool dynamic loads and to explore ways to assess their impact. As the direct result of action taken by the Mark II containment owners organization, a generic Dynamic Forcing Function Information Report was issued jointly by GE-NEPD and Sargent and Lundy for the Mark II owners in September 1975 (Section 3A.1.3).

3A.1.3 MARK II CONTAINMENT PROGRAM

PECo is a member of the Mark II owners group that was formed in June 1975 to define and investigate the dynamic loads due to SRV discharge and LOCA. The methods for calculating these hydrodynamic loads are described in the DFFR (Reference 3A-1). The DFFR also specifies load combinations for plant design assessment. The methods provided in the DFFR are based on a combination of analytical models, test data, and engineering judgment. The methods and information provided are sufficient for use in a conservative evaluation of the design adequacy of Mark II structures and components.

The Mark II Owners Group Containment Program concentrated initially on the tasks required for the licensing of the lead-plants (Zimmer, LaSalle, and Shoreham). This Lead-Plant Program established interim bounding loads appropriate for the anticipated life of each of the lead-plants.

The NRC acceptance criteria for the lead-plant LOCA and SRV load definitions are described in NUREG-0487 (Reference 3A-2) and NUREG-0487 Supplements 1 and 2 (References 3A-3 and 3A-4, respectively).

The remainder of the Mark II Owners Group Program concentrated on the tasks required to license the long-term plants, which include LGS. The NRC acceptance criteria for the long-term plant LOCA and SRV load definitions are described in NUREG-0808 (Reference 3A-5) and NUREG-0802 (Reference 3A-6), respectively. The objectives of the Long-Term Program were (a) to provide justification, by tests and analyses, for refinement of selected lead-plant bounding loads, and (b) to provide additional confirmation of certain loads used in the Lead-Plant Program.

As a task separate from the Mark II Owners Group Program, a Mark II SRV discharge Line T-quencher device and load specification was developed in 1978 by Kraftwerk Union for Pennsylvania Power and Light for use in the Susquehanna Steam Electric Station. The T-quencher provides a reduction in the containment wall loads as compared to the loads generated by the original Ramshead quencher design. The T-quencher also promotes effective heat transfer and condensation of discharge steam in the suppression pool. PECo decided to use the same T-quencher design for LGS. Following this decision, KWU compared the LGS and SSES SRV-related parameters and concluded that the same load specification could be used by PECo for the LGS containment analysis. The LGS and SSES SRV-related parameters are compared in Table 3B-1.

The quencher load specification was submitted to the NRC by PP&L in April 1978. In addition, a full-scale SSES unique unit cell test (Section 3B.8) was performed by KWU in 1979. This test verifies KWU's design approach for the quencher load specification used for LGS.

Table 3A-1 provides a summary of the LGS licensing basis as a result of the Mark II Containment Program.

Table 3A-2 presents a summarizing review of the LGS suppression pool dynamic loadings. This is achieved by comparing the NRC Acceptance Criteria with the LGS plant unique position.

3A.1.4 PLANT DESCRIPTION

The LGS, Units 1 and 2, is located on the east bank of the Schuylkill River in Limerick Township of Montgomery County, Pennsylvania, approximately 1.7 miles southeast of the limits of the Borough of Pottstown and approximately 20.7 miles northwest of the Philadelphia city limits. Each of the LGS units employs a GE BWR designed to operate at a rerated core thermal power of 3515 MWt.

3A.1.4.1 Primary Containment

The containment is a reinforced concrete structure consisting of a cylindrical suppression chamber beneath a truncated conical drywell. Figures 3A-1 and 3A-2 show the cross-section of the containment and suppression chamber (including pedestal), respectively. The conical portion of the primary containment (drywell) encloses the reactor vessel, reactor coolant recirculation loops, and associated components of the RCS. The drywell is separated from the wetwell, i.e., the pressure- suppression chamber and pool, by the drywell floor, also named the diaphragm slab. The cone and cylinder form a structurally integrated reinforced concrete vessel, lined with steel plate and closed at the top of the drywell with a steel domed head. The carbon steel liner plate is anchored to the concrete by structural steel members embedded in the concrete and welded to the liner plate.

The entire containment is structurally separated from the surrounding reactor enclosure except at the base foundation slab (a reinforced concrete mat, top lined with a carbon steel liner plate) where a seismic gap filled with rodofoam is provided between the two adjoining foundation slabs. The containment structure dimensions and parameters are listed in Tables 3A-3 and 3A-4.

Major systems and components in the containment include the vent pipe system (downcomers) connecting the drywell and wetwell, vacuum relief system, containment cooling system, and MSRV discharge piping and associated quencher components. Figure 3A-3 shows the locations and orientation of the quenchers and discharge piping.

3A.1.4.1.1 Penetrations

Services and communications between the inside and the outside of the containment are performed through penetrations. Basic penetration types include pipe penetrations, electrical penetrations, and access hatches (equipment hatches, personnel lock, suppression chamber access hatches, and CRD removal hatch). Each penetration consists of a pipe sleeve with an annular ring welded to it. The ring is embedded in the concrete wall and provides an anchorage for the penetration to resist normal operating and accident loads. The pipe sleeve is also welded to the containment liner plate to provide a leak-tight penetration.

3A.1.4.1.2 Internal Structures

The internal structures consist of reinforced concrete and structural steel and have the major functions of supporting and shielding the rector vessel, supporting the piping and equipment, and forming the pressure-suppression boundary. These structures include the diaphragm slab, the reactor pedestal (a concentric cylindrical reinforced concrete shell resting on the containment base foundation slab and supporting the reactor vessel; Figure 3A-2 shows pedestal cross-section), the reactor shield wall, the suppression chamber columns (hollow steel pipe columns supporting the diaphragm slab), the drywell platforms, the seismic trusses, the quencher supports, and the reactor steam supply systems supports.

3A.2 SUMMARY

3A.2.1 LOAD DEFINITION SUMMARY

3A.2.1.1 SRV Load Definition Summary

Hydrodynamic loads resulting from SRV actuation fall into two categories: loads on the SRV system itself (the discharge line and the discharge quencher device), and the loads on the suppression pool walls and submerged structures.

Loads on the SRV system during SRV actuation include loads on the SRV piping due to effects of steady back pressure, transient water slug clearing, and SRV line temperature. Determination of loading on the quencher body, arms, and support is based on transients resulting from valve opening (water clearing and air clearing), valve closing, and operation of an adjacent quencher.

Air clearing loads are examined for four loading cases: symmetric (all-valve) SRV actuation, asymmetric adjacent SRV actuation, single SRV actuation, and automatic depressurization system (ADS-five valve) actuation. Dynamic forcing functions for loading of the containment walls, pedestal, basemat, and submerged structures are developed using techniques discussed in

Section 3B.4.1 and 3A.11. Loads on the SRV system due to SRV actuation are discussed in Section 3B.4.1.3, and loads on suppression pool walls and submerged structures due to SRV actuation are discussed in Section 3B.4.1.4. A full-scale, unit cell test program was conducted at the KWU laboratories to verify these SRV loading specifications. These tests are described in Section 3B.8.

Adjacent structures indirectly affected by SRV loads include the reactor enclosure, control structure, and associated equipment and components. The assessment methodology used in determining the SRV load effect on these adjacent structures is described in Section 3A.7.1.1.2.

3A.2.1.2 LOCA Load Definition Summary

The spectrum of LOCA-induced loads acting on the LGS containment structure is characterized by LOCA loads associated with pool-swell and condensation oscillation and chugging, as well as long-term and secondary LOCA loads.

The LOCA loads associated with pool-swell result from short duration transients and include downcomer clearing loads, water jet loads, pool-swell impact and drag loads, poll fallback drag loads, pool-swell air bubble loads, and loads due to drywell and wetwell temperature and pressure transients. Techniques used to evaluate these loads are described in Section 3A.4.2.1.

Condensation oscillations result from mixed flow (air-steam) and pure steam flow effects in the suppression pool. Chugging loads result from low mass flux pure steam condensation. The load definitions from these phenomena are contained in Section 3A.4.2.2.

Long-term LOCA loads result from those wetwell and drywell pressure and temperature transients associated with DBAs, IBAs, and SBAs. Their load definitions are contained in Section 3A.4.2.4.

Structures directly affected by LOCA loads include the drywell walls and floor, wetwell walls, RPV pedestal, basemat, liner plate, columns, downcomers, downcomer bracing system, and wetwell piping. Their loading conditions are described in Section 3A.4.2.5.

Adjacent structures indirectly affected by LOCA loads include the reactor enclosure, control structure, and associated equipment and components. The assessment methodology used in determining the LOCA load effect on these adjacent structures is described in Section 3A.7.1.1.2.

3A.2.2 Design Assessment Summary

Design assessment of the LGS structures and components is achieved by analyzing the response of the structures and components to the load combinations explained in Section 3A.5. In Section 3A.7, predicted stresses and responses (from the loads defined in Sections 3A.4 and 3B.4 and combined as described in Section 3A.5) are compared with the applicable code allowable values identified in Section 3A.6.

3A.2.2.1 Containment Structure, Reactor Enclosure, and Control Structure Assessment Summary

3A.2.2.1.1 Containment Structure Assessment Summary

The primary containment walls, base slab, diaphragm slab, reactor pedestal and reactor shield are analyzed for the effects of SRV and LOCA in accordance with Table 3A-14. The ANSYS finite-element program is used for the dynamic analysis of structures.

Response spectra curves are developed at various locations within the containment structure to assess the adequacy of components. Stress resultants due to dynamic loads are combined with other loads in accordance with Table 3A-14 to evaluate rebar and concrete stresses. Design safety margins are defined by comparing the actual concrete and rebar stresses at critical sections with the code allowable values. The assessment methodology of the containment structure is given in Section 3A.7.1.1.1.

The containment mode shapes, modal frequencies, and hydrodynamic response spectra are given in Section 3A.9.

The results of the structural assessment of the containment structure are given in Section 3A.12.

3A.2.2.1.2 Reactor Enclosure and Control Structure Assessment Summary

The reactor enclosure and control structure are assessed for the effects of SRV and LOCA loads in accordance with Table 3A-14 and Table 3A-15.

Pressure time histories in the wetwell are used to investigate the reactor enclosure and control structure response to SRV and LOCA loads. Maximum time history force responses and broadened response spectra curves are approximately used to assess the adequacy of associated structural components. The assessment methodology of the reactor enclosure and control structure is presented in Section 3A.7.1.1.2.

The mode shapes, modal frequencies, and hydrodynamic response spectra of the reactor enclosure and control structure are presented in Section 3A.10.

The results of the structural assessment are summarized in Section 3A.13.

3A.2.2.2 Containment Submerged Structures Assessment Summary

Load combinations for the downcomer bracing and suppression chamber columns are presented in Table 3A-15. Load combinations for the downcomers are presented in Table 3A-17. The hydrodynamic design assessment methodology for the downcomers, bracing, and columns is presented in Sections 3A.7.1.2 and 3A.7.1.4. The results of the analysis are presented in Section 3A.12.

The suppression pool liner plate loads are combined in accordance with Table 3A-14. Results from the analysis indicated that no structural modification is required (Sections 3A.7.1.3 and 3A.7.2.1.5).

3A.2.2.3 BOP Piping Systems Assessment Summary

Containment and reactor enclosure BOP piping systems were analyzed by the methods presented in Section 3A.7.1.5. The load combinations for piping are described in Table 3A-18. The results of the analysis are presented in Section 3A.14.

3A.2.2.4 NSSS Assessment Summary

3A.2.2.4.1 Introduction

GE performed a design assessment of LGS Unit 1 to demonstrate that the NSSS piping and safety-related equipment and associated supports have sufficient capability to accommodate combinations of seismic and hydrodynamic loadings. The scope of the evaluation included the RPV, RPV internals and associated equipment, main steam and recirculation piping, and GE-supplied floor-mounted equipment, pipe-mounted equipment, and control and instrumentation equipment and all associated supports.

The methodologies described in Section 3A.7.1.6 were used to perform the evaluation. Load combinations and acceptance criteria listed in Table 3A-19 were used for the evaluation of ASME Class 1, 2 and 3 piping, equipment, and supports.

3A.2.2.4.2 Design Assessment Results

The results of the assessment have demonstrated that the NSSS piping and safety-related equipment have sufficient capability to accommodate combinations of seismic and hydrodynamic loadings for the normal, upset, emergency and faulted conditions.

Detailed results of the NSSS piping and major safety-related equipment evaluations are given in Sections 3.9 and 3.10.

3A.2.2.5 BOP Equipment Assessment Summary

Safety-related BOP equipment in the containment, reactor enclosure, and control structure are assessed by the methods contained in Section 3A.7.1.7. Loads are combined as shown in Table 3A-20.

3A.2.2.6 Electrical Raceway System Assessment Summary

The electrical raceway system located in the containment, reactor enclosure, and control structure is assessed for load combinations in accordance with Table 3A-21. The assessment methodology and analysis results are presented in Section 3A.7.1.8.

3A.2.2.7 HVAC Duct System Assessment Summary

The HVAC duct system located in the containment, reactor enclosure, and control structure is assessed for load combinations in accordance with Table 3A-22. The assessment methodology and analysis results are presented in Section 3A.7.1.9

3A.2.2.8 Suppression Pool Temperature Assessment Summary

SPTMS design criteria and adequacy assessment, analysis of suppression pool temperature response to SRV discharge, and analysis of the suppression pool local-to-bulk temperature difference (ΔT) are presented in Section 3A.15.

3A.2.2.9 Wetwell-to-Drywell Vacuum Breaker and Downcomer Capping Assessment Summary

The assessment of the wetwell-to-drywell vacuum breakers to adequately withstand the dynamic effects of pool-swell and chugging is summarized in Section 3A.16. The design assessment of the downcomer capping arrangement is also summarized in Section 3A.16.

3A.3 SRV DISCHARGE AND LOCA TRANSIENT DESCRIPTION

3A.3.1 DESCRIPTION OF SAFETY/RELIEF VALVE DISCHARGE

LGS is equipped with a safety/relief system that condenses reactor steam in a suppression chamber pool. By this arrangement, reactor steam is conducted to the wetwell via fast-acting SRVs and quencher-equipped discharge lines. This section discusses the causes of SRV discharge, describes the SRV discharge process, and identifies the resultant SRV discharge actuation cases. Section 3B.4.1 presents a quantitative description of specific SRV-related loads.

3A.3.1.1 Causes of SRV Discharge

During certain reactor operating transients, the SRVs may be actuated (by pressure, by electrical signal, or by operator action) for rapid relief of pressure in the RPV. The following reactor operating transients have been identified as those which may result in SRV actuation:

a. Turbine-generator trip (with bypass or without)

b. MSIV closure

c. Loss of condenser vacuum

d. Feedwater controller failure - maximum demand

e. Pressure regulator failure - closed

f. Generator load rejection (with and without bypass)

g. Loss of ac or auxiliary power

h. Loss of feedwater flow

i. Trip of two recirculation pumps

j. Recirculation flow control failure - decreasing flow

k. Inadvertent safety/relief valve opening

l. Control rod withdrawal error

m. ATWS

n. Failure of shutdown cooling

A description of these transients is provided in Chapter 15.

3A.3.1.2 Description of the SRV Discharge Phenomena and SRV Loading Cases

Before an individual SRV opens, the water level in the discharge line is approximately equal to the water level in the pool. As a valve opens, steam flows into the discharge line air space between the valve and the water column and mixes with the air. Because the downstream portion of the discharge line contains a water slug, the pressure inside the line increases. The increased pressure expels the water slug from the SRV discharge line and quencher. The magnitude of the water clearing pressure is primarily influenced by the steam flow rate through the valve, the degree to which entering steam is condensed along the discharge line walls, the volume of the discharge line airspace, and the volume of the water slug to be accelerated.

The clearing of water is followed by an expulsion of the enclosed air-steam. The exhausted gas forms an oscillating systems with the surrounding water, where the gas acts as the spring and the water acts as the mass. This oscillating system is the source of short-term air clearing loads.

As the air-steam mixture oscillates in the pool, its also rises because of buoyancy and eventually breaks through the pool water surface, at which time air clearing loads cease. When all the air leaves the safety/relief system, steam flows into the suppression pool through the quencher holes and condenses. The LGS quencher design ensures stable condensation even with elevated pool water temperature.

The SRV actuation cases resulting from the transients listed in Section 3A.3.1.1 are classified as being bounded by one of the following cases:

a. Symmetric all-valve, or abnormal operating transient discharge

b. Asymmetric discharge

c. Single valve discharge

d. ADS discharge

The symmetric discharge case is classified as the type of SRV discharge that would follow rapid isolation of the vessel from the turbine such as turbine trip, closure of all MSIVs, loss of condenser vacuum, etc. As pressure builds up following isolation of the vessel, the SRVs actuate sequentially according to the pressure setpoints of the valves. This may or may not result in actuation of all the SRVs, but for conservatism in loading considerations, all valves are assumed to actuate simultaneously.

Asymmetric discharge is defined as the firing of the SRVs for the three adjacent quencher devices which results in the greatest asymmetric pressure loading on the containment. This situation is hypothesized when, following a reactor scram and isolation of the vessel, decay heat raises vessel pressure so that low setpoint valves actuate. If, during this time of discharge of decay heat energy, manual actuation of the two other adjacent SRVs that comprise the asymmetric case is assumed, this actuation would result in the maximum asymmetric pressure load on the containment.

The single valve discharge case is classified as the firing of the SRV which gives the single largest hydrodynamic load. Transients that could potentially initiate such a case are an inadvertent SRV discharge or DBA. Refer to Section 3A.3.2.3 for a discussion of the latter possibility.

The ADS discharge is defined as the simultaneous actuation of the five SRVs associated with the ADS. Figure 3A-3 shows the location of the quencher devices associated with the ADS valves. The ADS is assumed to actuate during an IBA or SBA. (The IBA and SBA are described in Sections 3A.3.2.2 and 3A.3.2.1, respectively.) The effects of an increased suppression pool temperature (resulting from steam condensation during the LOCA transient) and increased suppression chamber pressure (resulting from clearing of the drywell air into the pool during the transient) are considered in the calculation of pressure loadings for the ADS discharge case.

Section 3A.4.1.4.2 describes the loads resulting from symmetric, asymmetric, single valve, and ADS discharge transients.

3A.3.2 Description Of Loss-Of-Coolant Accident

This event involves the postulation of a spectrum of piping breaks inside the containment varying in size, type, and location. For the analysis of hydrodynamic loadings on the containment, the postulated LOCA event is identified as a SBA, and IBA, or a DBA.

3A.3.2.1 Small Break Accident

This section discusses the containment transient associated with small primary system blowdowns. The primary system ruptures in this category are those ruptures that will not result in reactor depressurization from either loss of reactor coolant or automatic operation of the ECCS equipment, i.e., those ruptures with a break size less than 0.1 ft^2.

The following sequence of events is assumed to occur. With the reactor and containment operating at the maximum normal conditions, a small break occurs that allows blowdown of reactor steam or water to the drywell. The resulting pressure increase in the drywell leads to high drywell pressure signal that scrams the reactor and activates the containment isolation system. The drywell pressure continues to increase at a rate dependent upon the size of the steam leak. The pressure increase lowers the water level in the downcomers. At this time, air and steam enter the suppression pool at a rate dependent upon the size of the leak. Once all the drywell air is carried over to the suppression chamber, pressurization of the suppression chamber ceases and the system reaches an equilibrium condition. The drywell contains only superheated steam, and continued blowdown of reactor steam condenses in the suppression pool. The principal loading condition in this case is the gradually increasing pressure in the drywell and suppression pool chamber and the loads related to the condensation of steam at the end of the vents.

3A.3.2.2 Intermediate Break Accident

This section discusses the containment transient associated with intermediate primary system blowdowns. This classification covers breaks for which the blowdown will result in limited reactor depressurization and operation of the ECCS, i.e., the break size is equal to slightly greater than 0.1 ft^2.

Following the break, the drywell pressure increases at approximately 1.0 psi/sec. This drywell pressure transient is sufficiently slow so that the dynamic effect of the water in the vents is negligible and the vents will clear when the drywell-to-suppression chamber differential pressure is equal to the hydrostatic pressure corresponding to the vent submergence. The resulting pressure increase in the drywell will lead to a high drywell pressure signal that will scram the reactor and activate the containment isolation system. Approximately 5 seconds after the 0.1 ft^2 break occurs, air, steam, and water will be condensed, and the air will rise to the suppression chamber free space. The continual purging of drywell air to the suppression chamber will result in a gradual pressurization of both the wetwell and drywell. The ECCS will be initiated by the break and will provide emergency cooling of the core. The operation of these systems is such that the reactor will be depressurized in approximately 600 seconds. This will terminate the blowdown phase of the transient. The principal loading condition in this case will be gradually increasing pressure in the drywell and suppression chamber and the loads related to the condensation of the steam at the end of the vents.

3A.3.2.3 Design Basis Accident

An occurrence of events that could result in a DBA (instantaneous rupture of main steam or recirculation line) is a remote possibility. Because such an accident provides an upper limit estimate to the resultant effects for this category of pipe breaks, it is evaluated without causes being identified. For LGS, an assumed instantaneous double-ended rupture of a recirculation line causes the maximum drywell pressure and therefore the governing LOCA hydrodynamic loads.

The sequence of events immediately following the rupture of a recirculation line has been determined. A drywell high pressure signal is almost instantaneously sensed, initiating a scram and containment isolation and signaling the HPCI, CS and LPCI to start. The flow in both sides of the break will accelerate to the maximum allowed by the critical flow considerations. In the side adjacent to the suction nozzle, the flow will correspond to critical flow in the pipe cross-section. In the side adjacent to the injection nozzle, the flow will correspond to critical flow at the 10 jet pump nozzles associated with the broken loop. In addition, the cleanup line cross-tie will add to the critical flow area. This high rate of flow out of the ruptured recirculation line results in a drywell pressure rise of approximately 42.1 psig in 8.7 seconds (Table 6.2-5A and Figure 6.2-3A).

This rapid increase in drywell pressure accelerates the water initially in the containment vent system out through the vents. Immediately following vent water clearing, a coalescing air-steam bubble starts to form at the downcomer exits. Initially, the bubble pressure is essentially equal to the current drywell pressure. As the flow of air-steam from the drywell becomes established in the vent system, the initial vent exit bubble expands, thus accelerating upward the suppression pool water above the vent exits. The steam fraction of the flow is condensed, but continued injection of drywell air and expansion of the air bubble results in a rapid rise in the suppression pool surface known as pool-swell.

Following the pool-swell and fall back, there is a period of high steam flow rate through the containment vent system. For large primary system ruptures, reactor blowdown and, therefore, vent steam condensation last for approximately 40 seconds (approximately 60 seconds for MSLB; see Tables 6.2-10 and 6.2-11).

Shortly after a DBA, the ECCS pumps (HPCI, CS, and LPCI) automatically start pumping CST water or suppression pool water in to the RPV. Within 70 seconds, all ECCS pumps are at rated flow (Table 6.3-2). This floods the reactor core until water starts to cascade into the drywell from the break. The time at which this occurs would depend upon break size and location. Because the drywell would be full of steam at the time of vessel flooding, the sudden introduction of cold water causes steam condensation and drywell depressurization. When the drywell pressure falls below the suppression chamber pressure, the drywell vacuum relief system is actuated and air from the suppression chamber enters the drywell. Eventually, sufficient air returns to the drywell to equalize the pressures. Similarly, small differential pressures between the drywell and the suppression chamber can be produced if the containment spray system is actuated, condensing steam in the drywell.

Following the vessel flooding and drywell/suppression chamber pressure equalization phase of the accident, suppression pool water will be continuously recirculated through the core by the ECCS pumps. The energy associated with the core decay heat will result in a slow heatup of the suppression pool. The suppression pool temperature is controlled by the RHR heat exchangers. The capacity of these heat exchangers is such that the maximum suppression pool temperature increase is reached after several hours. The suppression pool can experience a peak temperature of 205°F under worst case conditions (Table 6.2-5A). The post-LOCA containment heatup and pressurization transient is terminated when the RHR heat exchangers reduce the pool temperature and containment pressure to nominal values.

The primary loads on the containment generated by a DBA are the pressure build-ups in the drywell and suppression chamber, and loads resulting from various modes of steam condensation at the vent ends. The high rate of system depressurization resulting from a DBA militates against the firing of an SRV; however, for conservatism, SRV discharges are considered coincident with the DBA for containment structural loading purposes (Table 3A-14).

3A.4 LOAD DEFINITION

3A.4.1 MAIN STEAM SAFETY/RELIEF VALVE DISCHARGE LOAD DEFINITION (PROPRIETARY - SEE APPENDIX 3B)

3A.4.2 LOCA Load Definition

Sections 3A.4.2.1 and 3A.4.2.2 discuss the numerical definition of loads resulting from a LOCA in the LGS containment. The LOCA loads are divided into four groups:

a. Short-term LOCA loads associated with pool-swell (Section 3A.4.2.1)

b. Condensation oscillation and chugging loads (Section 3A.4.2.2)

c. Secondary loads (Section 3A.4.2.3)

d. Long-term LOCA loads (Section 3A.4.2.4)

The application of these loads to the various components and structures on the LGS containment is discussed in Section 3A.4.2.5.

3A.4.2.1 LOCA Loads Associated with Pool-Swell

NOTE: The load definition defined in Section 3A.4.2.1 for the LOCA loads associated with pool swell is historical and is based on original design basis conditions. Section 6.2.1.8 discusses the methods and results used for current plant conditions. However, the short-term containment response conditions with power rerate are within the conditions used to define the pool swell loads. The initial drywell pressurization rate used to define the pool swell load is negligibly affected by rerated power. The short-term containment response conditions for vent flow rate and pool temperature are negligibly affected by power rerate. Therefore, the LOCA load definition for loads associated with pool swell is not affected by power rerate.

In the first few seconds following a postulated LOCA, a mixture of air and steam is carried through the containment downcomers into the suppression pool. The loads associated with the transfer of the air-steam mixture are referred to as pool-swell loads. A description of the LOCA/pool-swell transient is given in Section 3A.3.2.3. The LOCA loads associated with pool-swell are listed in Table 3A-5.

3A.4.2.1.1 Wetwell/Drywell Pressures During Pool-Swell

The drywell pressure transient used for the pool-swell portion of the LOCA transient ($\leq$2.0 sec) is tabulated in Table 3A-6. This drywell pressure transient includes the blowdown effects of pipe inventory and reactor subcooling and is the highest possible drywell pressure case for pool-swell. This drywell pressure transient is calculated using the method documented in Reference 3A-7.

The short-term wetwell pressure transient due to pool-swell is calculated by applying the pool-swell model contained in Reference 3A-8 and section 4.2.2 of Reference 3A-1. Input used for calculation of the LGS unique pool-swell transient is shown in Table 3A-7.

The short-term wetwell pressure transient calculated with the pool-swell code is shown in Figure 3A-6. The short-term wetwell pressure peak is 53.644 psia (38.944 psig).

3A.4.2.1.1.1 Differential Pressure Load on Diaphragm Floor

A vertical load on the diaphragm floor will occur because of the pressure difference between the drywell and the wetwell airspace. Normally, the net load acts downward, although an upward load my occur due to rapid pressurization of the wetwell airspace during the pool-swell transient. A value of 5.5 psid will be used as a design value for the upward load on the diaphragm floor in Mark II containments, as recommended in Reference 3A-5 and section 4.2.5.2 of Reference 3A-1.

3A.4.2.1.2 Submerged Boundary Loads During Vent Clearing

The submerged jet formed by the expulsion of the water leg in the downcomers creates a vent clearing load on the basemat and the submerged wetwell walls. This loading is defined by Reference 3A-9 as a 24 psi overpressure statically applied with hydrostatic pressure to surfaces below the vent exit, linearly attenuating to zero at the pool surface (Figure 3A-4). This load is applied during vent clearing as required by section 2.1.2.1 of Reference 3A-5.

3A.4.2.1.3 LOCA Jet Loads

The LOCA jet formed by the expulsion of the water leg in the downcomers also imposes jet loads and induced drag loads on structures in the paths and in the vicinity of the jet respectively. The direct jet loads is calculated based on a simple stoppage of momentum [Ref. 3A.10]:

$$F = KA_lV^2/2g_c,$$

where V is the jet velocity, A_l is the intercepted jet area normal to the jet direction, and K = 2 for structures which fully or partially intercepts the jet. The induced drag loads are caused by the induced velocity and acceleration fields created by the passing jets in the suppression pool.

The original methodology employed to predict the drag forces is contained in Reference 3A-10 (often called the Moody jet model) and is an analytical representation of an unsteady water jet discharging into a suppression pool. The jet is made up of constant velocity fluid particles traveling at the speed at which they exited the discharge pipe. The jet front is described as the locus of points through which a particle overtakes the one exiting immediately before it. No velocities or accelerations are defined in the fluid external to the jet.

Reference 3A-2, subsection III.D.1.a, proposed that velocity and acceleration be predicted throughout the pool using the potential function of a sphere at the jet front. A modification of the load calculated at jet impingement was also required. The acceptance criteria was a simple method to determine a bounding jet load for all structures below the downcomer exits.

The Moody jet model was clearly derived from jets with constant or linearly increasing acceleration. However, the vent clearing transients predicted for Mark II plants typically have an increase in acceleration greater than linear. Strict application of Reference 3A-10 leads to unrealistic mathematical results. Two interpretations of the results are possible depending on the time base employed. Examining the jet in "real-time" (Reference 3A-10), a jet can be seen with two independent fronts traveling at different speeds at different locations which coincide only at the point of jet dissipation. On the other hand, if the "exit-time" (τ) is used as a basis, the jet reverses and moves backward in both space and "real-time" before dissipation. Clearly neither of these observations is of much use in calculating loads on structures.

To overcome the difficulties of using this model, an alternative methodology has been formulated. The jet front will be described by the motion of the particle having traveled the farthest at any instant in time. This will be identical to the Moody jet motion for jets with linearly increasing acceleration but will yield a single continuous velocity and acceleration time history even if the acceleration increases more rapidly.

A sphere is then placed at the jet front generating a potential flow described by the following function:

$$\varphi = \frac{-3}{8\pi} U_j \; V_w \; \frac{\cos\theta}{r^2} \qquad \text{(EQ. 3A-1)}$$

where:

(r, θ)	=	spherical coordinates from the sphere center to some position in the suppression pool with θ measured from the jet direction
U_j	=	the velocity of the sphere determined by the velocity of the particle having traveled the farthest at the instant in the time the draft forces are being computed
V_w	=	the initial volume of water in the vent.

The local velocity (U_{∞}) and acceleration ($\mathring{U}_{\infty}$) are then calculated from the above relation by the methods of Reference 3A-10. Once the local velocity and acceleration are known, the drag forces are computed from Reference 3A-11 as follows:

$$F_A = \frac{\mathring{U}_{\infty n} \nu \rho}{g_c} \qquad \text{(EQ. 3A-2)}$$

$$F_S = \frac{C_D \, A_X \, U^2_{\infty n} \, \rho}{2 g_c}$$

where:

F_A	=	the acceleration drag
$\mathring{U}_{\infty n}$	=	the local acceleration field normal to the structure
ν	=	the acceleration drag volume for flow normal to the structure
ρ	=	the fluid density
F_S	=	the standard drag
C_D	=	the drag coefficient for flow normal to the structure
A_x	=	the projected structure area normal to $U_{\square n}$
$U_{\infty n}$	=	the local velocity field normal to the structure.

When the jet is predicted to dissipate, the sphere is traveling at the final jet velocity at the point of maximum jet penetration. This condition is used as the final load calculation point. The final jet velocity is that of the jet front just before the last particle leaving the vent reaches the jet front. The velocity of the last particle is disregarded.

The largest induced water jet drag loads on affected components are given in Table 3A-8 for the original plant operating conditions.

For power rerate plant conditions, the increase in drywell pressurization rate and maximum vent velocity is 2% or less. The LOCA jet loads are controlled by the drywell pressure history and vent clearing velocities up to the time of vent clearing. There is sufficient conservatism in the methodology used to calculate the original LOCA jet loads and margin to design limits in the resulting component stress calculations to accommodate this increase in LOCA jet loads. Therefore, power rerate does not impact the pool swell design loads which occur up to the time of vent clearing.

3A.4.2.1.4 Boundary Loads During Pool-swell

During the pool-swell transient, the high pressure air bubble that forms in the vicinity of the vent exit creates an increase in pressure on all suppression pool boundaries below the vent exit as well as those walls with which it is in direct contact. Boundaries that are between the bubble location and the point of maximum pool elevation also experience increased pressure loads corresponding to the increased pressure in the wetwell airspace, as well as the hydrostatic contribution of the water slug.

Reference 3A-1, section 4.2.5, and Reference 3A-5, section 2.1.2.5, describe the methodology for specification of these boundary loads. The pool-swell analytical model is used to determine the maximum values of bubble pressure and wetwell airspace pressure. The analysis takes the maximum pool elevation as 1.5 times the initial submergence. Using this data, a static loading is applied to the containment structure as follows:

a. For the basemat - uniform pressure equal to the maximum bubble pressure superimposed on the hydrostatic load corresponding to a submergence from vent exit to the basemat

b. For the containment walls below the vent exit - maximum bubble pressure plus hydrostatic head corresponding to vertical distance from vent exit.

c. For the containment walls between the vent exit and maximum pool elevation - linear variation between maximum bubble pressure and maximum wetwell airspace pressure.

d. For the containment walls above maximum pool elevation - maximum wetwell airspace pressure.

The pressure distribution used for the LGS analysis is shown in Figure 3A-5 for the original plant operating conditions.

The original pool swell boundary loads calculations were reassessed for power rerate conditions. The original calculations for both the maximum calculated bubble pressure and peak wetwell pressure assume no credit for bubble breakthrough which occurs when the wetwell pressure exceeds the drywell pressure by about 2.5 psi.

The highest wetwell pressure for power rerate shown in Table 6.2-5A (39.0 psig or 53.7 psia) is essentially the same as the original peak wetwell pressure value of 53.64 psia shown in figure 3A-5. The maximum pool swell elevation of 19.51 ft is valid for Power Rerate operation. The peak bubble pressures at the time of peak pool swell are about six (6) psi lower than that was assumed in the original calculations (48.25 psia). If credit was taken for bubble breakthrough, the bubble pressure at breakthrough would be about 12 psi lower than the 48.25 psia in the original calculations. In addition, the containment design is based on the design pressure of 55 psig (69.7 psia) and that the boundary loads during pool swell are not the governing load for the design of the containment walls, basemat, or liners. Therefore, there is sufficient conservatism in the original calculation of the boundary loads during pool swell to accommodate Power Rerate operation.

3A.4.2.1.5 Pool-Swell Asymmetric Air Bubble Load

The methodology used in Section 3A.4.2.1.4 assumes that the air flow rate in each downcomer is equal, leading to a symmetric loading of the containment boundary. Concern has been expressed (Reference 3A-2, subsection III.B.3.e) that circumferential variations in the downcomer air flow rate can occur, due to drywell air-steam mixture variation, that would result in variations in the bubble pressure load on the wetwell wall. This asymmetric loading condition is calculated by statically applying the maximum air bubble pressure, obtained from the PSAM computer code, to half of the submerged boundary and statically applying the hydrostatic pressure of the water column to the other half of the submerged boundary. The pressure load on the basemat and wetwell walls below the vent exit is the sum of the air pressure and the hydrostatic pressure. For the portion of the wall above the vent exit, the pressure increase due to the air bubble is linearly attenuated from the bubble pressure at the vent exit to zero at the pool surface. This increase is then added to the local hydrostatic pressure to obtain the total pressure. The time period of application of the load is from the termination of vent clearing until the maximum swell height is reached.

These loading conditions are conservative with respect to the NRC's long-term criteria for asymmetric bubble loads (Reference 3A-5, Appendix A).

3A.4.2.1.6 Pool-Swell Impact Load

As the pool rises during pool-swell, structures located between the initial suppression pool surface and the peak pool-swell height are subject to the pool-swell impact load. The pool-swell maximum elevation is determined by the pool-swell analytical model with polytropic exponent of 1.2 for wetwell air compression to a maximum swell height which is the greater of 1.5 times the maximum vent submergence or the elevation corresponding to the drywell floor uplift pressure of 2.5 psid (References 3A-1 and 3A-5). For LGS, Reference 3A-1 separates all impacted structures into two classes:

a. Impact loads on small structures (one dimension < 20 in)

b. Impact loads on large structures (both dimensions > 20 in). These structures are treated on a case-by-case basis.

Pool-swell impact loads on small structures are determined as specified in Reference 3A-5, Appendix A.

The PSAM computer runs summary is provided on Figures 3A-6 through 3A-10for the original plant operating conditions. These graphs present various pool-swell plant unique characteristics, including pressure-time, ΔP-time, velocity-time, velocity-height, and height-time parameters. The pool swell response was reanalyzed assuming power rerate plant operating conditions. This analysis showed that the peak pool velocity and pool swell height is insensitive to changes in the plant operating conditions. Therefore, the original pool swell impact load definition remains bounding for power rerate operation.

3A.4.2.1.7 LOCA Air Bubble Submerged Structure Load

During the drywell air purge phase of a LOCA, an expanding bubble is created at the downcomer exits. These rapidly expanding bubbles create three-dimensional velocity and acceleration fields.

To determine the drag loads, the system was modeled acoustically by the inhomogeneous wave equation (Reference 3A-14). A bubble source was developed from 4T test data and qualitative information. Table 3A-9 presents major LOCA air bubble loads for the original plant operating conditions. The LOCA air bubble response was reanalyzed assuming power rerate plant operating conditions. This analysis showed that the drywell pressurization rate is insensitive to changes in the plant operating conditions. Therefore, the original LOCA air bubble submerged structure load definition remains bounding for power rerate operation.

3A.4.2.1.8 Pool-Swell Drag Load

Subsequent to bubble contact, all bubbles are assumed to coalesce into a blanket of air, and the pool-swell drag loads are due to the slug of water rapidly accelerating upward. The loads act in the vertical direction only (except for lift forces that act in the transverse direction to the flow). The one-dimensional pool-swell model is used to predict the velocity and acceleration at the structure location. As recommended in References 3A-5 and 3A-2 and consistent with section 3A.4.2.3.5 of Reference 3A-1, the velocity is increased by 10% for additional conservatism to account for possible bubble asymmetry. Once the flow field is known, the drag forces are calculated by the methods of Section 3A.11. This methodology conservatively estimates a standard drag coefficient for unsteady flow. This drag load applies to any structure located between the elevation of the vent exit and the peak pool-swell height. The duration of the drag load begins when the vent clears, except for structures that are originally not submerged. For structures that are not submerged, the drag load duration is based on the slug transient time (Reference 3A-12, pp. 4-78, step 3). Friction drag forces on vertical piping, downcomers, and columns are given in Table 3A-10 for the original plant operating conditions. The pool swell response was reanalyzed assuming power rerate plant operating conditions. This analysis showed that the peak pool velocity and pool swell height is insensitive to changes in the plant operating conditions. Therefore, the original pool swell impact load definition remains bounding for power rerate operation.

3A.4.2.1.9 Pool-Swell Fallback Load

After the termination of pool-swell, the slug of water falls under the influence of gravity, causing drag forces on structures located between the peak pool-swell height and the vent exit. The motion of water is described by the following equations:

$$H(t) = H_{max} - \tfrac{1}{2}gt^2 \qquad \text{(EQ. 3A-3)}$$

$$V_{FB}(t) = gt$$

$$\dot{V}_{FB} = g$$

where:

g	=	the acceleration of gravity
$H(t)$	=	the height above initial water level at time (t)
H_{max}	=	the maximum swell height
t	=	the time (starting with t = 0) at maximum swell height

The drag load is then calculated from the methods of Section 3A.11. The loading stops when H(t) has fallen below the structure or when H(t) has returned to the normal water level, whichever is calculated to occur first.

The pool-swell fallback analysis of piping that has interference effects was performed by using the FORCE II computer code. The results indicate that the interference effects increase the vertical load component by a maximum of 16%, depending on the elevation.

3A.4.2.2 Condensation Oscillations and Chugging Loads

Condensation oscillation and chugging loads follow the pool-swell loads in time. There are basically three loads in this secondary time period, i.e., from about 4-60 seconds after the break. Condensation oscillation is broken down into two phenomena, a mixed flow regime and a steam flow regime. The mixed flow regime is a relatively high mass flux phenomenon that occurs during the final period of air purging from the drywell to the wetwell when the mixed flow through the downcomer vents contains some air as well as steam. The steam flow portion of the condensation oscillation phenomena occurs after all the air has been carried over to the wetwell and a relatively high intermediate mass flux of pure steam flow is established.

Chugging is a pulsating condensation phenomenon that can occur either following the intermediate mass flux phase of a LOCA or during the class of smaller postulated pipe breaks that result in steam flow through the vent system into the suppression pool. A necessary condition for chugging to occur is that only pure steam flows from the LOCA vents. Chugging imparts a loading condition to the suppression pool boundary and all submerged structures.

3A.4.2.2.1 Containment Boundary Loads Due to Condensation Oscillations

The containment boundary loads due to condensation oscillation are based on direct application of pressure measurements in the drywell and the suppression pool from the full-scale 4TCO tests, as described in section 4.3 of Reference 3A-1, and Reference 3A-13.

The basic condensation oscillation load is a bounding load for any condensation oscillation condition expected during a hypothetical LOCA in the plant. All 28 of the 4TCO test runs were analyzed to determine the bounding time periods. The criterion for the selection of these time periods was to bound the maximum power spectral density values observed at the bottom center pressure throughout the condensation oscillation period in all runs - in any 2.048 second block for all frequencies from 0-60 Hz - in approximately 0.5 Hz increments. The selected time periods were independently confirmed to be bounding by the amplified response spectra analysis (Reference 3A-13, Appendix A).

The pressure response spectrum envelope for the time periods selected is shown in Figure 3A-11; the spatial pressure distribution is shown in Figure 3A-12. The drywell pressure histories for the time periods defined in Reference 3A-13 are applied uniformly throughout the drywell.

3A.4.2.2.2 Pool Boundary Loads Due to Chugging

The Mark II generic chugging load definition was developed by applying the acoustic chugging methodology described in Reference 3A-14 to the chugging data base provided by the Mark II 4T Condensation Oscillation (4TCO) Test Program (Reference 3A-15). The definition of a chugging load starts with the identification of steam-bubble collapse as the fundamental excitation mechanism. The collapse produces acoustic responses in the suppression pool and the vents. The combined excitation of the suppression pool and vent response is characterized as a time-varying volumetric point source in the acoustic model. Point sources for the 4TCO facility are inferred from 4TCO wall pressures via the 4TCO acoustic model. These point sources can be applied to an acoustic model of the Mark II suppression pool because the bubble collapse and vent response in Mark II are correctly simulated by the prototypical 4TCO geometry and blowdown conditions. The multivent effects of variation in chug strength and chug time among vents are incorporated in the Mark II application (Reference 3A-16).

Seven large (key) chugs from the 4TCO data base were used to develop design sources to be applied to the acoustic model of the LGS containment. These design sources are to be applied desynchronized, using the set of chug start times having the smallest variance in one-thousand Monte Carlo trails drawn from a uniform distribution of start times having a width of 500 milliseconds. The chug start times are randomly assigned to the vents in the Mark II containment.

The observation of vent desynchronization has been verified by determining the time delay between individual bubble collapses in the full-scale, 7 vent tests conducted by the Japan Atomic Energy Research Institute. Conservatism is ensured by applying to the Mark II plant models a minimum estimate of the time window within which the individual bubble collapses must occur.

Two cases of source application are specified: symmetric and asymmetric. The symmetric case is defined as the desynchronized application of each of the design sources in turn, at every vent exit location in the LGS pool. The definition of the asymmetric case starts with the identification of a design moment axis which divides the suppression pool into two halves. Adjustment factors are applied to the design sources to raise their strength on one side of the pool and lower their strength on the other side. This procedure and its rationale are described in Reference 3A-16.

3A.4.2.2.3 Downcomer Lateral Loads

During chugging and condensation oscillation, a downcomer will experience intermittent lateral loading. However, the 4TCO tests (Reference 3A-15) have shown that the magnitude of the lateral loading in a Mark II facility during the condensation oscillation phase is relatively small compared to chugging-induced lateral loads. The chugging lateral load may be the result of asymmetric steam-bubble collapse or the result of the impact on the vent caused by rapidly inflowing water. In either case, the loads occur near the downcomer exit and have been observed to be impulsive in nature and random in both magnitude and direction. The stochastic nature of the loads appears unaffected by the proximity of other structures such as containment walls or another downcomer as close as three vent diameters away. The duration of an individual lateral load is typically less than 10 ms half sine wave. The single vent, lateral load specification for LGS consists of a static-equivalent load of 10 kips and 6 ms for low intensity chugs, 30 kips and 3 ms for the high intensity chugs, and 65 kips and 3 ms for the low probability, very high intensity chugs (Figure 3A-13). This 65,000 lbf load (Reference 3A-5) corresponds to the maximum load implied by extrapolation in the cold pool tests of GKM II data with an exceedance of 0.1 per LOCA.

3A.4.2.2.4 Multiple Vent Lateral Loads

Test data observations indicate that chugging forces on a single downcomer occur periodically in random directions for short time durations. The probability that the number of downcomers loaded with the maximum force in a particular time interval in the same direction is extremely small. Nonetheless, there is a small but finite probability that some fraction of the downcomers may experience a fraction of the load acting in the same direction at the same time.

The methodology used for driving the lateral loads on the various downcomer group combinations that will result in a conservative assessment is described in Reference 3A-5. The results indicate that a probability level of 10^{-4} for exceeding an impulse in 265 chugs is adequate for determining the total load on a group of downcomers. Phasing between vents is completely neglected. These two factors result in a conservative methodology for multiple vent lateral loads. The value of 265 chugs was reached based on consideration of a range of small liquid breaks (Reference 3A-2).

3A.4.2.2.5 Submerged Structure Loads Due to Condensation Oscillation and Chugging

Condensation oscillation and chugging create velocity and acceleration fields in the suppression pool that cause submerged structure drag loads. The pressure distributions corresponding to sources from the GE 700 series (Reference 3A-16) are computed at several elevations (nodes) around the submerged structure using IWEGS/MARSOFT (for condensation oscillation) and IWEGS/MARS-P (for chugging). These pressure responses around the body of each level are then spatially integrated to obtain the dynamic load due to fluid motion (force per unit length).

$$F = \int Pds \qquad \text{(EQ. 3A-4)}$$

where p is the fluid pressure acting on an area increment ds = nds, n being the inward-pointing normal unit vector at ds. The submerged structure load is equal to double the dynamic load due to the effect of the hydrodynamic mass. Table 3A-11 provides a summary of maximum force per unit length on various submerged structures for condensation oscillation and chugging phases.

3A.4.2.3 Secondary Loads

The previous sections have identified and specified loading methodologies that result in significant containment dynamic loads. In addition, several pool dynamic loads can occur that are considered secondary when compared to the previous loads or because the containment and related equipment response is small when subjected to them. The following sections identify the secondary loads and the load criteria to be applied to the LGS containment.

3A.4.2.3.1 Downcomer Friction Drag Loads

Friction drag loads are experienced internally by the downcomers during vent clearing and subsequent air or steam flow. In addition, the downcomers experience an external drag load during pool-swell. Using standard drag force calculation procedures, these loads are determined to be 0.6 kips and 0.3 kips per downcomer, respectively, and are not considered in the structural evaluation of the containment.

3A.4.2.3.2 Sonic Waves

Immediately following the postulated instantaneous rupture of a large primary system pipe, a sonic wave front is created at the break location and propagates through the drywell to the vent system. This load has been determined to be negligible and, therefore, none is specified.

3A.4.2.3.3 Compressive Wave

The compression of the air in the drywell and vent system causes a compressive wave to be generated in the downcomer water legs. This compressive wave propagates through the pool and causes a differential pressure loading on the submerged structures and on the wetwell wall. This load has been evaluated and is considered negligible.

3A.4.2.3.4 Fallback Loads on Submerged Boundaries

During fallback, water hammer type loads could exist if the water slug remained intact during this phase. However, available test data indicate that this does not occur, and the fallback process consists of a relatively gradual setting of the pool water to its initial level as the air bubble percolates upward. This is based on visual observations during the EPRI tests (Reference 3A-17) as well as indirect evidence provided by an examination of pool bottom pressure forces from the 4T, EPRI, foreign licensee, and Marviken tests. Thus, these loads are small and will not be considered.

3A.4.2.3.5 Vent Clearing Loads on the Downcomers

The expulsion of the water leg in the downcomers at vent clearing creates a transient water jet in the suppression pool. This jet formation may occur asymmetrically leading to lateral reaction loads on the downcomer. However, this load is bounded by the load specification during chugging and will not be considered for containment analysis.

3A.4.2.3.6 Postpool-Swell Waves

Following the pool-swell process, continued flow through the vent system generates random pool motion. The pool motion creates waves that have potential loading impingement effects on the LGS wetwell wall and internal components. In accordance with the response to Question M020.8 documented in Appendix A of the DFFR, Revision 3 (June 1978), this load is considered negligible when compared to the other design basis loads.

3A.4.2.3.7 Seismic Slosh

The computer code SOLA-3D was used to estimate the suppression pool seismic slosh hydrodynamic loads. The results indicate the seismic slosh loads in the plant are much less that the LOCA chugging loads or the SRV air clearing bubble oscillation loads (on the order of a few psi at a relatively low frequency depending on location and direction).

The maximum wave (sloshing) height is 1.6 feet. The nodal force close to the pool bottom oscillates between 112 kips to 88 kips (including static load). Therefore, the bottom pressure rises to about 1.2 psi above the static pressure due to sloshing. The dominant frequency of the sloshing motion is 0.1 Hz, whereas the dominant frequency of the seismic acceleration is about 2 Hz.

3A.4.2.3.8 Thrust Loads

Thrust loads are associated with the rapid venting of air and/or steam through the downcomers. To determine this load, a momentum balance for a control volume consisting of the drywell, diaphragm floor, and vents is taken. Results of the analysis indicate that the load reduces the downward pressure differential on the diaphragm.

3A.4.2.4 Long-Term LOCA Loads

The LOCA causes pressure and temperature transients in the drywell and wetwell due to mass and energy released from the line break. The drywell and wetwell pressure and temperature time histories are required to establish the structural loading conditions in the containment because they are the basis for other containment hydrodynamic phenomena. The response must be determined for a range of parameters such as break size, reactor pressure, and containment initial conditions.

3A.4.2.4.1 Design Basis Accident Transients

The DBA LOCA for LGS is conservatively estimated to be a 3.538 ft^2 break of the recirculation line. This transient results in the maximum drywell pressure and therefore governs the LOCA hydrodynamic loads. The LGS unique assumptions and input for the analysis are given in Section 6.2.1. Drywell and wetwell pressure and temperature responses are shown in Figures 3A-14 and 3A-15. This description of the transient does not include the effect of reactor subcooling.

3A.4.2.4.2 Intermediate Break Accident Transients

The worst case intermediate break for LGS is a 0.1 ft^2 break of a liquid line. The drywell and wetwell pressure and temperature responses are shown in Figures 3A-16 and 3A-17. This description of the transient does not include the effect of reactor subcooling.

3A.4.2.4.3 Small Break Accident Transients

Plant unique SBA data for LGS is not available. The wetwell and drywell pressure and temperature transients for a typical Mark II containment are used to estimate the LGS containment response to these accidents. These curves are shown in Figure 3A-18 (extracted from Reference 3A-12).

3A.4.2.5 LOCA Loading Histories for LGS Containment Components

The various components directly affected by LOCA loads are shown schematically in Figure 3A-19. These components may in turn load other components as they respond to the LOCA loads. For example, lateral loads on the downcomer vents produce minor reaction loads in the drywell floor from which the downcomers are supported. The reaction load in the drywell floor is an indirect load resulting from the LOCA and is defined by the appropriate structural model of the downcomer/drywell floor system. Only the direct loading situations are described in detail here. Table 3A-12 is a LOCA load chart for LGS. This chart shows which LOCA loads directly affect the various structures. Details of the loading time histories are discussed below.

3A.4.2.5.1 LOCA Loads on the Containment Wall and Pedestal

Figure 3A-20 shows the LOCA loading history for the LGS containment wall and the RPV pedestal. The wetwell pressure loads apply to the unwetted elevations in the wetwell; addition of the appropriate hydrostatic pressure is made for loads on the wetted elevations. Condensation oscillation and chugging loads are applied to the wetted elevations in the wetwell only. The pool-swell air bubble load applies to the wetwell boundaries as shown in Figures 3A-11 and 3A-12.

3A.4.2.5.2 LOCA Loads on the Basemat and Liner Plate

Figure 3A-21 shows the LOCA loading history for the LGS basemat and liner plate. Wetwell pressures are applied to the wetted and unwetted portions of the liner plate as discussed in Section 3A.4.2.5.1. The downcomer water jet impacts the basemat line plate as does the pool-swell air bubble load. Chugging and condensation oscillation loads are applied to the wetted portion of the liner plate.

3A.4.2.5.3 LOCA Loads on the Drywell and Drywell Floor

Figure 3A-22 shows the LOCA loading history for the LGS drywell and drywell floor. The drywell floor undergoes a vertically applied, continuously varying differential pressure, the upward component of which is especially prominent during pool-swell when the wetwell airspace is highly compressed.

3A.4.2.5.4 LOCA Loads on the Columns

Figure 3A-23 shows the LOCA loading history for the LGS columns. Pool-swell drag and fallback loads are minor because the column surface is oriented parallel to the pool-swell and fallback velocities. The pool-swell air bubble, condensation oscillations, and chugging will provide loads on the submerged (wetted) portion of the columns.

3A.4.2.5.5 LOCA Loads on the Downcomers

Figure 3A-24 shows the LOCA loading history for the LGS downcomers. The downcomer clearing load is a lateral load applied at the downcomer exit (in the same manner as the chugging lateral load) plus a vertical thrust load. Pool-swell drag and fallback loads are minor because the downcomer surfaces are oriented parallel to the pool-swell and fallback velocities. The pool-swell air bubble load is applied to the submerged portion of the downcomer as are the chugging and condensation oscillation loads.

3A.4.2.5.6 LOCA Loads on the Downcomer Bracing

Figure 3A-25 shows the LOCA loading history for the LGS downcomer bracing system. This system is not subject to impact loads because it is submerged at el 203'-5". As a submerged structure, it is subject to pool-swell drag, fallback, and air bubble loads. Condensation oscillations and chugging at the vent exit will also load the bracing system both through downcomer reaction (indirect load) and directly through the hydrodynamic loading in the suppression pool.

3A.4.2.5.7 LOCA Loads on the Wetwell Piping

Figure 3A-26 shows the LOCA loading history for piping in the LGS wetwell. Because the wetwell piping occurs at a variety of elevations in the LGS wetwell, sections may be completely submerged, partially submerged, or initially uncovered. Piping may occur parallel to pool-swell and fallback velocities, as with the main steam safety/relief piping. For these reasons, there are a number of potential loading situations that arise, as shown in Table 3A-13. In addition, the pool-swell air bubble load applies to the submerged portion of the wetwell piping as do the condensation oscillation and chugging loads.

3A.5 LOAD COMBINATIONS FOR STRUCTURES, PIPING, AND EQUIPMENT

3A.5.1 INTRODUCTION

To verify the adequacy of mechanical and structural design, it is necessary first to define the load combinations to which structures, piping, and equipment may be subjected. In addition to the loads due to pressure, weight, thermal expansion, seismic, and fluid transients, hydrodynamic loads resulting from LOCA and SRV discharge are also considered in the design of structures, piping, and equipment in the drywell and suppression pool. This chapter specifies how the LOCA and SRV discharge hydrodynamic loads will be combined with the other loading conditions. For the load combinations discussed in this chapter, seismic and hydrodynamic responses are combined by the methods specified in Reference 3A-1, section 5.1.2.

3A.5.2 LOAD COMBINATIONS FOR CONCRETE DESIGN IN CONTAINMENT, REACTOR ENCLOSURE, AND CONTROL STRUCTURE

The loads on the containment, its concrete internals (i.e., RPV pedestal, diaphragm slab), reactor enclosure, and control structure are combined to assess the structural integrity in accordance with the design load combinations given in Table 3A-14. The factored load approach is used in the assessment of the concrete structural components. The load factors adopted are based on the degree of certainty and probability of occurrence for the individual loads as discussed in Reference 3A-1, section 5.1.2.

The LOCAs are characterized by several phenomena that result in nonconcurrent loadings on the structures. Time sequences of occurrence of the various time-dependent loads, as shown in figures 5-5 through 5-20 of Reference 3A-1, are taken into account to determine the most critical loading conditions.

3A.5.3 STRUCTURAL STEEL AND ASME CLASS MC STEEL COMPONENTS LOAD COMBINATIONS

The load combinations for structural steel in the containment, reactor enclosure, and control structure are given in Table 3A-15. These combinations apply to the suppression chamber steel columns, the downcomer bracing, and miscellaneous structural steel within the containment, reactor enclosure, and control structure.

The LOCAs are characterized by several phenomena that result in nonconcurrent loadings on the structures. Time sequences of occurrence of the various time-dependent loads, as shown in figures 5-5 through 5-20 in Reference 3A-1, are taken into account to determine the most critical loading conditions.

The load combinations for the ASME Class MC steel components in the concrete containment are given in Table 3A-16. These combinations apply to the drywell head assembly, equipment hatches, personnel lock, suppression chamber access hatches, CRD removal hatch and piping and electrical penetrations.

3A.5.4 LINER PLATE LOAD COMBINATIONS

The liner plate and its anchorage system, being an integral part of the containment system, is assessed for the same load combinations listed in Table 3A-14. However, for the liner system, the load factors are taken as unity and the acceptance criteria are specified in Section 3A.6.4.

The LOCAs are characterized by several phenomena that result in nonconcurrent loadings on the structures. Time sequences of occurrence of the various time-dependent loads, as shown in figures 5-5 through 5-20 in Reference 3A-1 are taken into account to determine the most critical loading conditions.

3A.5.5 DOWNCOMER LOAD COMBINATIONS

Load combinations and stress allowables for the downcomers are given in Table 3A-17. These load combinations are based in the load combinations given in table 5-2 of Reference 3A-1.

The LOCAs are characterized by several phenomena that result in nonconcurrent loadings on the structures. Time sequences of occurrence of the various time-dependent loads, as shown in figures 5-5 through 5-20 in Reference 3A-1, are taken into account to determine the most critical loading conditions.

3A.5.6 PIPING, QUENCHER, AND QUENCHER SUPPORT LOAD COMBINATIONS

LOCA loads considered on piping systems include pool-swell impact loads, pool-swell drag loads, downcomer water jet loads, pool-swell air bubble loads, fallback drag loads, condensation oscillation loads, chugging loads, and inertial loading due to the acceleration of the containment structure produced by LOCA loads. Loads due to SRV discharge on piping systems include water clearing loads, air clearing loads, fluid transient loads on SRV discharge piping, reaction forces at the quencher, and inertial loading due to the acceleration of the containment structure produced by SRV discharge loads.

The load combinations and stress limits for piping systems are given in Table 3A-18.

3A.5.6.1 Load Considerations for Piping Inside the Drywell

Piping systems inside the drywell are subjected to inertial loading due to the acceleration of the containment produced by LOCA and SRV discharge loads in the wetwell. The SRV discharge piping in the drywell is also subjected to fluid transient forces due to SRV discharge.

3A.5.6.2 Load Considerations for Piping Inside the Wetwell

All piping in the wetwell is subject to the inertial loading due to LOCA and SRV discharge.

Drag and impact loads due to LOCA and SRV discharge on individual pipes in the wetwell depend on the physical location of the piping. Other SRV discharge and LOCA loads applicable to piping in the wetwell are discussed in the paragraphs that follow.

Piping systems located below the suppression chamber water level are shown on Figures 3A-27 and 3A-28. In addition to the inertial loads, these piping systems are subjected to SRV air bubble and LOCA air bubble loads, condensation oscillation loads, and chugging loads. The SRV piping, quencher, and quencher support are also subject to fluid transient forces due to SRV discharge. Piping systems located within the jet impingement cone of the downcomer are also subjected to downcomer water jet loads.

Piping systems within the pool-swell zone are shown on Figures 3A-28, 3A-29, and 3A-30. All horizontal runs of these pipes are above the suppression chamber water level. The following loads, in addition to the inertial loads, act on these systems:

a. The horizontal runs of pipe below el 225'-8", experience pool-swell impact, pool-swell drag, and fallback drag loads.

b. The vertical portions of pipe in the water below el 225'-8" experience pool-swell drag and fallback drag loads.

3A.5.6.3 Quencher and Quencher Support Load Considerations

The quencher and quencher supports are subjected to the following hydrodynamic loads in addition to the pressure, weight, thermal, and seismic loads:

a. Unbalanced loads on the quencher due to SRV water clearing and air clearing transients, irregular condensation, and steady-state blowdown.

b. Drag loads due to SRV discharge and LOCA.

c. SRV piping end loads.

d. Inertial loading due to the acceleration of he containment produced by SRV discharge and LOCA.

3A.5.6.4 Load Considerations for Piping in the Reactor Enclosure

The effects of the inertial loading due to acceleration of the containment produced by SRV discharge and LOCA loads are evaluated for this piping.

3A.5.7 NSSS LOAD COMBINATIONS

Load combinations and acceptance criteria for ASME Class 1, 2, and 3 NSSS piping, equipment, and supports are provided in Table 3A-19.

3A.5.8 BOP EQUIPMENT LOAD COMBINATIONS

Safety-related equipment located within the primary containment, reactor enclosure, and control structure are assessed for the governing load combinations shown in Table 3A-20.

3A.5.9 ELECTRICAL RACEWAY SYSTEM LOAD COMBINATIONS

Load combinations for the electrical raceway system are given in Table 3A-21.

3A.5.10 HVAC DUCT SYSTEM LOAD COMBINATIONS

Load combinations for the HVAC duct system are given in Table 3A-22.

3A.6 DESIGN CAPABILITY ASSESSMENT CRITERIA

3A.6.1 INTRODUCTION

The criteria by which the design capability is determined are discussed in this chapter. Design of the LGS is assessed as adequate when the design capability of the structures, piping, and equipment is greater then the loads (including LOCA and SRV discharge) to which the structures piping and equipment are subjected. Loading combinations are discussed in Section 3A.5. The margins by which design capabilities exceed these loads are discussed in Section 3A.7.

3A.6.2 CONTAINMENT, REACTOR ENCLOSURE, AND CONTROL STRUCTURE CAPABILITY ASSESSMENT CRITERIA

3A.6.2.1 Containment Structure Capability Assessment Criteria

The acceptance criteria detailed in Section 3.8.1.5 have been used to assess the structural integrity of the containment and internal structures. No changes are made in these acceptance criteria when the effects of the dynamic SRV discharge and LOCA loads are included.

3A.6.2.2 Reactor Enclosure and Control Structure Capability Assessment Criteria

The acceptance criteria for seismic Category I structures presented in Section 3.8.4.5 have been used to assess the structural integrity of the reactor enclosure, control structure, and their components. No changes are made in these acceptance criteria when the effects of the dynamic SRV discharge and LOCA loads are included.

3A.6.3 STRUCTURAL STEEL AND ASME CLASS MC STEEL COMPONENT CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for structural steel in the containment, reactor enclosure, and control structure are given in Table 3A-15. These criteria apply to the suppression chamber steel columns, the downcomer bracing, and miscellaneous structural steel within the containment, reactor enclosure, and control structure.

The allowable stresses for ASME Class MC steel components in the concrete containment are given in Table 3A-16. These allowable stresses apply to the drywell head assembly, equipment hatches, personnel lock, suppression chamber access hatches, and piping and electrical penetrations.

3A.6.4 LINER PLATE CAPABILITY ASSESSMENT CRITERIA

The strains in the liner plate and anchorage system (welds and anchors) from self-limiting loads such as dead load, creep, shrinkage, and thermal effects are limited to the allowable values specified in table CC-3720-1 of Reference 3A-18. The displacements of the liner anchorage are limited to the displacement values of table CC-3730-1 of Reference 3A-18.

Stresses in the liner plate and anchorage system (welds and anchors) from mechanical loads such as SRV discharge and chugging are checked according to Reference 3A-19. Specifically, primary plus secondary membrane plus bending stresses are checked according to subsection NE-3222.2. Fatigue strength evaluation is based on subsection NE-3222.4. Allowable design stress intensity values, design fatigue curves, and material properties that are used conform to subsection NA, Appendix I.

The capacity of the liner plate anchorage is limited by the concrete pull-out to the service load allowable for concrete as specified in Reference 3A-20.

3A.6.5 DOWNCOMER CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for the downcomers are given in Table 3A-17. These allowable stresses are in accordance with subsection NE of Reference 3A-19. As permitted by subsection NE-1120 for MC components, the downcomers are analyzed in accordance with subsection NB-3650 of Reference 3A-19. However, the lower allowable stresses, S_m, from table I-10.1 for MC components, are used when performing the analysis.

3A.6.6 BOP PIPING, QUENCHER, AND QUENCHER SUPPORT CAPABILITY ASSESSMENT CRITERIA

BOP piping systems in the containment and reactor enclosure are analyzed in accordance with ASME Section III, Division 1 (1971 Edition with Addenda through Winter 1972 for Class 2 and 3 piping, and 1977 Edition through Summer 1979 Addenda for Class 1 piping and Class 2 and 3 flanges), subsections NB-3600, NC-3600, and ND-3600, and ANSI B31.1 (Power Piping Code) for the loading described in Table 3A-18. In addition to these code requirements, when piping is required to deliver rated flow during or following an emergency or faulted event, the functional capability requirement shall be met for the load combinations with the event.

The quencher and quencher support are designed in accordance with ASME Section III, Division 1 (1977 Edition with Addenda through Summer 1979), subsections NC-3200 and NF-3000, respectively, for the loading discussed in Section 3A.5.6.3.

3A.6.7 NSSS CAPABILITY ASSESSMENT CRITERIA

The capability assessment criteria used for the evaluation of NSSS piping systems, RPV, RPV supports, RPV internals and floor-mounted equipment are shown in Table 3A-19. Table 3A-19 is in agreement with a conservative general interpretation of the NRC technical position, "Stress Limits for ASME Class 1, 2 and 3 Components and Component Supports of Safety-Related Systems and Core Support Structures Under Specific Service Loading Combinations".

Peak response due to related dynamic loads postulated to occur in the same time frame but from different events are combined by the SRSS method. A discussion of this load combination technique is given in Reference 3A-24.

3A.6.8 <u>BOP EQUIPMENT CAPABILITY ASSESSMENT CRITERIA</u>

All BOP equipment is required to withstand the dynamic loads resulting from seismic and hydrodynamic loads (SRV, SBA, IBA, and DBA) as follows:

a. OBE alone ½% damping

b. SSE alone 1% damping

c. Combination of seismic and hydrodynamic loads 2% damping

Cases a and b are discussed in Section 3.7.3. Case c is considered in accordance with the load combinations shown in Table 3A-20. The adequacy of the qualification is verified by the following methods:

a. Analysis

b. Testing

c. Combination of analysis and testing

3A.6.8.1 <u>Analysis</u>

Safety-related equipment located in the primary containment, reactor enclosure, and control structure are analyzed to satisfy load combinations 1a, 1b, 2, 3d, and 3e of Table 3A-20. The maximum load effects result from simultaneous excitation in all three principal directions for all combinations involving dynamic loads as detailed in Section 3A.7.1.7.4.1.3.

3A.6.8.2 Testing

When safety-related equipment is qualified by testing, the TRS is to envelope the RRS for load combinations 1b, 3e, and 4 of Table 3A-20. The minimum test sequence is to perform five runs for load combination 1b, followed by one run of load combination 3e. The input motion for load combination 3e is such that the TRS generated for 2% damping envelopes the RRS for load combination 4. Qualification is achieved if the equipment does not fail or malfunction during the test. Operability is verified before and after the test sequence. Active components required to function during a dynamic event are also verified during the test.

3A.6.8.3 Combined Analysis and Test

Some equipment is qualified by a combination of analysis and testing procedures.

An analysis is conducted on the overall assembly to determine its stress level and the transmissibility of motion from the base of the equipment to the critical components. The critical components are removed from the assembly and subjected to a simulation of the environment on a test table.

Testing methods are used to aid the formulation of the mathematical model for any piece of equipment. Mode shapes and frequencies are determined experimentally and incorporated into a mathematical model of the equipment. The model and subsequent analysis will meet the requirements of Section 3A.7.1.7.4.1.

3A.6.9 ELECTRICAL RACEWAY SYSTEM CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for the electrical raceway system are given in Table 3A-21.

3A.6.10 HVAC DUCT SYSTEM CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for the miscellaneous steel for the HVAC duct system are given in Table 3A-22.

3A.7 DESIGN ASSESSMENT

3A.7.1 ASSESSMENT METHODOLOGY

Loads on LGS structures, piping, and equipment are defined in Sections 3A.4 and 3B.4. The methods by which these loads are combined are discussed in Section 3A.5. The criteria for establishing design capability are stated in Section 3A.6.

This section describes the assessment methodology used in the final evaluation of structures, piping, and equipment.

3A.7.1.1 Containment, Reactor Enclosure, and Control Structure Assessment Methodology

3A.7.1.1.1 Containment Structure

3A.7.1.1.1.1 Hydrodynamic Loads

3A.7.1.1.1.1.1 Structural Models

The dynamic analysis for the structural response of the containment and internal structures due to the SRV discharge loads and LOCA loads is performed using the finite-element method. The ANSYS (Section 3.8.7) finite-element computer program was chosen for the transient dynamic analysis. Figure 3A-31 shows the ANSYS finite-element model. The concrete containment walls, slabs, RPV, RPV pedestal, and shield wall are modeled with shell elements. The refueling bellows and stabilizer truss are modeled with spar elements. The RPV internals are modeled with beam elements. The suppression pool fluid mass is modeled with lumped-mass elements. The ANSYS model includes a total of 797 elements and 206 dynamic degrees of freedom.

The soil-structure interaction is taken into consideration by modelling the soil using a series of discrete springs and dampers in three directions as shown in Figure 3A-31. The properties of the discrete springs and dampers are calculated based on the formulae for lumped-parameter foundations found in Reference 3A-21.

3A.7.1.1.1.1.2 Damping

a. Structural Damping

The equations of motion for a discrete structure must include a term to account for viscous damping that is linearly proportional to the velocity. The equations of motion for a damped system are:

$$[M]\{\ddot{r}\} + [C]\{\dot{r}\} + [K]\{r\} = \{R(t)\} \qquad \text{(EQ. 3A-5)}$$

where [C] is the viscous damping matrix.

A viscous damping matrix of the form

$$[C] = \alpha [M] + \beta [K] \qquad \text{(EQ. 3A-6)}$$

was used (Reference 3A-22) where α and β are proportionality constants that relate damping to the velocity of the nodes and the strain rates, respectively. This damping matrix leads to the following relation between α and β and the damping ratio of the i^{th} mode C_i:

$$C_i = \alpha/2\omega_i + \beta\omega_i/2 \qquad \text{(EQ. 3A-7)}$$

where ω is the natural circular frequency of the i^{th} mode. For the usual case of only structural damping, $\alpha = 0$ and therefore $\beta = 2C_i/\omega_i$.

Because only a single value of β is permitted in the ANSYS input, the most dominant natural frequency of the structure is selected for the computation of β (Reference 3A-23).

A value of β equal to 0.00063 is used in the ANSYS model which corresponds to structural modal damping of approximately 4% of critical at 20 Hz which is the most dominant natural frequency of the structure.

Figure 3A-32 shows modal damping ratio versus modal frequency for structural stiffness-proportional damping.

b. Soil Springs and Radiation Damping

The elastic half-space theory as described by Reference 3A-21 was used to compute the values of the spring constants and dampers in the horizontal, vertical, and rocking directions (K_H, K_V, K_ψ, C_H, C_V, C_ψ).

The following parameters are used to represent the rock foundation:

G = Shear modulus of foundation medium
= 1.154×10^3 KSI

ν = Poisson's ratio of foundation medium
= 0.3

ρ_s = Material density of foundation medium
= 0.00481 k-sec^2/ft^4

V_S = Shear-wave velocity
= 6180 ft/sec

From which we get the following:

K_H = 3.37×10^6 k/in

C_H = 1.57×10^4 k-sec/in

K_V = 3.96×10^6 k/in

C_V = 2.72×10^4 k-sec/in

K_ψ = 9.5×10^{11} k-in/Rad

C_ψ = 2.29×10^9 k-in-sec/Rad

The above-lumped foundation springs and dampers were then distributed to every node on the basemat according to the tributary area.

3A.7.1.1.1.1.3 Fluid-Structure Interaction

The ANSYS finite-element model with appropriate fluid-structure coupling was developed for the analysis of the containment structure. The water mass constitutes only 1/7 of the total mass of the reinforced concrete structure. The model used considers fluid-structure coupling by lumping the water mass in the suppression pool at each node of the wetted surface. The weighted area approach was considered to determine the fluid mass at each node of the suppression pool.

3A.7.1.1.1.1.4 Supplementary Computer Programs

Supplementary computer programs were used for preprocessing and postprocessing of data generated for or by the ANSYS computer program.

Preprocessing programs called PREPRC1, PREPRC2, and PREPRC3 were developed to convert the SRV, condensation oscillation, and chugging pressure time histories into force time histories, respectively, acting at the associated nodes of the ANSYS model. The programs write the nodal force time histories onto a file for processing by ANSYS.

A postprocessor program was developed to calculate the nodal acceleration time history. This program is called DISQGE. It reads the structural response displacement time histories generated from ANSYS (displacement pass option), scans for the maximum displacements, and generates the acceleration time histories using the Fast Fourier Transformation method.

Bechtel in-house computer program MSPEC was used to compute the ARS obtained from DISQGE. The program also performs plotting and broadening of the spectrum.

A computer program ENVELOP was developed to envelope response spectra obtained from MSPEC.

Computer program SCALE was developed to scan the maximum absolute stresses generated by ANSYS (stress pass option). An explanation of SCALE is given in Section 3A.7.1.1.1.1.6.2.

Verification of PREPRC1, PREPRC2, PREPRC3, DISQGE, ENVELOP, and SCALE are available for review.

3A.7.1.1.1.1.5 Load Application

3A.7.1.1.1.1.5.1 SRV Discharge Loads

The SRV discharge load used in the analyses was taken from the KWU load report (Reference 3B-2). The analyses were done for KWU SRV pressure traces 35, 76, and 82. Axisymmetric and asymmetric pressure distributions were considered. Section 3B.4.1 contains a detailed SRV load definition. The load definition takes into account the variation in pressure amplitude and frequency in the input forcing functions by applying a change of key frequencies in the assumed range of 55% to 125% of original frequency content (included are 55%, 67%, 87%, 100%, and 125% of the original frequencies) and a pressure multiplier of 1.5 to each input load trace. A total of 15 axisymmetric load traces and 15 asymmetric load traces were used in the analyses.

3A.7.1.1.1.1.5.2 LOCA-Related Loads

The main LOCA loads that significantly affect the dynamic analysis are condensation oscillation and chugging loads.

Because CO and chugging are sequential nonsimultaneous events, formulation of the LOCA load is conservatively accomplished by enveloping the CO and chugging results obtained from dynamic analyses.

The CO analysis was performed for two cases: the basic CO case and the CO-ADS case. Both CO and CO-ADS load definitions are based on direct application of measured pressure data from the 4TCO facility, a BWR Mark II prototypical unit cell used to produce expected bounding CO load data (Reference 3A-1). The CO load case is related to the basic CO load that covers all LOCA blowdown conditions resulting in CO, whereas the CO-ADS load case is data associated with the combination of CO and ADS events. Both events (CO and CO-ADS) produce wall pressure loading of axisymmetric nature. The wetwell pressure load vector was appropriately applied to the ANSYS model for a dynamic analysis. Also considered in the analysis is associated drywell pressure load defined in Reference 3A-1, based on a direct application of the measured drywell acoustic pressure time histories. A total of 17 time segments of CO and two time segments of CO-ADS are considered in the analysis.

The LGS Mark II chugging load pressure transients were calculated by Bechtel proprietary computer code IWEGS/MARS-P using GE700 series CHUG source data supplied by GE (Reference 3A-1). The source data were based on measured data from 4TCO test facility, a BWR Mark II prototypical unit cell used to simulate the chugging loads during a postulated Mark II LOCA. A total of 14 chugging time histories are considered in the chugging analyses.

3A.7.1.1.1.1.6 Analysis

3A.7.1.1.1.1.6.1 Response Spectra Generation

Acceleration time histories, maximum structural displacements and accelerations, and broadened ARS are developed for the analysis of piping, equipment, and NSSS systems. Gross acceleration time histories are generated at the interface between pedestal and diaphragm slab, the stabilizer location at the containment wall, the top of drywell at the refueling bellows, and at the interface between wetwell wall and base slab.

The maximum containment response to SRV axisymmetric loads is obtained by enveloping the ARS of the 15 axisymmetric SRV cases. Likewise, the response spectra for the 15 asymmetric SRV cases are enveloped.

The maximum containment response to the condensation oscillation loads is obtained by enveloping the ARS of the 17 CO segments. Likewise, the response spectra of the two CO-ADS segments are enveloped.

The maximum containment response to the chugging loads is obtained by enveloping the ARS of the 14 chugging cases.

Enveloped floor response spectra of 8 damping values, between 0.5% and 20% of critical are generated. For clarity, these 8 enveloped floor spectra are grouped into two separate plot sets of 4 dampings each. The low damping plot sets, furnished in Section 3A.9, include damping ratios of ½%, 1%, 2%, and 5% of critical. The high damping plot sets include damping ratios of 7%, 10%, 15%, and 20% of critical. Floor response spectra of high damping values (i.e., greater than 7% critical) are generated for application to systems and components where larger system or material damping values are justified. Reference 3A-31 provides an example of such an application. The spectra are broadened by ±15% to account for the uncertainties in the structural modeling techniques and material properties.

3A.7.1.1.1.1.6.2 Stress Analysis

The ANSYS computer program (stress pass option) is used to compute the force and moment resultants due to SRV and LOCA-related loads. A postprocessor program called SCALE is used to scan for the maximum absolute values of forces and moments in the circumferential and meridional directions.

The forces and moments due to chugging and condensation oscillation loads are considered for the load combinations including the LOCA loads. The governing forces and moments from the six different frequencies are used in the stress analysis.

3A.7.1.1.1.2 Seismic Loads

Seismic loads constitute a significant loading in the structural assessment. The same seismic loads as those used in the initial building design are used. In that design, a dynamic analysis was made using discrete mathematical idealization of the entire structure using lumped masses. The resulting axial forces, moments, and shear forces at various levels due to OBE and SSE are used (Section 3.7). The effects of the seismic overturning moment and vertical accelerations are converted into forces at the elements.

3A.7.1.1.1.3 Static and Thermal Loads

The loads under consideration are the static loads (dead load and accident pressure) and temperature loads (operating and accident temperature) which are all axisymmetrical.

a. To analyze the above static loads, an in-house computer program, FINEL (Section 3.8.7), is used. Moments, axial forces, and shear forces are computed by FINEL in an uncracked axisymmetric finite-element containment model.

b. The operating and accident temperature gradients are computed using ME 620 (Section 3.8.7) computer program (Bechtel program).

c. The results from a, b, and the hydrodynamic/seismic analysis are combined and applied to a containment element. The element contains data relative to rebar location, direction, and quantity and concrete properties. Within that wall element, force equilibrium and strain compatibility between the rebar and concrete is established by allowing the concrete to crack in tension. In this way, the stresses in the rebar and concrete are determined. The program used for this analysis is called CECAP (Section 3.8.7).

3A.7.1.1.1.4 Load Combinations

All load combinations from equations 1 through 7a as presented in Table 3A-14 have been analyzed.

The reversible nature of the structural responses due to the pool dynamic loads and seismic loads is taken into account by considering the peak positive and negative magnitudes of the response forces and maximizing the total positive and negative forces and moments governing the design.

Seismic and pool dynamic load effects (SRV and LOCA) are combined by conservatively summing the peak responses of each load by the absolute sum method. Even though the SRSS method is more appropriate because the peak effects of all loads may not occur simultaneously (Reference 3A-24), the conservative absolute sum method is used in the design assessment of the containment and internal concrete structures to expedite licensing.

3A.7.1.1.1.5 Design Assessment

Material stresses at the critical sections in the primary containment and internal concrete structure are analyzed using the CECAP computer program. Critical sections for bending moment, axial force and shear in three directions are located throughout the containment structure. Liner plate is not considered as a structural element. The CECAP program considers concrete cracking in the analysis of reinforced concrete sections. CECAP uses an iterative technique to obtain stresses considering redistribution of forces due to cracking and, in the process, it reduces the thermal-stresses due to the relieving effect of concrete cracking. The program is also capable of describing the spiral and transverse reinforcement stresses directly. The input data for the program consists of the uncracked forces, moments and shears calculated by FINEL, ANSYS, and seismic analysis. The loads are then combined in accordance with Table 3A-14 with appropriate load factors. The stress margins are calculated in Section 3A.7.2.

3A.7.1.1.2 Reactor Enclosure and Control Structure

3A.7.1.1.2.1 Hydrodynamic Loads

3A.7.1.1.2.1.1 Load Definitions

The reactor enclosure and control structure were analyzed for both the SRV discharge load and the LOCA condensation oscillation and chugging loads. Description of the different load cases are presented in Section 3A.7.1.1.1.1.5.

3A.7.1.1.2.1.2 Hydrodynamic Analysis Models

For the hydrodynamic loads described in Section 3A.7.1.1.2.1.1, different mathematical models are constructed for the determination of the reactor enclosure and control structure hydrodynamic responses. The mathematical models are presented in detail in the following sections and are summarized in Table 3A-23.

3A.7.1.1.2.1.2.1 SRV Analysis Models

The reactor enclosure and control structure were modeled to simulate global structural response during SRV actuation. Included in the analyses were an axisymmetric model for axisymmetric SRV loads and flexible base vertical, N-S, and E-W stick models for the asymmetric SRV loads. The latter uses the ANSYS containment finite-element model response as input. The mathematical models and analysis procedures are described below.

3A.7.1.1.2.1.2.1.1 Axisymmetric SRV Analysis Model

An axisymmetric model, based on Bechtel proprietary code CE971-FESS, was created to generate vertical response data for the NSSS new loads' structure and equipment adequacy assessment. The axisymmetric model has been closely correlated with in-plant test data (Reference 3A-25).

The model represents a containment system, adjacent structure (including reactor enclosure and control structure), and the soil medium as shown in Figure 3A-33. Figure 3A-38 shows a mass-proportional and stiffness-proportional damping simulation. The containment system and soil medium were modeled as FESS axisymmetric finite-elements, whereas the adjacent structure was simulated by a coupled stick model. Altogether, the model has a combination of 673 dynamic degrees of freedom.

The model was modified to simulate as-built conditions (i.e., concrete aging effect, etc.) and normal plant operating conditions (i.e., RPV mass, etc.) for generation of response data used for associated equipment adequacy evaluation. The analytical elements have the material properties as shown in Table 3A-31.

3A.7.1.1.2.1.2.1.2 Asymmetric SRV Analysis Models

Analysis models for the asymmetric load include the combined use of the ANSYS finite-element containment model response as input to the flexible base vertical, N-S horizontal and E-W horizontal stick models of the reactor enclosure and control structure. The ANSYS containment model is shown in Figure 3A-31, and the stick models are shown in Figures 3A-34 and 3A-35. The stick model damping uses the composite damping method (Reference 3A-21).

The vertical stick model was taken from the verified axisymmetric (FESS) coupled model. This model has 46 dynamic degrees of freedom. The flexible base was simulated by a soil spring and a damper as recommended in the Bechtel design guide (Reference 3A-21).

The N-S and E-W analytical stick models were similar to those used in the seismic analyses. Each stick model has 12 dynamic degrees of freedom.

Input load data were taken from associated ANSYS containment analysis output data. This includes use of a vertical input time history at the adjacent structure base equal to an average vertical response acceleration time history (from ANSYS) at the containment wall base, multiplied by an attenuation factor and use of horizontal input acceleration time history at the adjacent structure base equal to the gross motion generated from the associated containment ANSYS output data.

3A.7.1.1.2.1.2.2 CO Analysis Model

The reactor enclosure and control structure were modeled to simulate global structural response due to CO loads. Included in the analyses were an axisymmetric model for basic CO load case and CO-ADS load case, as was used in the axisymmetric SRV analysis described in Section 3A.7.1.1.2.1.2.1.1.

3A.7.1.1.2.1.2.3 CHUG Analysis Models

The reactor enclosure and control structure were modeled to simulate global structural response during various CHUG events. Included in the time history analyses were flexible base stick models presented in Section 3A.7.1.1.2.1.2.1.2, which use the ANSYS containment model response as input for the CHUG asymmetric loads, and an axisymmetric model for the CHUG equivalent axisymmetric loads. The mathematical models and analytical procedures are described below.

3A.7.1.1.2.1.2.3.1 CHUG Asymmetric Analysis Models

Analysis models for the CHUG asymmetric loads, as were used for SRV asymmetric loads, include the combined use of the ANSYS finite- element containment model response as input to the flexible base vertical, N-S horizontal and E-W horizontal stick models of the reactor enclosure and control structure. The ANSYS containment model is shown in Figure 3A-31, and the stick models are shown in Figures 3A-34 and 3A-35. The stick model damping used the composite damping method (Reference 3A-21).

The vertical stick model used was taken from the verified axisymmetric (FESS) coupled model. This model has 46 dynamic degrees of freedom. The flexible base was simulated by a soil spring and damper as recommended in the Bechtel design guide (Reference 3A-21).

The N-S and E-W analytical stick models were the same as were used in the seismic analyses. Each stick model has 12 dynamic degrees of freedom.

Input load data were taken from associated ANSYS containment analysis output data. This includes the use of a vertical input time history at the reactor enclosure and control structure base equal to an average vertical response acceleration time history (from ANSYS) at the containment wall base, multiplied by an attenuation factor, and the use of horizontal input acceleration time history at the reactor enclosure and control structure base equal to the gross motion generated from the associated containment ANSYS output data (no attenuation factor being used).

3A.7.1.1.2.1.2.3.2 CHUG Axisymmetric Analysis Model

An axisymmetric model, based on Bechtel proprietary code CE971-FESS, was created to generate vertical response data for the NSSS new loads' structure and equipment adequacy assessment.

Similar to the axisymmetric SRV analysis model (Section 3A.7.1.1.2.1.2.1.1) and the axisymmetric CO analysis model (Section 3A.7.1.1.2.1.2.2), CHUG axisymmetric analysis model represents a containment system, an adjacent structure (including reactor enclosure and control structure), and the soil medium as shown in Figure 3A-33. The containment system and soil medium were modeled as FESS axisymmetric finite-elements, whereas the adjacent structure was simulated by a coupled stick model. The model has a combination of 673 dynamic degrees of freedom. The model was modified to simulate as-built conditions (i.e., concrete aging effect, etc.) and normal plant operating conditions (i.e., RPV mass, etc.), for generation of response data used for associated equipment adequacy evaluation.

The analytical elements have the material properties as shown in Table 3A-31.

3A.7.1.1.2.1.2.4 Control Structure Floor/Local Models

Based on the excitation source at floor-wall junctions, analytical models for the selected floors were constructed to generate floor vertical response. Each floor considered was as a finite-element model, with boundaries at walls simulated by clamped edges. Along the line of symmetry (N-S direction), symmetric boundary conditions were imposed in the construction of a "half-model" for the transient analyses, i.e., SRV and CHUG loads.

To deal with dynamic problems of larger load duration, i.e., CO, CO-ADS, and seismic loads, a "quarter-model" was formed by taking a symmetric line in the E-W direction of the "half-model". Symmetric boundary were imposed similarly.

The half-model (Figure 3A-36) consists of 42 model nodes and 30 quadrilateral elements. By choosing five dynamic degrees of freedom to each interior node and three DDOF to each symmetric node, the model has 115 DDOF. Similarly, the quarter-model has 9 model nodes and 4 quadrilateral elements (Figure 3A-37), with 12 DDOF selected for analysis.

All floor models considered have identical nodal coordinates and similar model material properties (i.e., equivalent floor element thickness and mass density to take into account the beam-slab system action).

Floor-supporting steel girders have contributed a substantial portion of equivalent floor element thickness calculated for the beam-slab system. The contribution of the girders are different in magnitude, depending upon girder size and junction with or without shear connectors. The floors, except that of el 269' (control room), were built with shear connectors. The floor model at el 269' (control room) was verified by data correlation/ comparison with an in-plant test.

In addition, the models were modified to simulate as-built conditions (e.g., concrete aging effect, etc). To deal with seismic events, the models were further modified to consider cracking effects.

Floor model material properties are shown in Table 3A-24.

3A.7.1.1.2.1.3 Hydrodynamic Analysis

3A.7.1.1.2.1.3.1 Analysis Procedures

3A.7.1.1.2.1.3.1.1 Axisymmetric Analysis Procedure

The axisymmetric analysis general procedure is to perform a time history analysis using equivalent axisymmetric input forcing vectors described in Sections 3A.7.1.1.1.1.5.1 and 3A.7.1.1.1.1.5.2, using Bechtel proprietary code CE971-FESS. ARS data are generated using the acceleration response time histories obtained from the time history analysis using Bechtel proprietary code CE789-MSPEC. All associated ARS data are enveloped, widened ±15%, and plotted, using Bechtel proprietary codes ENVLPS and MSPEC.

3A.7.1.1.2.1.3.1.2 Asymmetric Analysis Procedure

The general analytical procedure for asymmetric analysis consists of generating input load vectors to ANSYS model from appropriate use of the load definition and applying ANSYS transient response for asymmetric loadings to adjacent structure decoupled stick models (N-S, E-W, and vertical). A transient analysis is performed using decoupled BSAP stick models for each load case. The ARS data are generated using the response acceleration time histories and Bechtel proprietary code CE789-MSPEC. All associated ARS data are enveloped, widened ±15%, and plotted.

3A.7.1.1.2.1.3.1.3 Floor/Local Model Analysis Procedure

The floor model analysis general procedure is to perform a time history analysis using input forcing vectors taken from the output of stick model analyses described in Sections 3A.7.1.1.2.1.3.1.1 and 3A.7.1.1.2.1.3.1.2 and using the model according to Bechtel proprietary code CE800-BSAP. ARS data are developed using the acceleration response time histories and Bechtel proprietary codes CE789-MSPEC and ENVLPS.

3A.7.1.1.2.1.3.2 Generation of Response Data

3A.7.1.1.2.1.3.2.1 Acceleration Response Spectra Data

3A.7.1.1.2.1.3.2.1.1 SRV ARS Data

Two sets of ARS data were generated. One set is for SRV axisymmetric analysis and the other set is for SRV asymmetric analysis. The ARS data, enveloped from associated data and broadened ±15% at peak frequencies, represent global response, applicable to structural assessment and NSSS equipment (or other safety-related equipment) adequacy evaluations located at or near the adjacent structure walls and/or columns. The ARS at selected typical locations on the reactor enclosure and control structure are presented in Section 3A.10.

3A.7.1.1.2.1.3.2.1.2 CO ARS Data

Two sets of ARS data are generated. One set is for basic CO load case analysis and the other set is for the CO-ADS load case. Again, the ARS data, enveloped from associated data and broadened ±15% at all peak frequencies, represent global response. The data are applicable to structure and/or equipment adequacy assessment located at or near the adjacent structure walls and/or columns. The ARS at selected locations are presented in Section 3A.10.

3A.7.1.1.2.1.3.2.1.3 CHUG ARS Data

Two sets of broadened ARS data are presented in Section 3A.10 for appropriate use in structure and equipment adequacy assessment. Set one is for CHUG asymmetric analysis case, and set two is for the CHUG equivalent axisymmetric analysis case.

The ARS data for the CHUG asymmetric case were developed and plotted similar to the SRV asymmetric analysis case. The data plots include the broadened ARS data in the three global directions (vertical, N-S, and E-W axes).

The CHUG asymmetric vertical ARS data provide responses for the applicable areas for the NSSS equipment adequacy assessment. The N-S and E-W ARS data apply to all NSSS equipment situated in any location of the reactor enclosure and control structure.

The ARS data for CHUG equivalent axisymmetric analysis cases were developed and plotted similar to SRV axisymmetric analysis cases.

Again, the data represent only global response, applicable to the NSSS equipment adequacy evaluations located at or near the adjacent structure walls and/or columns. Local/floor models are required for generating vertical ARS data for some floor-mounted equipment.

3A.7.1.1.2.1.3.2.1.4 Hydrodynamic Local ARS Data

The local ARS data in the control structure were generated based on the floor/local model analytical procedure described in Sections 3A.7.1.1.2.1.2.4 and 3A.7.1.1.2.1.3.1.3. The data was broadened ±15 percent at all peaks of the data enveloped from associated dynamic events.

The hydrodynamic events considered in the enveloping were SRV, CHUG, CO (basic), and CO-ADS.

The hydrodynamic local ARS data are used for the structures, components, and floor-mounted equipment where the global ARS data are not applicable.

3A.7.1.1.2.2 Seismic Loads

The seismic analysis methodology is discussed in Section 3.7.2.1. A seismic local model (Section 3A.7.1.1.2.1.2.4) was developed to generate local ARS data for the floors of the control structure.

3A.7.1.1.2.3 Static Loads

The static loads are discussed in Section 3.8.4.3.

3A.7.1.1.2.4 Load Combinations

All individual loads for concrete structures are combined with the appropriate load factors, as shown in Table 3A-14, for analysis of all loading combinations.

Steel structures are checked for the load combinations listed in Table 3A-15.

3A.7.1.1.2.5 Design Assessment

Critical sections for bending moment, axial force, and shear in all three directions are located throughout the reactor enclosure and control structure. Design capability at the critical sections is determined, and then the design capability is compared with the actual forces and moments acting on the sections under all the load combinations. This comparison yields design margins. The design margins are discussed in Section 3A.7.2.

3A.7.1.2 Structural Steel and ASME Class MC Steel Components Assessment Methodology

3A.7.1.2.1 Suppression Chamber Columns

There are 12 suppression chamber columns, which are 42 inch diameter pipe with 1¼ inch wall thickness. The columns are attached at the underside of the diaphragm slab at el 234'-2" and at the basemat at el 181'-11".

3A.7.1.2.1.1 Structural Models

The columns were independently analyzed for static and dynamic loads. The analytical methods used for nonhydrodynamic loads such as dead, live, pressure, temperature, seismic, and pipe rupture loads are described in Section 3.8.3.4.5.

To deal with dynamic effects from seismic and hydrodynamic events, two analytical approaches were used. The ANSYS containment model (Section 3A.7.1.1.1), in which the columns were also modeled, was used for LOCA load cases. For seismic and SRV loads, the BSAP beam model (Figure 3A-44) was used. The beam model has 13 beam elements and 14 nodes, with effective water mass in the submerged portion. The column ends were modeled as clamped edges.

3A.7.1.2.1.2 Loads

The columns, partially submerged in the suppression pool, are subjected to direct pressure loads from air bubble oscillation, etc, and inertia loads due to building response (or movement) from dynamic loads (seismic and hydrodynamic). Thermal loads are induced due to the rise of temperature during hydrodynamic LOCA events.

3A.7.1.2.1.2.1 SRV Discharge Loads

The SRV discharge pressure time histories are considered as acting on the submerged portions of the columns.

The inertia forces from building response due to SRV discharge load are included by using the response spectra shown in Section 3A.9.

3A.7.1.2.1.2.2 LOCA-Related Loads

The manner in which the LOCA-related loads are applied to the column is the same as described for SRV loads in Section 3A.7.1.2.1.2.1.

3A.7.1.2.1.2.3 Seismic Loads

The seismic loads on the column were obtained by response spectrum method. The response spectra used are developed for OBE and SSE as described in Section 3.7.

3A.7.1.2.1.2.4 Static Load

Static loads, including dead load and thermal load, were considered in the column analysis.

3A.7.1.2.1.2.5 Load Combinations

The load combinations and allowable stresses are in accordance with Section 3A.5.3. The peak dynamic responses due to the seismic and pool dynamic load effects are combined by the SRSS method. The resulting combined dynamic loads are combined with the static loads by the absolute sum technique.

3A.7.1.2.1.2.6 Design Assessment

The combined stresses due to axial force and bending moment were calculated and compared with allowable stresses.

3A.7.1.2.2 Downcomer Bracing

The following covers the methodology used in the assessment of the bracing system at el 203'-5" in the primary containment suppression pool.

3A.7.1.2.2.1 Bracing System Description

The downcomer bracing system is designed as a two-dimensional truss system to provide horizontal support for 87 downcomers, 14 MSRV discharge lines, and other miscellaneous piping in the suppression pool. The bracing system is supported vertically by the 87 downcomers and at 12 anchor points around the RPV pedestal wall. The bracing system is made of stainless steel members connected to carbon steel collars at the downcomers and embedment plates at the pedestal wall by high strength stainless steel bolts. The bracing members consist of 10 inch and 12 inch diameter schedule 160 pipe sections, and 3¼ inch end connection plates. The bracing system is designed in accordance with Reference 3A-30.

The bracing system layout and typical connection details are shown in Figures 3A-39 and 3A-40. The mathematical model used in the bracing system is presented in Figure 3A-396.

3A.7.1.2.2.2 Loads

The bracing system is assessed for all plant operation induced loads described below. The basis for all hydrodynamic loads considered in the analysis is presented in Section 3A.4 and 3B.4.

3A.7.1.2.2.2.1 SRV Discharge Loads

Discharge through the SRV discharge pipe creates horizontal as well as vertical loading on the bracing system due to unbalanced pressures. The horizontal (lateral) load is considered as acting on the downcomers and the SRV discharge pipes. The vertical load is considered acting on the bracing members alone. These loads are applied to the bracing system by considering them as equivalent static loads using a dynamic magnification factor which is obtained from the dynamic analysis of the downcomer, as described in Section 3A.7.1.4.

The SRV discharge also induces hydrodynamic forces in the containment structure. Inertial forces of the bracing system, due to the response of the containment structure, are considered using hydrodynamic response spectra of the containment structure shown in Section 3A.9.

The lateral loads and the containment structure response form the complete SRV discharge load set on the bracing system.

3A.7.1.2.2.2.2 LOCA-Related Loads

LOCAs are characterized by several phenomena that result with nonconcurrent loadings on the bracing system as described in Section 3A.4.2. These hydrodynamic loads induce accelerations of the containment structure, which in turn induce additional loads on the bracing system. These loads are obtained from the hydrodynamic ARS shown in Section 3A.9.

In addition, the LOCA event induces lateral forces on the submerged portion and tip of downcomers. The loads include drag loads, pressure loads, and chugging tip load. The hydrodynamic analysis of a single downcomer for the lateral loads is presented in Section 3A.7.1.4. The resulting reaction forces at the bracing support are applied as equivalent static load in accordance with section 3.1 of Reference 3A-26.

3A.7.1.2.2.2.3 Seismic Loads

The forces due to the seismic accelerations of the downcomers, the SRV lines, and the bracing members are obtained by analysis of these structures using the response spectra developed for OBE and SSE as described in Section 3.7.2.

3A.7.1.2.2.2.4 Static Loads

The dead load of the bracing members is considered with allowance for buoyancy.

3A.7.1.2.2.2.5 Thermal Load

The operating and accident temperature considered is 90°F and 210°F, respectively. The reference temperature of the system is assumed to be 60°F.

3A.7.1.2.2.2.6 Load Combinations

The load combinations and allowable stresses are described in Table 3A-15. Although the loads on the bracing system under consideration act in random horizontal directions, each individual load is applied on the system in the worst possible direction to find the maximum resultant forces.

3A.7.1.2.2.3 Design Assessment

The two-dimensional truss model of the bracing system is analyzed for the static, thermal, and equivalent static hydrodynamic loads using the computer program STRUDL. The ASME truss model is analyzed for the containment structure inertia response due to seismic and hydrodynamic events using the computer program ANSYS. The bracing member forces calculated above for the various loading conditions are combined by the SRSS method and assessed in accordance with the loading combinations and stress allowables specified in Table 3A-15.

3A.7.1.2.3 ASME Class MC Steel Components

The ASME Class MC steel components include suppression chamber access hatch, equipment hatch, equipment hatch/personnel airlock, refueling head and CRD removal hatch. Details of these components are shown in Figures 3.8-31 through 3.8-34. All of these components were reevaluated for additional loads due to Mark II hydrodynamic effects (SRV and LOCA) by Chicago Bridge and Iron Company under subcontract from Bechtel. The refueling head and the equipment hatch/personnel airlock were analyzed using Chicago Bridge and Iron computer program E0781. This computer program calculates the stresses and displacements in thin wall elastic shells of revolution when subjected to static edge, surface, and/or temperature loads with an arbitrary distribution over the surface of the shell. The other components (CRD removal hatch, suppression chamber access hatch, and equipment hatch) were reassessed using manual computations in accordance with the load combinations and allowable stresses shown in Table 3A-16.

An analysis, using the ANSYS 5.7, was performed by Structural Integrity Associates to reduce the Unit 2 drywell head bolt preload, (See Section 3A.7.2.1.9.1).

3A.7.1.2.3.1 Loads

Loads considered in the assessment of the components included dead load, live load, design accident pressure and thermal load, external pressure load, and jet load resulting from postulated pipe rupture as discussed in Section 3.8.2.3. Equivalent static loads were considered for the seismic load and Mark II hydrodynamic loads using appropriate peak spectral accelerations.

3A.7.1.2.3.2 Load Combinations

Load combinations and allowable stresses used in the re-assessment are given in Table 3A-16. Loads due to SRV, seismic, and LOCA events were combined using the SRSS technique.

3A.7.1.2.3.3 Design Assessment

The resultant membrane stresses, surface stresses, shear stresses and stress in welds were evaluated against allowable stresses given in Table 3A-16 for all components. The preloads and maximum stresses in connecting bolts were also assessed. Relative deflections and rotations were examined at locations where leak-tightness is required. The assessment results for the components are discussed in Section 3A.7.2.

3A.7.1.3 Liner Plate Assessment Methodology

Section 3.8.1.1.2 provides a description of the containment liner plate and its anchorage system.

The analysis and design of the liner plate anchorages for nonhydrodynamic loads is in accordance with Reference 3A-27.

In the assessment of the concrete-backed liner plate and anchorages for hydrodynamic pressure loads, the controlling load on the liner plate and anchorage system is that due to the net negative pressure load if present. The net negative pressure load is determined from the dynamic negative pressure due to SRV actuation and/or LOCA chugging minus the static positive pressure due to the wetwell hydrostatic pressure and/or LOCA wetwell pressure. Figures 3A-41 and 3A-42 describe the loads on the suppression chamber liner plate for the normal and abnormal load conditions.

For the normal condition, the hydrostatic pressure on the basemat liner is 10.4 psi (positive) and the maximum negative pressure due to the actuation of all SRVs is 7.8 psi (negative). The distribution of these pressures on the suppression chamber wall is shown in Figure 3A-41. The maximum net pressure is 2.6 psi (positive).

For the abnormal condition, the combined pressure distribution due to hydrostatic, LOCA wetwell pressure, SRV, and chugging loads is shown in Figure 3A-42. The total positive pressure on the basemat linear is 35.4 psi which consists of 10.4 psi (positive) from hydrostatic pressure plus 25.0 (positive) from a small or intermediate break LOCA. The total cyclic pressure on the basemat liner is 17.6 psi (negative) due to the axisymmetric chugging and SRV loads. Although the maximum negative pressures due to SRV actuation and chugging are combined for conservatism, it is recognized that the probability of these two phenomena producing peak negative pressures at the same time is very low.

The assessment of the liner plate is contained in Section 3A.7.2.1.5.

3A.7.1.4 Downcomer Assessment Methodology

3A.7.1.4.1 Structural Model

There are 87, 24 inch OD, steel pipe downcomers running vertically down from the diaphragm slab. The downcomers are embedded in the diaphragm slab and extend downward to el 193'-11", which is approximately 12 feet below high water level, as shown in Figure 3A-2. All downcomers are supported laterally at el 203'-5" by the downcomer bracing system. Any vertical loads are transmitted by the bracing system to the downcomers and therefore to the diaphragm slab.

The structural model considers the downcomer as a vertical pipe fixed at the underside of the diaphragm slab with a spring in the horizontal direction at bracing level. This model is shown in Figure 3A-43. The inertial effect of the water in the submerged portion of the downcomer (12 feet) was approximated by the addition of a equivalent mass of water lumped at the appropriate nodal points. The model is evaluated for three spring values for a representative support stiffness provided by the bracing system to the downcomers. The bracing spring is set to 50 k/in, 350 k/in, and 15000 k/in to represent the tangential mode, the radial mode, and rigid response of the bracing system.

3A.7.1.4.2 Loads

The downcomer is subjected to static and dynamic loads due to normal, upset, emergency, and faulted conditions. Loading cases and combinations are described in Table 3A-17. The basis for all hydrodynamic loads considered in the analysis is presented in Section 3A.4 and 3B.4.

3A.7.1.4.3 Analysis

Downcomers are analyzed for the specified loading conditions using the Bechtel computer program BSAP. The downcomers are analyzed for both the hydrodynamic loads acting directly on the submerged portions and the inertial forces due to containment responses to the hydrodynamic and seismic loads.

The hydrodynamic load analyses, due to SRV discharge and LOCA- related loads acting on the submerged portion of the downcomers, are performed using the mode-superposition time history technique. The seismic and hydrodynamic load analyses, due to containment responses, are performed using the response spectrum analysis procedure. Damping values used are equal to 2% of critical for OBE and SRV loads, and 7% of critical for SSE and LOCA loads.

3A.7.1.4.4 Design Assessment

The resultant stresses in the downcomers due to the load combinations described in Table 3A-17 are compared with the allowable stresses in accordance with the criteria given in Reference 3A-19.

3A.7.1.4.5 Fatigue Evaluation Of Downcomers In Wetwell Air Space

A fatigue analysis of the downcomers was conducted in accordance with ASME Section III, Division 1 (1979 Summer Addendum), subsection NB-3650. Only that portion of the downcomer in the air space of the suppression chamber need be evaluated for fatigue. Figures 3A-394 and 3A-395 show the number of cycles considered and the load histogram, respectively.

3A.7.1.5 BOP Piping and SRV Systems Assessment Methodology

BOP piping and SRV systems were analyzed for the load combinations described in Table 3A-18 using Bechtel computer program ME101. This program is described in Section 3.9. Hydrodynamic load considerations are provided in Section 3A.5.6. Static and dynamic analysis of the piping and SRV systems are performed as described in the paragraphs below.

Static analysis techniques are used to determine the stresses due to steady-state loads and/or dynamic loads having equivalent static loads.

Response spectra at the piping anchors are obtained from the dynamic analysis of the containment subjected to LOCA and SRV loading. Piping systems are then analyzed for these response spectra following the method described in Reference 3A-28. Alternatively, the multiple response spectra/independent support motion method of analysis may be used where distinct response spectra are applied to the piping system attachment points.

Time history dynamic analysis of the SRV discharge piping subjected to fluid transient forces in the pipe due to relief valve opening is performed using Bechtel computer code ME101.

3A.7.1.5.1 Fatigue Evaluation of MSRV Discharge Lines in Wetwell Air Volume

In an effort to evaluate the steam bypass potential arising from a failure of the MSRV discharge line in the wetwell air space, a complete fatigue analysis has been performed. Specifically, structural analyses of the MSRV discharge lines from the diaphragm

slab penetration to the quencher was performed. Fatigue evaluations of flued head penetration, elbows, tees, taper transitions, and anchors were done. This analysis considered the cyclic loading acting on the MSRV discharge lines and is in accordance with the applicable portions of ASME Code. This evaluation is considered supplemental and does not displace the original design basis for these lines as set forth in the appropriate UFSAR sections.

3A.7.1.5.1.1 Loads and Load Combinations Used for Assessment

The MSRV discharge lines are subject to numerous dynamic and hydrodynamic loads from normal, upset, and LOCA-related plant operating conditions. For purposes of fatigue evaluation, the following loads are included: (1) significant thermal and pressure transients, (2) cyclic loads due to hydrodynamic effects including MSRV actuations, CO and chugging, and (3) seismic effects. The determination of load combinations as well as number and duration of each event is obtained from the applicable sections of Reference 3A-1 and the UFSAR.

3A.7.1.5.1.2 Acceptance Criteria

The design rules, as set forth in ASME Section III, subsection NB, were used for the fatigue assessment.

3A.7.1.5.1.3 Methods of Analysis

The MSRV discharge lines in the wetwell air volume were analyzed for the appropriate load combinations and their associated number of cycles. The combined stresses and corresponding equivalent stress cycles were computed to obtain the fatigue usage factors in accordance with the equations of subsection NB-3600 of the ASME Code.

3A.7.1.5.1.4 Results and Design Margins

The cumulative usage factors for flued head, elbows, tees, tapered transitions, and anchors are summarized in Table 3A-27.

3A.7.1.6 NSSS Assessment Methodology

Safety-related NSSS piping and equipment located within the containment, reactor enclosure, and control structure are subjected to hydrodynamic loads due to SRV and LOCA discharge effects principally originating in the suppression pool of the containment structure. The NSSS piping and equipment are assessed to verify their adequacy to withstand these hydrodynamic loads in combination with seismic and all other applicable loads in accordance with the load combinations given in Table 3A-23.

The structural system responses for the SRV and LOCA suppression pool hydrodynamic phenomena are generated by Bechtel using defined forcing functions. These structural system responses are transmitted to GE in the form of (1) broadened response spectra and (2) acceleration time histories at the pedestal to diaphragm floor intersection and at the stabilizer elevation.

The response spectra for piping attachment points on the RPV, shield wall and pedestal complex (above the pool area) are generated by GE, based on the acceleration time histories supplied by Bechtel, using a detailed lumped-mass beam model for the reactor pressure vessel internals, including a representation of the structure. For the assessment of the NSSS primary piping (main steam and recirculation), a combination of GE and Bechtel developed response spectra are used as input responses for all attachment points of each piping system. For the assessment of the NSSS floor-mounted equipment, except the RPV, the broadened response spectra supplied directly by Bechtel are used.

The acceleration time histories and the detailed RPV and structure lumped-mass beam model are used to generate the forces and moments acting on the RPV supports and internal components. These forces and moments are used for the GE assessment of RPV supports and internals.

The structural system response to the LOCA-induced annulus pressurization transient asymmetric pressure buildup in the annular region between the biological shield wall and RPV is based on pressure time histories supplied by Bechtel. These pressure time histories are combined with jet reaction, jet impingement, and pipe whip restraint loads for the assessment. A time history analysis is performed resulting in accelerations, forces and moment time histories as well as response spectra at the piping attachment points on the RPV, shield wall, pedestal, RPV supports, and external components.

3A.7.1.6.1 <u>NSSS Qualification Methods</u>

3A.7.1.6.1.1 <u>NSSS Piping</u>

The NSSS piping stress analyses are conducted to consider the secondary dynamic responses from: (1) the original design basis loads including seismic vibratory motions, (2) the structural system feedback loads from the suppression pool hydrodynamic events, and (3) the structural system loads from the LOCA-induced annulus pressurization from postulated feedwater and recirculation pipe breaks.

Lumped-mass models are developed by GE for the NSSS primary piping systems, main steam, and recirculation. These lumped-mass models include the snubbers, hangers, and pipe-mounted valves and represent the major BOP branch piping connected to the main steam and recirculation systems. Amplified response spectra for all attachment points within the piping system are applied; i.e., distinct acceleration excitations are specified at each piping support and anchor point. The detailed models are analyzed independently to determine the piping system resulting loads (shear and moments) for:

a. Each design basis load which includes pressure, temperature, weight, seismic events, etc.

b. Bounding suppression pool hydrodynamic event

c. Annulus pressurization dynamic effects on the unbroken piping system.

In addition, the end reaction forces and/or accelerations for the pipe mounted/connected equipment (valves and nozzles) are simultaneously calculated.

The piping stresses from the resulting loads (shears and moments) for each load event are determined and combined in accordance with the load combinations given in Table 3A-19. These stresses are calculated at geometrical discontinuities and compared to ASME code allowable determined stresses (ASME Section III, NB-3650) for the appropriate loading condition to ensure design adequacy. Fatigue usage is calculated for the range of stress between all operating and upset events and summed to ensure that the fatigue usage factor is less than one.

3A.7.1.6.1.2 Valves

The reaction forces and/or accelerations acting on the pipe-mounted equipment when combined in accordance with the required load combinations are compared to the valve allowables to assure design adequacy. The RCPB valves are qualified for operability during seismic and hydrodynamic loading events by both analysis and test.

3A.7.1.6.1.3 Reactor Pressure Vessel, Supports, and Internal Components

The bounding load combinations for seismic, hydrodynamic, and annulus pressurization forces are established within each service condition category (upset, emergency, and faulted).

The loads for these bounding load combinations are compared to the design basis loads originally used to establish the component design. When the calculated bounding loads are less than the design basis loads, the component design is deemed adequate. When the calculated loads are greater than the design basis loads, the new stresses are calculated and are compared to the code allowable stresses. When the calculated stresses are below the code allowable stresses, the design is deemed adequate. If the increased stresses are above the code allowable stresses, the specific load combination is identified and a more refined stress analysis is performed, if possible, to demonstrate the component design adequacy.

In certain cases, component test results are combined with analyses to assess component adequacy. Fatigue evaluations of the RPV, supports, and internal components are also conducted for SRV cyclic duty loads. The equipment is analyzed for fatigue usage due to SRV load cycles based on the loading during the SRV events. SRV fatigue usage factors are calculated and combined with all other upset condition usage factors to obtain a cumulative fatigue usage factor.

3A.7.1.6.1.4 Floor-Mounted Equipment

3A.7.1.6.1.4.1 Qualification Methods

The adequacy of the design of the equipment is assessed by one of the following methods:

a. Dynamic analysis

b. Testing

c. Combination of testing and analysis

The choice depends on function, type, size, shape, and complexity of the equipment and the reliability of the qualification method.

In general, the requirements outlined in IEEE 344 (1975) are followed for the qualification of equipment. See Section 3.10.

3A.7.1.6.1.4.1.1 Dynamic Analysis

3A.7.1.6.1.4.1.1.1 Methods and Procedures

The dynamic analysis of various equipment is classified into three groups according to the relative rigidity of the equipment based on the magnitude of the fundamental natural frequency described below.

a. Structurally simple equipment - comprises equipment that can be adequately represented by frame-type structures consisting of members physically similar to beams and columns.

b. Structurally rigid equipment - Comprises that equipment whose fundamental frequency is:

    1. Greater than 33 Hz for the consideration of seismic loads, and,

    2. Greater than the zero period acceleration frequency of the suppression pool hydrodynamic load RRS.

c. Structurally complex equipment - Comprises equipment that cannot be classified as structurally simple or structurally rigid.

The appropriate response spectra for specific equipment are obtained from the response spectra for the floor at which the equipment is located in a building for OBE, SSE, and hydrodynamic loads. This includes the vertical as well as both the N-S and E-W horizontal directions. For equipment that is structurally simple, the dynamic loading (either seismic or hydrodynamic) consists of a static load corresponding to the equipment weight times the acceleration selected from the appropriate response spectrum. The acceleration selected corresponds to the equipment natural frequency, if the equipment natural frequency is known. If the equipment natural frequency is not known, the acceleration selected corresponds to the maximum value of the response spectra, which is multiplied by a static coefficient of 1.5 to take into account the effects of both multifrequency excitation and multimode response.

For equipment that is structurally rigid, the seismic load consists of a static load corresponding to the equipment weight times the acceleration at 33 Hz, selected from the appropriate response spectrum. The hydrodynamic loading consists of a static load corresponding to the equipment weight times the acceleration at the zero period acceleration, selected from the appropriate response spectrum.

The analysis of structurally complex equipment uses an idealized mathematical model which predicts the dynamic properties of the equipment. A dynamic analysis is performed using any standard analysis procedure. An acceptable alternative method of analysis is by static coefficient analysis for verifying structural integrity of frame-type structures that can be represented by a simple model. No determination of natural frequencies is made, and the response of the equipment is assumed to be the peak of the response spectrum. This response is multiplied by a static coefficient to take into account the effects of both multifrequency excitation and multimode response. The static coefficient used for structurally complex equivalent is justified and is consistent with Regulatory Guide 1.100 guidelines.

3A.7.1.6.1.4.1.2 Testing

Dynamic adequacy for some equipment is established by providing dynamic test data instead of performing dynamic analysis. Such data must conform to one of the following:

a. Performance data of equipment that has been subjected to equal of greater dynamic loads (considering appropriate frequency range) than those to be experienced under the specified dynamic loading conditions.

b. Test data from comparable equipment previously tested under similar conditions that has been subjected to equal or greater dynamic loads than those specified.

c. Actual testing of equipment in operating conditions simulating, as closely as possible, the actual installation, the required loadings and load combinations.

The equipment to be tested is mounted in a manner that simulates the actual service mounting. Sufficient monitoring devices are used to evaluate the performance of the equipment. With the appropriate test method selected, the equipment is considered to be qualified when the TRS envelopes the RRS and the equipment does not malfunction or fail. A new test does not need to be conducted if equipment requires only minor modifications such as additional bracings or change in switch model, etc, and if proper justification is given to show that the modifications would not jeopardize the strength and function of the equipment.

3A.7.1.6.1.4.1.3 Combined Analysis and Testing

This method has not been used in the NSSS piping and safety-related equipment adequacy evaluations.

3A.7.1.7 BOP Equipment Assessment Methodology

Safety-related equipment located within the containment, the reactor enclosure, and the control structure are subjected to hydrodynamic loads due to SRV and LOCA (SBA, IBA, and DBA) discharge effects principally originating in the suppression pool of the containment structure. The equipment and equipment supports are assessed to verify their adequacy to withstand these hydrodynamic loads in combination with seismic and all other applicable loads in accordance with the load combinations given in Table 3A-20. In addition, safety-related active pumps and valves located within the containment, the reactor enclosure, and the control structure are qualified for operability during seismic and hydrodynamic events.

3A.7.1.7.1 Dynamic Loads

3A.7.1.7.1.1 SRV Discharge Loads

Loadings associated with the axisymmetric and asymmetric SRV discharges are described in Sections 3A.3, 3A.4, and 3B.4. ARS at the various elevations where the equipment are located have been generated for all appropriate pressure history traces (Figures 3B-25 through 3B-27) for damping values of ½%, 1%, 2%, and 5%.

3A.7.1.7.1.2 LOCA-Related Loads

Loadings associated with a LOCA are described in Sections 3A.3, 3A.4 and 3B.4. The various LOCA loadings considered include condensation oscillation and chugging (Section 3A.4.2.2). ARS at various elevations where the equipment are located have been generated for the above LOCA loads for damping values of ½%, 1%, 2%, and 5%.

3A.7.1.7.1.3 Seismic Loads

The details of seismic input and seismic loads are discussed in Section 3.7. The effects of both the OBE and SSE are considered. These loads are provided in the form of ARS at each floor for damping values of ½%, 1%, 2%, and 5% for each of N-S, E-W and vertical directions.

3A.7.1.7.2 Load Combinations

Seismic, SRV, and LOCA loads have been combined for various load combinations in accordance with Table 3A-20 at all floor elevations. For the same equipment located at various elevations, the combined response spectra are enveloped into a single curve for a damping value of 2%. Such enveloped curves are generated for each of the N-S, E-W, and vertical directions.

3A.7.1.7.3 Other Loads

In addition to hydrodynamic and seismic loads, other loads such as dead loads, live loads, operating loads, pressure loads, thermal loads, nozzle loads and equipment piping interaction loads, as applicable, are also considered.

3A.7.1.7.4 Qualification Methods

The adequacy of the design of the equipment is assessed by one of the following:

a. Dynamic analysis

b. Testing

c. Combination of testing and analysis.

The choice is based on the practicality of the method depending upon function, type, size, shape, complexity, and nonlinear effects of the equipment and the reliability of the qualification method.

In general, the requirements outlined in Reference 3A-29 are followed for the qualification of equipment.

3A.7.1.7.4.1 Dynamic Analysis

3A.7.1.7.4.1.1 Methods and Procedures

The dynamic analysis of various equipment is classified into three groups according to the relative rigidity of the equipment based on the magnitude of the fundamental natural frequency described below:

a. Structurally simple equipment - comprised of that equipment which can be adequately represented by one degree of freedom system.

b. Structurally rigid equipment - Comprised of that equipment whose fundamental frequency is:

   1. Greater than 33 Hz for the consideration of seismic loads, and,

   2. Greater than 100 Hz for the consideration of hydrodynamic loads.

c. Structurally complex equipment - Comprised of that equipment which cannot be classified as structurally simple or structurally rigid.

When the equipment is structurally simple or rigid in one direction but complex in the other, each direction may be classified separately to determine the dynamic loads.

The appropriate response spectra for specific equipment are obtained from the response spectra for the elevation at which the equipment is located in a building for OBE, SSE, and hydrodynamic loads. This includes the vertical as well as both the N-S and E-W horizontal directions.

For equipment that is structurally simple, the dynamic loading (either seismic or hydrodynamic) consists of a static load corresponding to the equipment weight times the acceleration (in "g's") selected from the appropriate response spectrum. The acceleration selected from the response spectrum corresponds to the equipment's natural frequency, if the equipment's natural frequency is known. If the equipment's natural frequency is not known, the acceleration selected corresponds to the maximum "g" value of the response spectra.

For equipment that is structurally rigid, the seismic load consists of a static load corresponding to the equipment weight times the acceleration at 33 Hz, selected from the appropriate response spectrum and the hydrodynamic loading consists of a static load corresponding to the equipment weight times the acceleration at 100 Hz, selected from the appropriate response spectrum.

For the analysis of structurally complex equipment, the equipment is idealized by a mathematical model that adequately predicts the dynamic properties of the equipment, and a dynamic analysis is performed using any standard analysis procedures such as response spectrum modal analysis or a time history analysis. The responses of interest such as deflection, stress, acceleration, etc., are determined by combining each modal response considering all significant modes by the SRSS. The absolute sum of similar effects is considered for closely spaced in-phase modes. Closely spaced modes are those with frequencies differing by 10% or less.

An acceptable alternative method of analysis is by static coefficient analysis for verifying structural integrity of frame-type structures such as members physically similar to beams and columns that can be represented by a simple model. No determination of natural frequencies is made, and the response of the equipment is assumed to be the peak of the response spectrum at damping values in accordance with Section 3A.7.1.7.4.1.2. This response is then multiplied by a static coefficient of 1.5 to take into account the effects of both multifrequency excitation and multimode response.

For nonlinear analysis that may be necessary to account for the nonlinear material properties or the geometry-related nonlinearities, the analysis will include a detailed justification for the approach used for the qualification. Alternatively, the testing method of qualification is used where the effects of nonlinearities are to be considered.

3A.7.1.7.4.1.2 Appropriate Damping Values

The following damping values are used for the design assessment:

a.	Load combinations involving OBE but not hydrodynamic loads	½%
b.	Load combinations involving SSE but not hydrodynamic loads	1%
c.	Load combinations involving hydrodynamic loads, or seismic and hydrodynamic loads	2%

Higher damping values may be used where justified.

3A.7.1.7.4.1.3 Three Components of Dynamic Motions

The responses such as internal forces, stresses, and deformations at any point from the three principal orthogonal directions of the dynamic loads are combined as follows.

The response value used shall be the maximum value obtained by adding the response due to vertical earthquake with the larger value of the responses due to one of the horizontal earthquakes by the ABS method.

For the other dynamic loads, the response value shall be obtained by combining the response due to three orthogonal directions of an individual load by the SRSS method.

3A.7.1.7.4.2 Testing

Qualification by testing is used in cases where operability requires verification and the effects of nonlinearities have to be considered. For these instances, dynamic adequacy is established by providing dynamic test data. Such data must conform to one of the following:

a. Performance data of equipment that has been subjected to equal or greater dynamic loads (considering appropriate frequency range) than those to be experienced under the specified dynamic loading conditions.

b. Test data from comparable equipment previously tested under similar conditions that has been subjected to equal or greater dynamic loads than those specified.

c. Actual testing of equipment in operating conditions simulating, as closely as possible, the actual installation, the required loadings and load combinations.

A continuous sinusoidal test, sine beat test, or decaying sinusoidal test is used when the applicable floor acceleration spectrum is a narrow band response spectrum. Otherwise, random motion test (or equivalent) with broad frequency content is used.

The equipment to be tested is mounted in a manner that simulates the actual service mounting. Sufficient monitoring devices are used to evaluate the performance of the equipment. With the appropriate test method selected, the equipment is considered to be qualified when the TRS envelopes the RSS and the equipment does not malfunction or fail. A new test does not need to be conducted if equipment requires only minor modifications such as additional bracings or change in switch model, etc, and if proper justification is given to show that the modifications would not jeopardize the strength and function of the equipment.

3A.7.1.7.4.3 Combined Analysis and Testing

There are several instances where the qualification of equipment by analysis alone or testing alone is not practical or adequate because of its size, or its complexity, or large number of similar configurations. In these instances, a combination of analysis and testing is the most practical. The following are general approaches:

a. An analysis is conducted on the overall assembly to determine its stress level and the transmissibility of motion from the base of the equipment to the critical components. The critical components are removed from the assembly and subjected to a simulation of the environment on a test table.

b. Experimental methods are used to aid in the formulation of the mathematical model for any piece of equipment. Mode shapes and frequencies are determined experimentally and incorporated into a mathematical model of the equipment.

3A.7.1.8 Electrical Raceway System Assessment Methodology

3A.7.1.8.1 General

The analysis and design of supports of electrical raceway systems for nonhydrodynamic loads are in accordance with Reference 3A-32. SRV discharge and LOCA loads are considered similar to seismic loads by using appropriate floor response spectra for the hydrodynamic loads. A damping value of 3% critical is used for all raceway systems for the normal load condition involving SRV discharge loading only. The damping ratios used for the electrical raceway assessment are in accordance with Reference 3A-32. For the abnormal/extreme load condition, a damping value of 10% of critical is used for cable tray support systems; 7% damping for conduit and wireway gutter trapeze-type support systems; 5% damping for conduit and wireway gutter nontrapeze-type support systems. These damping values are based on the results of the Cable Tray and Conduit Raceway Seismic Test Program (Reference 3A-31).

The cable tray system damping is substantially greater than that of bolted steel structures due to the cable motion within the trays. The test program demonstrated that cable tray system damping is, in general, much higher than 10%, and damping values up to 50% were reported. The damping values recommended in Reference 3A-32, and shown in Figure 3A-45, are based on the lower bound values developed from the test program. An unloaded tray will have an associated lower bound damping value of about 7% as shown in Figure 3A-45.

Analysis using 10% damping for a fully loaded tray system under the abnormal/extreme load conditions is conservative and will envelop an analysis of an unloaded tray with a 7% damping ratio for the following reasons:

The frequency shift resulting from reduced mass in a relatively unloaded tray may result in either higher of lower response, depending on the individual response spectrum. However, when the combined effects of frequency shift, reduced damping, and lower weights are considered, the result will be a more conservative design. For example, consider the comparison of accelerations, weights, and resulting seismic forces for fully loaded and unloaded trays shown in Table 3A-26. A fully loaded tray typically weighs approximately eight times more than an empty tray. The maximum acceleration for the unloaded tray case (at 7% damping) is four times that for the fully loaded tray case (at 10% damping) assuming that frequency shift, due to the reduced mass of the unloaded tray, results in the maximum increase in acceleration. In calculating the resulting seismic forces for both cases, it is apparent that the loaded tray case yields the higher seismic load.

In addition, based on a random sampling of cable tray supports and conservatively assuming a fully loaded tray and peak acceleration, approximately 75% of the sampled members have a stress margin of 30% or more. The remaining 25% of the members are within allowable stress limits.

LGS cable tray systems are similar to those tested in Reference 3A-32, i.e., the trays are of the same material and of similar construction, and the hangers and installation are similar in construction and design. Therefore, the dynamic behavior of LGS tray systems will parallel the dynamic behavior of the tested tray systems.

For conduit systems, the test program demonstrates that, at the abnormal/extreme load condition, the damping value equals 7% of critical. This damping value is consistent with Regulatory Guide 1.61 recommended values for bolted steel structures. Therefore, 7% damping is used for conduit with trapeze-type support systems, and a more conservative 5% damping is used for conduit with nontrapeze-type support systems.

Wireway gutters were not tested; however, the manner in which they are constructed (with more bolted connections and more cables than conduit) provides more damping mechanisms than those present in conduit systems. Therefore, it is conservative to use the conduit system damping value.

3A.7.1.8.2 Loads

3A.7.1.8.2.1 Static Loads

The static loads are the dead loads and live loads. For cable trays, the weight of the cable plus tray is considered to be 36 lb/ft (except unique situations where heavier weights are considered) and a concentrated live load of 200 lb applicable at any point on the cable tray span is used.

3A.7.1.8.2.2 Seismic Loads

The details of the seismic motion input are discussed in Section 3.7. The effects of the OBE and the SSE are considered.

For the normal load condition, involving SRV discharge loading, a damping value equal to 3% of critical is used for all raceway systems. The SRV load is considered similar to an OBE load; therefore, a 3% damping value is considered conservative because 4% damping is recommended by Regulatory Guide 1.61 for bolted steel structures for the OBE loading.

3A.7.1.8.2.3 Hydrodynamic Loads

The details of the axisymmetric and asymmetric SRV discharge loads as well as LOCA loads including condensation oscillation and chugging are discussed in Sections 3A.4 and 3B.4.

The enveloped ARS at each floor for N-S, E-W, and vertical directions have been generated and widened by ±15%. These curves form the basis for the hydrodynamic load assessment of the electrical raceway system. Examples of the response spectrum curves for the containment and reactor and control enclosures are presented in Sections 3A.9 and 3A.10.

3A.7.1.8.3 Analytical Methods

Electrical raceway systems are modeled as a three-dimensional dynamic system consisting of several consecutive supports complete with raceways and longitudinal and transverse bracing. The cable tray properties are determined from the load-deflection tests. Member joints are modeled as spring elements having rotational stiffness with known spring values as determined from the test results.

Composite spectra are developed by enveloping the floor response spectra after broadening by ±15% for critical floors for seismic, SRV, and LOCA loading conditions. The design spectrum is obtained by adding these response spectra curves by either the SRSS method or the ABS method. A frequency variation of ±20% is used to further broaden the spectrum at the fundamental frequency of the electrical raceway system. The composite response spectra curves are obtained for vertical and two horizontal directions.

Modal and response spectrum analyses are performed using the Bechtel Structural Analysis Program (BSAP), which is a general purpose finite-element computer program. The total response due to the dynamic loads is calculated by determining the absolute sum of the vertical response and only the larger response of the two horizontal responses.

Dead and live load stresses are determined from a static analysis of a plane frame model using the BSAP computer program or hand calculation, and these results are combined with those from the response spectrum analysis. For normal load conditions, SRV discharge stresses are proportioned from the response spectrum analysis of SSE plus SRV discharge plus LOCA loads according to their spectral acceleration ratios at the fundamental frequencies. Several different support types that are widely used have been analyzed by these methods.

An alternative method for analyzing other support types uses hand calculations by a response spectrum analysis technique. The support may be idealized as a single degree of freedom system. In general, the maximum peak spectral accelerations were used in the analysis. In some cases where the stresses are critical, a more refined value for the acceleration response was used corresponding to the computed system fundamental frequency and considering a frequency variation as explained earlier in this section. The total response due to the dynamic loads is calculated by determining the absolute sum of the vertical response and only the larger response of the two horizontal responses. The member stresses are kept within the elastic limit.

3A.7.1.9 HVAC Duct System Assessment Methodology

The SRV discharge and LOCA loads are considered similar to seismic loads by using appropriate floor response spectra generated for the CO, chugging, and SRV loads described in Sections 3A.4 and 3B.4.

A damping value of 5% of critical is used for load combinations involving SSE, SRV discharge, and LOCA loads, while a damping value of 3% of critical is used for load combinations involving OBE and/or SRV discharge loads. For a discussion of the seismic and hydrodynamic loads input for HVAC duct system assessment, refer to Sections 3A.7.1.8.2.2 and 3A.7.1.8.2.3, respectively. The

HVAC duct system has been analyzed by determining the fundamental frequencies of the system in three directions. The inertia forces are determined from the composite spectra to establish member forces and moments due to hydrodynamic as well as seismic loads.

3A.7.2 DESIGN CAPABILITY MARGINS

This section describes the design margins for structures, piping, and equipment resulting from the LGS design assessment which uses the methods of Section 3A.7.1.

3A.7.2.1 Stress Margins

Stresses at the critical sections for all of the structures, piping, and equipment described in Section 3A.7.1 are evaluated for the loading combinations presented in Section 3A.5.

The stress margin (SM) in percent is defined as follows:

$$SM = (1 - SR) \times 100$$

where SR represents the stress ratio. SR is calculated by dividing the factored stress ($C_n f_n$) by the associated stress allowable (F_n) or, mathematically,

$$SR = \Sigma (C_n f_n / F_n) \qquad \text{(EQ. 3A-8)}$$

3A.7.2.1.1 Containment Structure

The detailed results from the structural assessment of the containment structure are summarized in Section 3A.12.1. Figure 3A-362 shows the design sections in the basemat, shield walls, containment walls, reactor pedestal, and the diaphragm slab that were considered in the structural assessment. Figures 3A-363 through 3A-386 give the calculated maximum design stresses for the load combinations listed in Table 3A-14.

Both rebar stresses and concrete stresses are calculated based on the applicable load combination equations. The stresses in the drywell wall are calculated at design sections 1 to 5 and are tabulated in Figures 3A-363 through 3A-366. The stresses in the wetwell wall are calculated at design sections 6 to 11 and are tabulated in Figures 3A-367 through 3A-370. The stresses in the shield wall are calculated at design sections 12 and 13 and are tabulated in Figures 3A-371 and 3A-372, respectively. The RPV pedestal stresses are calculated at design sections 14 to 20 and are tabulated in Figures 3A-373 through 3A-377. The stresses in the diaphragm slab are calculated at design sections 21 to 25 and are tabulated in Figures 3A-378 through 3A-381. The stresses in the basemat are calculated at design sections 26 to 30 and are tabulated in Figures 3A-382 through 3A-386.

The containment assessment is summarized as follows:

a. The calculated stress level is very low for load combination equation 1 (an operating condition), i.e., rebar stresses are far less than 20 ksi.

b. The maximum rebar stress is predicted as 53.9 ksi at design sections 6 and 11, located in the wetwell vertical direction. The magnitude is within the rebar stress allowable (0.9 F_y = 54 ksi).

c. In general, rebar stresses and concrete compressive stresses are within stress allowables.

3A.7.2.1.2 Reactor Enclosure and Control Structure

Results of the structural assessment of the reactor enclosure and control structure are summarized in Section 3A.13. Figures 3A-398 through 3A-418 show the selected structural elements and sections where stresses were calculated.

Section 3A.13 contains tabulations of predicted stresses, stress allowables, and design margins for critical loading combinations considered. The sections selected for assessment were considered to be the most critical based on previous seismic calculations.

The critical load combinations are tabulated considering critical locations/sections related to reactor enclosure and control structure shear walls, foundations, floor slabs and supporting steel, steel platforms, and floor support columns.

Emphasis is placed on margins of principal resisting structural elements, with reinforcing bar stresses for reinforced concrete structures and axial and/or bending stresses for steel structures.

Also included in Section 3A.13 are diagrams of axial forces, N-S shear forces, N-S overturning moments, E-W shear forces, E-W overturning moments for reactor enclosure and control structure as shown in Figures 3A-419 through 3A-428.

The reactor enclosure floor system stress margins were calculated for both slabs and floor support steel beams, including floors at el 201', 217', 253', 283', 313', 333', and 352'. Calculated slab stress levels were generally governed by either equation 1 or 7a of Table 3A-14. The highest reinforcing bar stress was found at the floor of el 253', having a stress intensity of 51.26 ksi and an associated stress margin of approximately 5%. Figure 3A-429 shows rebar stresses and related stress margins of the aforementioned floors. In addition, the stresses and related stress margins of floor support steel beams are presented in Figure 3A-430. The governing equations were equations 1 and 7 of Table 3A-15. Stress levels were generally low.

In the case of reactor enclosure support columns, load combination 7 of Table 3A-15 governs the column stress interaction. Stress interaction calculations were performed and show that columns were generally understressed (Figure 3A-431). The column at column lines 30.5 and E of el 217' to el 253' has a fully stressed situation.

The reactor enclosure shear wall sections close to the base (el 177') were assessed as shown in Figure 3A-432. The highest stress conditions occurred in the walls of column lines 14.1 (west wall) and 31.9 (east wall) due to shearing effect at the base. The corresponding stress margin was approximately 1%.

The floor system of the control structure, including the concrete slabs and their supporting steel beams, are shown in Figure 3A-406 through 3A-414, while the stress margins are listed in Figures 3A-433 and 3A-434.

In general, none of those selected critical sections were found overstressed in the control structure. All concrete floors were assessed. The concrete slabs are governed by the normal load conditions, equation 1 of Table 3A-14. The steel floor beams supporting the concrete slabs are governed by the abnormal extreme environmental load conditions, equation 7 of Table 3A-14. Generally, the concrete slabs have a higher stress margin than the supporting steel beams.

For the control structure shear walls, the stress levels are critical in the walls close to the base due to seismic loads. The stress margins for the shear walls at column lines 19.4 and 26.6, as shown in Figure 3A-435, were found most critical under the abnormal extreme environmental load condition including DBE and seismic torsional effects.

The steel platforms at el 313', el 322', el 340', and el 350' were also assessed. The dynamic loads applied on the steel frames which support the platforms were found less significant than the normal loads. All the steel frames are governed by the normal load condition, equation 2 of Table 3A-15, with its associated allowable stresses. Those assessed steel members are shown in Figures 3A-415 through 3A-418. As demonstrated in Figure 3A-436, steel frames are generally understressed.

3A.7.2.1.3 <u>Suppression Chamber Columns</u>

The column vibration mode shapes are calculated using computer program BSAP. The mode shapes are shown in Figure 3A-387. The equivalent water mass is equal to the column volume.

The stresses at the top and bottom of the suppression chamber columns were calculated and combined in accordance with the load combinations shown in Table 3A-15. The maximum stresses in the column are governed by load combination equation 7. The maximum stresses in the column (42 inch diameter pipe), top anchorage, and bottom anchorage are shown in Figure 3A-388. The lowest stress margin in the column structure is 10%.

3A.7.2.1.4 <u>Downcomer Bracing</u>

The bracing member forces and the corresponding design margins due to the governing load combinations are given in Figure 3A-397 for the critical bracing members.

3A.7.2.1.5 <u>Liner Plate</u>

For the normal and abnormal conditions, the liner plate system does not experience any net negative pressures as demonstrated in Figures 3A-41 and 3A-42. There is a large stress margin because the liner plate is designed for resisting a large suction (i.e., 5 psi negative).

3A.7.2.1.6 <u>Downcomers</u>

The downcomer vibration mode shapes are calculated for the modal analyses using computer program BSAP. The mode shapes are shown in Figures 3A-389 through 3A-391, for the three representative bracing system spring stiffnesses. The equivalent water mass included in the model is equal to the downcomer volume.

The downcomers were assessed in accordance with ASME Section III, Division 1, subsection NB-3652, using load combinations in Table 3A-17. Stresses and design margins are given in Figure 3A-392.

Downcomer fatigue at three critical locations were also checked. Loads are combined by the absolute sum method. Figure 3A-393 shows the fatigue usage factors at these critical locations, computed in accordance with ASME Section III, Division 1, subsection NB-3650 (1979 Summer Addenda). Downcomers are adequate for fatigue considerations.

3A.7.2.1.7 Electrical Raceway System

The electrical raceway system was analyzed using the load combinations in Table 3A-21 in accordance with the methodology described in Section 3A.7.1.8. The stress margins were found to be most critical under the abnormal/extreme load condition. Stresses are below allowable stress levels for all members of the electrical raceway system.

3A.7.2.1.8 HVAC Duct System

The HVAC duct system was analyzed using the load combinations in Table 3A-22 in accordance with the methodology described in Section 3A.7.1.9. The stress margins were found to be most critical under the abnormal/extreme load condition. Stresses are below allowable stress levels for all members of the HVAC duct system.

3A.7.2.1.9 ASME Class MC Steel Components Margins

3A.7.2.1.9.1 Refueling Head And Flange

The refueling head and flange were found to have no stresses exceeding the specified allowable limits.

The leak-tightness of the flanged joint is investigated for the combined effect of temperature, pressure, seismic, SRV, LOCA and jet forces. Vertical separation at the flange faces is prevented by providing sufficient bolt preload to offset uplift due to the applied loads. Similarly, relative horizontal movement between the flange faces is prevented by the bolt preload induced frictional forces. For Unit 1 a preload of 157k per bolt is required to maintain leak-tightness at the flange joint. For Unit 2 a preload of 130k per bolt is required to maintain leak-tightness at the flange joint. (The Unit 2 preload is based on an analysis performed by Structural Integrity Associates.)

3A.7.2.1.9.2 Suppression Chamber Access Hatch, CRD Removal Hatch, and Equipment Hatch

For these components, the analysis by Chicago Bridge and Iron Company indicated that there are no stresses in excess of the specified allowable limits when considering the additional hydrodynamic loading.

3A.7.2.1.9.3 Equipment Hatch/Personnel Airlock

The equipment hatch with personnel airlock has been assessed for hydrodynamic and seismic loads. Modifications to some cap screws of the attachment brackets are required to accommodate the additional hydrodynamic loading. The equipment hatch with personnel airlock and all related components are within the specified allowable limits.

3A.7.2.1.10 BOP Piping and MSRV Systems Margins

As described in Section 3A.7.1.5, all seismic Category I BOP piping components and their supports located inside the containment, reactor enclosure, and control structure have been included in the design assessment and have been analyzed for seismic and hydrodynamic loads. The loads from the analyses are combined as described in Table 3A-18. Additional supports and modification of existing supports where required to accommodate the hydrodynamic and seismic loads for some piping systems have been completed.

Stresses and stress margins for selected BOP piping systems are summarized in Section 3A.14. The stress reports for the evaluation of the BOP piping will be available for NRC review.

3A.7.2.1.11 BOP Equipment Margins

All seismic Category I BOP equipment and their supports have been included in the design assessment and analyzed for hydrodynamic and seismic loads (Section 3A.7.1.7) via the LGS SQRT program. Structural modifications necessitated by the addition of suppression pool hydrodynamic loads have been completed. For each piece of BOP equipment, a five page SQRT summary form has been prepared documenting the re-evaluation of the equipment.

3A.7.2.1.12 NSSS Margins

Safety-related NSSS piping, equipment and their supports have been assessed for hydrodynamic and seismic loads. Detailed results of the evaluation are given in Sections 3.9 and 3.10. Structural modifications necessitated by addition of suppression pool hydrodynamic loads have been completed. In addition, GE has prepared Seismic Qualification Reevaluation Program forms, NSSS Loads Adequacy Evaluation Program Summary reports, and design stress reports to document the assessment of seismic and hydrodynamic loads on NSSS piping, safety-related equipment and all related supports. These forms and reports will be available for NRC review.

3A.7.2.2 Acceleration Response Spectra

3A.7.2.2.1 Containment Structure

The method of analysis and load description for the ARS generation are outlined in Section 3A.7.1.1.1.1.6.1. From a review of the ARS curves for the containment structure, the maximum spectral accelerations are tabulated for 1 percent damping of critical. For SRV and LOCA loads, the maximum spectral accelerations are presented in Table 3A-25.

The hydrodynamic ARS of the containment structure are presented in Section 3A.9.2.

3A.7.2.2.2 Reactor Enclosure and Control Structure

The method of analysis and load applications for the computation of the hydrodynamic ARS in the reactor enclosure and the control structure are described in Section 3A.7.1.1.2. The response spectra of the reactor enclosure and the control structure are shown in Section 3A.10.

3A.8 MARK II T-QUENCHER VERIFICATION TEST (PROPRIETARY – SEE APPENDIX 3B)

3A.9 CONTAINMENT MODE SHAPES AND HYDRODYNAMIC RESPONSE SPECTRA

3A.9.1 CONTAINMENT MODE SHAPES

The containment model is shown in Figure 3A-46. Figure 3A-47 shows containment frequencies from the modal analysis with water mass included as discussed in Section 3A.7.1.1.1.1.3. Containment mode shapes are shown in Figures 3A-48 through 3A-70, covering mode shapes 1 through 23.

3A.9.2 CONTAINMENT HYDRODYNAMIC RESPONSE SPECTRA

This section shows examples of the horizontal and vertical response spectra curves of the containment structure due to LOCA and SRV loading. Four spectral damping values, i.e., 0.005, 0.01, 0.02, and 0.05, are shown on each group of curves. The structural model of the containment is shown on Figure 3A-46. The modal frequencies and mode shapes are shown on Figures 3A-47 through 3A-70. The broadened response spectrum curves, shown on Figures 3A-71 through 3A-150, are submitted as representative examples of the containment structure response spectra. The loads under consideration are SRV and LOCA.

The KWU SRV loads consist of 3 pressure time histories. Five different time factors are applied to each pressure time history to account for possible variations in the frequency content. Therefore, a total of 15 axisymmetric and 15 asymmetric SRV load cases were analyzed.

The LOCA loads considered include 17 segments of CO, 2 segments of condensation oscillation with ADS (CO-ADS), and 14 cases of chugging.

Enveloped and broadened ARS at selected nodes for the respective hydrodynamic loads are included in this report. The locations of the selected nodes are shown on Figure 3A-46. The hydrodynamic response spectra included at the selected nodes are shown on Figures 3A-71 through 3A-86 for SRV axisymmetric load, on Figures 3A-87 through 3A-102 for SRV asymmetric load, on Figures 3A-103 through 3A-118 for CO load, on Figures 3A-119 through 3A-134 for CO-ADS load, and on Figures 3A-135 through 3A-150 for chugging load. However, the chugging response spectra presented is the envelope spectra of all nodal points at the same elevation and radius. Therefore, the chugging spectra consist of representative spectra at containment locations with the same elevation and radius as the labeled nodal points on Figure 3A-46.

3A.10 REACTOR ENCLOSURE AND CONTROL STRUCTURE MODE SHAPES AND HYDRODYNAMIC RESPONSE SPECTRA

3A.10.1 REACTOR ENCLOSURE AND CONTROL STRUCTURE MODE SHAPES

The reactor enclosure and control structure horizontal mathematical stick model (for N-S and E-W directions) is shown in Figure 3A-35. Mode frequencies and participation factors are shown in Figure 3A-151. Representative vibration mode shapes that have significant participation are plotted in Figures 3A-152 and 3A-153.

The reactor enclosure and control structure vertical mathematical decoupled stick model is shown in Figure 3A-34. Mode frequencies and participation factors are shown in Figure 3A-154. Representative vibration mode shapes that have significant participation are plotted in Figures 3A-155 to 3A-163.

The control structure floor vertical "half-model" is shown in Figure 3A-36. Mode frequencies and participation factors for a typical local floor model at el 269' in the control structure are shown in Figure 3A-164. Representative vibration mode shapes that have significant participation are plotted in Figures 3A-165 to 3A-168.

3A.10.2 REACTOR ENCLOSURE AND CONTROL STRUCTURE HYDRODYNAMIC ACCELERATION RESPONSE SPECTRA

This section shows representative examples of the horizontal and vertical response spectra curves of the structure due to LOCA and SRV loading. Five special damping values, i.e., 0.005, 0.01, 0.02, 0.03 and 0.05, are shown on each group of curves. The response spectra presented in this section are at representative locations of the building models (Figures 3A-33 to 3A-35).

The SRV loads are defined by KWU from measured pressure traces. Figures 3A-169 to 3A-226 show broadened response spectra for the SRV loads, considering both asymmetric and axisymmetric cases.

The LOCA loads consist of chugging and condensation oscillation. The chug loads were generated form the improved Mark II chugging load definition based on GE 700 series design sources. The source data were based on 4TCO test data. Figures 3A-227 to 3A-284 show broadened response spectra curves for chugging, considering both asymmetric and axisymmetric cases. The CO loads were generated from GE's generic 4TCO test data. Figures 3A-285 to 3A-352 show broadened response spectra curves for CO-Basic and CO-ADS (axisymmetric only).

The seismic loads are described in Section 3.7.

3A.11 SUBMERGED STRUCTURE METHODOLOGY

3A.11.1 INTRODUCTION

The Mark II suppression pool is expected to experience fluid motion as a result of SRV actuation and postulated LOCA. The velocity and acceleration fields will cause drag loads on structures submerged in the pool. These loads have been calculated in the past by assuming the existence of a uniform flow field and applying steady-state standard and acceleration drag coefficients. The NRC Lead Plan Acceptance Criteria, NUREG-0487, (Reference 3A-2) pointed out that this method might not be conservative under certain flow conditions and for certain structure geometries. This section explains the methods used by the lead-plants and LGS to ensure that the design loads are conservative.

Section 3A.11.2 presents a method of evaluating the correction to both standard and acceleration drag coefficients in unsteady flow and a method to evaluate the transverse (lift) force in this flow. Sections 3A.11.3 and 3A.11.4 describe the effect of neighboring structures on the submerged structure drag loads. This method provides modified drag coefficients for the range of geometries existing in Mark II plants.

Section 3A.11.5 presents the results of sensitivity studies that verify the adequacy of the nodalization used in predicting loads. These studies show that increasing the number of points at which loads are calculated will not make significant changes in the result.

All of the drag coefficients used for submerged structure load calculations for each particular accident condition were determined directly from the data that are presented in the references listed in Section 3A.17 and 3B.17. In addition, all modifications made to the drag coefficients describing the effects of neighboring structures and unsteady flow were based on actual data listed in these references. The theory provided in this section is used as background information and provides support to the load calculations performed on this plant. The theory presented also addresses the concerns raised in NUREG-0487.

3A.11.2 DRAG AND LIFT COEFFICIENTS FOR UNSTEADY FLOW

3A.11.2.1 General Considerations

Drag and lift loads on submerged structures in the suppression pool due to the LOCA charging air bubble, pool-swell, fallback, and the SRV air bubble are considered. In calculating these loads on submerged structures, acceleration and standard drag and lift coefficients are used whenever they are applicable to a specific situation. The effects of unsteady flow on the above mentioned coefficients are treated in this section, and interference effects,

if present, are addressed in Sections 3A.11.3 and 3A.11.4. The steady-state drag coefficients are corrected appropriately to include the effects of unsteady flow.

Because the majority of the available data for unsteady flow have been developed for a cylinder, the discussion provided herein is in terms of a cylinder. The structures in the LGS suppression pool are all analyzed as cylinders. If differently shaped structures were present, a cylinder with an equivalent diameter would be used for calculations. This approach is conservative for drag load calculations, with the possible exception of the prediction of initiation of vortex shedding. Lift forces due to vortex shedding on sharp-edged structures are calculated conservatively based on available data.

Possible shapes of submerged structures in a Mark II suppression pool include circular cylinders, box beams, and I-beams. Equivalent diameters can easily be determined for these structures.

First, to determine the unsteady effects on a submerged structure, a circular cylinder with an equivalent diameter is considered. Then, for the appropriate literature, the drag coefficient due to unsteady flow for cylinders are determined, and a drag coefficient multiplier is calculated as the ratio of the unsteady drag coefficients to the steady-state drag coefficients. Finally, these multipliers are applied to the steady-state drag coefficients of the particular submerged structure of interest. However, in computing the loads, the actual dimensions of the structure are used in order to properly determine the loads.

An equivalent diameter is determined by circumscribing a circle about any structure (Reference 3A-33). For a cylinder, the equivalent diameter is equal to the diameter of the cylinder.

If a box beam is considered, its equivalent diameter is:

$$D_{EQ} = \sqrt{a^2 + b^2} \qquad \text{(EQ. 3A-9)}$$

where:

a	=	height of box beam
b	=	width of box beam

For an I-beam, the equivalent diameter is:

$$D_{EQ} = \sqrt{a^2 + b^2} \qquad \text{(EQ. 3A-10)}$$

where:

a	=	depth of I-beam flange

b = width of I-beam flange

The nondimensional numbers on which drag coefficients depend are based on the equivalent diameter. They are:

$$\text{Reynolds number} - Re = \frac{U_m\ D_{EQ}}{\nu} \qquad \text{(EQ. 3A-11)}$$

$$\text{Period parameter} - K = \frac{U_m T}{D_{EQ}} \qquad \text{(EQ. 3A-12)}$$

$$\text{Strouhal number} - S = \frac{f D_{EQ}}{U_m} \qquad \text{(EQ. 3A-13)}$$

where:

U_m = maximum velocity at the location of the loaded structure during the transient

D_{EQ} = equivalent diameter

T = period of flow oscillation

f = vortex shedding frequency

ν = kinematic viscosity.

To properly determine the effect of unsteady flow, a drag coefficient multiplier is defined as the ratio of the unsteady to steady-state drag coefficients:

$$f_d = \frac{C_{D1}}{C_D} \qquad \text{(EQ. 3A-14)}$$

$$f_m = \frac{C_{M1}}{C_M} \qquad \text{(EQ. 3A-15)}$$

where:

C_D = steady-state standard drag coefficient

C_{D1} = unsteady standard drag coefficient

C_M = steady-state acceleration drag coefficient

C_{M1} = unsteady acceleration drag coefficient

f_d = standard drag coefficient multiplier

f_m = acceleration drag coefficient multiplier.

These factors are based on drag coefficients for circular cylinders. Once they are determined for cylinders using the appropriate data, the factors are applied to the steady-state drag coefficients for the particular structure of interest. These steady-state drag coefficients are described in Reference 3A-33. The factors are applied in the following manner:

$$C_{D3} = f_d C_{D2} \quad \text{(EQ. 3A-16)}$$

$$C_{M3} = f_m C_{M2} \quad \text{(EQ. 3A-17)}$$

where:

C_{D2} = steady-state standard drag coefficient for the particular submerged structure

C_{D3} = corrected unsteady standard drag coefficient

C_{M2} = steady-state acceleration drag coefficient for the particular submerged structure

C_{M3} = corrected unsteady acceleration drag coefficient.

The lift coefficients are determined using the actual lift data for the specific structure analyzed for the applicable transient conditions.

However, if submerged structures of unique shapes are encountered in the suppression pool, they need to be considered on a plant unique basis.

Finally, when all the coefficients are determined, the standard and acceleration drag forces are calculated based on the corrected drag coefficients and the actual structure dimensions. The sum of these forces is the in-line force.

The transverse force consists only of lift. The following equations present the contributions of the standard and acceleration drag forces to the in-line force:

$$F_S = \frac{C_{D3} \; A \; \rho \; U(t) \left| U(t) \right|}{2 \; g_c} \quad \text{(EQ. 3A-18)}$$

$$F_A = \frac{C_{M3} V_S \rho \grave{U}(t)}{g_c} \quad \text{(EQ. 3A-19)}$$

$$F_{IN-LINE} = F_S + F_A \quad \text{(EQ. 3A-20)}$$

where:

F_S = standard drag force

F_A = acceleration drag force

$F_{IN\text{-}LINE}$ = total in-line force

C_{D3} = corrected unsteady standard drag coefficient

C_{M3} = corrected unsteady acceleration drag coefficient

A = projected area of submerged structure

V_S = volume of submerged structure

ρ = fluid density

$U(t)$ = velocity in the in-line direction

$\mathring{U}(t)$ = acceleration in the in-line direction.

g_c = gravitational acceleration

The determination of the lift force is considered separately in each of the following sections.

3A.11.2.2 LOCA Charging Air Bubble

The LOCA charging air bubble is considered to be a nonoscillatory accelerating flow. It is readily observed from the velocity and acceleration time histories of the transient (Figures 3A-353 and 3A-354) that the transient exhibited an increasing velocity and high positive values of acceleration. In addition, the fluid flow never reverses and the acceleration is nearly constant. This is true for all locations in the suppression pool. Comparing typical velocity time histories (Figure 3A-353) to acceleration time histories (Figure 3A-354), one can observe that the acceleration is the major contributor to the drag load because the velocity is small. The velocity and acceleration time histories were generated using the LOCA charging air bubble model described in Reference 3A-33.

The geometric configuration that was used to determine the LOCA charging air bubble transient on a submerged structure is shown in Figures 3A-355 and 3A-356. A 36° segment of a typical Mark II suppression pool was used, which contained 10 downcomers. The LOCA charging air bubbles were used at these downcomer histories on a vertical submerged structure in the pool.

For this transient, Reference 3A-34 is used in determining the standard and acceleration drag coefficients, which are conservatively taken as 1.2 and 2.0, respectively.

Due to the low velocities and small duration of this transient, lift due to vortex shedding is not present. In Reference 3A-34, the author indicates that for unsteady flow, no lift force due to vortex shedding is present for small-period parameters. In addition, the author states that for a fluid starting from rest, vortex shedding is to be present.

With the information in Reference 3A-34, it was determined that the time required for separation to occur was longer than the duration of the LOCA charging air bubble transient. Therefore, lift due to unsteady flow effects is not considered for this transient.

3A.11.2.2.1 Lift Due to Vortex Shedding

According to Reference 3A-34, the separation necessary for vortex shedding to be present does not occur until a fluid has moved a distance:

$$S = 0.293D \qquad \text{(EQ. 3A-21)}$$

where:

S = traveled distance

D = cylinder diameter

The authors also state in Reference 3A-34 that:

$$S = \tfrac{1}{2}Vt \qquad \text{(EQ. 3A-22)}$$

where:

V = velocity

t = time for separation to occur

Assuming a representative case for LOCA charging air bubble velocity in a Mark II suppression pool, the maximum pipe diameter required for separation to occur can be determined. A linear velocity increase from 0.0 ft/sec to 3.0 ft/sec was assumed to closely resemble the actual transient velocity with a transient duration of 60 msec. Integrating the velocity, a traveled distance (S) of 0.09 foot was determined. Using the above mentioned equations, the traveled distance translates to a maximum pipe diameter of 3½ inches. In other words, for a pipe with a diameter of 3½ inches that experienced a velocity transient increasing linearly form 0.0 ft/sec to 3.0 ft/sec, separation would occur at 60 msec. This is the time when the LOCA charging air bubble transient has ended.

Following this procedure for other piping within the suppression pool experiencing the LOCA charging air bubble transient, it can be concluded that lift due to vortex shedding is not present and does not need to be considered for Mark II pool geometries.

3A.11.2.3 Pool-Swell

Pool-swell is regarded as being an oscillatory flow, with the pool-swell duration considered to be the half period of the flow field. This flow is exhibited by experimental data, namely, the EPRI and 4T tests. For Reynolds numbers in the subcritical region, the drag coefficients are determined from Reference 3A-35. These drag coefficients are dependent only on the period parameter. However, if the Reynolds number is in the supercritical region ($>4 \times 10^5$), the steady-state standard drag coefficient reduces from 1.2 to 0.71 (Reference 3A-36). To determine the unsteady standard and acceleration drag coefficients for flow at the supercritical Reynolds numbers, Reference 3A-37 is used, which correlates the Reynolds number, period parameter, and the pipe roughness to both the standard and acceleration drag coefficients. The correlations for smooth pipes are used because these correlations best represent the structures within the Mark II suppression pool.

In addition, lift due to vortex shedding is considered. Reference 3A-38 provides the necessary information to determine lift loads. As before, the lift coefficient is based on the period parameter and the Reynolds number where both are evaluated at the maximum velocity observed in the transient. Moreover, the vortex shedding frequency must also be defined. Reference 3A-37 provides a correlation of the relative frequency, f_r, to the period parameter and the Reynolds number evaluated at the maximum velocity.

$$f_r = \frac{f_v}{f_w} \qquad \text{(EQ. 3A-23)}$$

where:

f_r = relative frequency

f_v = vortex shedding frequency

f_w = oscillating fluid frequency

However, if the relative frequency falls out of the range shown in figure 21 of Reference 3A-37, Reference 3A-38 indicates that a Strouhal number of 0.3 should be used at high Reynolds numbers.

When determining the lift force due to vortex shedding, the maximum amplitude is based on the maximum velocity that the structure sees (Reference 3A-38):

$$F_L = \frac{C_L \; A \; \rho \; U_m^2 \; \sin 2 \pi f_v t}{2g_c} \qquad \text{(EQ. 3A-24)}$$

where:

F_L = lift force (transverse to flow direction)

C_L = lift coefficient

A = projected area of structure

g_c = gravitational acceleration

ρ = fluid density

U_m = maximum in-line velocity the structure observes

f_v = vortex shedding frequency

t = time

The vortex shedding frequency is specified from the correlation mentioned previously. With the maximum amplitude and frequency, the lift force is defined. The lift force varies with time and is sinusoidal in nature for viscous lift.

In this case, the acceleration drag force considers the effect of gravity and is determined in the following manner:

$$F_A = \frac{V_S \rho \; C_{M3} \; \dot{U}(t)}{g_c} \qquad \text{(EQ. 3A-25)}$$

where:

F_A = acceleration drag force

V_S = volume of submerged structure

C_{M3} = corrected unsteady acceleration drag coefficient

$\dot{U}(t)$ = acceleration in the in-line direction.

3A.11.2.4 Fallback

Fallback is considered to be a constantly accelerating flow. It is assumed that fallback behaves as a falling water slug. For this case, the standard and acceleration drag coefficients are determined from Reference 3A-34. As with pool-swell, the lift coefficients due to vortex shedding are also determined. The lift coefficient is given by Reference 3A-39 as CL = 1.0 for Karman vortices. To determine the vortex shedding frequency, Reference 3A-39 indicates that a Strouhal number of 0.22 should be used. This is also substantiated by Reference 3A-40. The force is then determined as:

$$F_L = \frac{C_L \; \Delta\rho \; U_m^2 \; \sin 2\pi f t}{2 g_c} \qquad \text{(EQ. 3A-26)}$$

In this case, the acceleration drag force is determined in the following manner:

$$F_A = \frac{C_H \; g \; V_S \; \rho}{g_c} \qquad \text{(EQ. 3A-27)}$$

where:

C_H = hydrodynamic mass coefficient ($C_H = C_M - 1$).

3A.11.2.5 SRV Air Bubbles

SRV air bubbles are considered to be of oscillatory nature. Reference 3A-35 is used to determine the unsteady standard and acceleration drag coefficients. These drag coefficients are based on the period parameter evaluated at the maximum velocity. However, if the unsteady drag coefficients are less than the steady-state drag coefficients, then the steady-state coefficients are used for load determination. If any lift is present, Reference 3A-35 is used, which also bases the lift coefficients on the period parameter. This reference mentions that no lift is present for period parameters less than 5. The drag loads are determined as described in Section 3A.11.2.1.

3A.11.3 INTERFERENCE EFFECTS ON ACCELERATION DRAG

When submerged structures are closely located in a flow field, they can interfere with one another, affecting the acceleration drag. The proximity effect can be accounted for by either (a) using actual data that is presented in References 3A-44, 3A-46, and 3A-47, (b) performing a detailed analysis, or (c) applying a conservative factor of 4 on the acceleration drag. For LGS, actual data that are presented in References 3A-44, 3A-46, and 3A-47 were used to determine the interference effects on acceleration drag.

A detailed method is presented in the following sections for determining interference effects of nearby cylinders and/or a boundary on the acceleration drag for circular cylinders and is based on References 3A-41 through 3A-46.

According to the method, the interference effect between any two stationary cylinders can be completely determined by six force coefficients that are functions solely of the radius ration and the relative spacing. For the case of more than two cylinders, the total proximity effect on a given cylinder may be approximately obtained simply by superimposing each interference effect between cylinder pairs.

3A.11.3.1 Method of Analysis

The following assumptions are considered in the method:

a. Two-dimensional potential flow without separations and wakes is considered.

b. The velocity and acceleration in the flow field are the same as those seen locally by the submerged structure (cylinder).

c. The containment and pedestal walls are considered as plane boundaries.

d. Coordinate system

+x : radially outward from reactor pressure vessel centerline.

+y : vertically upward.

+z : by right-hand rule parallel to the plane boundary.

Origin: at the center of cylinder in question.

3A.11.3.2 Two Stationary Cylinders (Real Cylinders)

If the pth cylinder is isolated in a free stream, the hydrodynamic (acceleration drag) force per unit length of the cylinder is:

$$F_{po} = 2 \rho \pi A_p^2 \grave{U}_{\infty n} \quad \text{(EQ. 3A-28)}$$

where:

F_{po} = acceleration drag force per unit length

ρ = fluid density

A_p = radius of p^{th} cylinder

$\mathring{U}_{\infty n}$ = acceleration normal (in-line) to p^{th} cylinder

When the n^{th} cylinder is in the vicinity of the p^{th} cylinder, the change in the force of the p^{th} cylinder, ΔF_{pn}, is:

$$\Delta F_{pn} = \rho \pi A_p^2 \, |\mathring{U}_{\infty n}| \, \{ (C_1 - 1)\exp(i\alpha_1) - C_2\exp[i(2\beta_{pn} - \alpha_1)] \}$$

$$+ \rho A_p \, |U_{\infty n}|^2 \, \{ (C_3 + C_4)\exp(i\beta_{pn}) - C_5\exp[i(3\beta_{pn} - 2\alpha_2)]$$

$$-C_6\exp(i(2\alpha_2 - \beta_{pn})] \} \qquad \text{(EQ.3A-29)}$$

where:

$U_{\infty n}$ = velocity normal (in-line) to the p^{th} cylinder

α_1 = angle of acceleration with respect to z-axis

α_2 = angle of velocity with respect to z-axis

β_{pn} = angle between the line through centers of cylinders and the z-axis.

$$C_1 = 1 + 2 \sum_{j=1}^{\infty} b_{1,2j+1}$$

$$C_2 = 2 \left(\frac{A_n}{A_p}\right)^2 \sum_{j=1}^{\infty} b_{1,2j+1}$$

$$C_3 = 4\pi \sum_{k=1}^{\infty} \sum_{j=1}^{\infty} \frac{b_{1,2k-1} b_{2,2j}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k-l} - \frac{A_n}{A_p} q_{2,2j}\right)^3}$$

$$C_4 = 4\pi \left(\frac{A_n}{A_p}\right)^4 \sum_{k=1}^{\infty} \sum_{j=1}^{\infty} \frac{b_{1,2k-1} b_{2,2j-l}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k-l} - \frac{A_n}{A_p} q_{2,2j-l}\right)^3}$$

$$C_5 = 4\pi \left(\frac{A_n}{A_p}\right)^2 \sum_{k=1}^{\infty} \sum_{j=1}^{\infty} \frac{b_{1,2k-1} \, b_{2,2j-1}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k-1} - \frac{A_n}{A_p} q_{2,2j-1}\right)^3}$$

$$C_6 = 4\pi \left(\frac{A_n}{A_p}\right)^2 \sum_{k=1}^{\infty} \sum_{j=1}^{\infty} \frac{b_{1,2k}\, b_{2,2j}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k} - \frac{A_n}{A_p} q_{2,2j}\right)^3}$$

where:

$b_{1,1}$ = 1

$b_{2,1}$ = 1

$b_{1,m}$ = $b_{2,m-1}\, q^{2}_{1,m}$ for $m \geq 2$

$b_{2,m}$ = $b_{1,m-1}\, q^{2}_{2,m}$ for $m \geq 2$

in which:

$q_{1,1}$ = 0,

$q_{2,1}$ = 0,

$q_{1,j}$ = $\dfrac{A_p}{L_{pn} - A_n\, q_{2,j-1}}$ for $j \geq 2$,

$q_{2,j}$ = $\dfrac{A_n}{L_{pn} - A_p\, q_{1,j-1}}$ for $j \geq 2$,

A_n = radius of the n^{th} cylinder

L_{pn} = distance between the centers of cylinders

3A.11.3.3 Stationary Cylinders Near a Plane Boundary (Real and Imaginary Cylinders)

A single stationary cylinder in a uniform stream, $U_{\infty n}$, is hydrodynamically equivalent to a cylinder moving at a speed $-U_{\infty n}$ in a still fluid, except that the former cylinder experiences an extra force, $\rho\pi A_p^2 \dot{U}_{\infty n}$, from the pressure field that has been created to provide the fluid acceleration $(\dot{U}_{\infty n})$. This is also true for any number of cylinders if the cylinders move together.

When a cylinder is moving in a arbitrary direction (on a line or on a curve) with respect to the plane boundary, it can be considered as two equal cylinders moving symmetrically with respect to the plane boundary because the plane acts as a perfect reflector (mirror) of the hydrodynamic pressure. A similar argument can be applied to multiple cylinders.

Based on the above discussion, the plane boundary can be removed and replaced by an imaginary cylinder of the same size as the original (real) cylinder and the plane boundary away from the original cylinder. Similarly, multiple imaginary cylinders can be obtained by reflecting those multiple real cylinders near the plane boundary.

Now if the n^{th} imaginary cylinder is in the proximity of the p^{th} cylinder, the change in the hydrodynamic force of the p^{th} cylinder (ΔF_{pn}) can be derived from Reference 3A-41 and is:

$$\Delta F_{pn} = \rho\pi A_p^2 | U_{\infty n}| \ \{ (C_1 - 1)\exp(i\alpha_1) - C_2\exp[i(\alpha_1 + 2\beta_{pn})] \}$$

$$+ \rho A_p|U_{\infty n}|^2 \ \{ (C_3 + C_4)\exp(i\beta_{pn}) - C_5\exp(i3\beta_{pn}) - C_6\exp(-i\beta_{pn}) \}$$

(EQ. 3A-30)

where:

C_1 through C_6 are the same as described earlier.

3A.11.3.4 Total Acceleration Drag Force

Summing up each effect from all the surrounding N real and imaginary cylinders, the force on the p^{th} cylinder is approximately given as:

$$F_p = F_{po} + \sum_{\substack{n=1 \\ n\neq p}}^{n} \Delta F_{pn} = 2\rho\pi A_p^2 \grave{U}_{\infty n} + \sum_{\substack{n=1 \\ n\neq p}}^{n} \Delta F_{pn} \qquad \text{(EQ. 3A-31)}$$

or:

$$F_p = C_m \rho\pi A_p^2 \ |\mathring{U}_{\infty n}| + C_v\rho A_p |U_{\infty n}|^2 \qquad \text{(EQ. 3A-32)}$$

where:

C_m = acceleration drag coefficient

C_v = convective force coefficient

3A.11.3.5 Practical Application

When the increase in force on the p^{th} cylinder arising from interference effects is calculated, only those real and imaginary cylinders that have a significant contribution should be considered. Significant contributions to the summation equations presented in Section 3A.11.3.4 arise only from those cylinder pairs within a gap distance of 3D, where D is the larger diameter of the pair being considered.

If the flow is omnidirectional during a specific transient, a magnification factor K_M may be obtained from the maximum $|C_m|$ that is determined in the range of $0°\leq\alpha_1\leq180°$. This is performed to account for the interference effect on the acceleration drag. Similarly, to account for the lift force, the maximum $|C_v|$ can be determined by varying α_2 in the range of $0°\leq\alpha_2\leq180°$. Then the maximum lift coefficient is combined with the standard drag coefficient, C_D, by the SRSS to include the lift force due to the proximity effect.

The acceleration and drag forces are determined as follow:

$$|F_{Ap}| = \frac{2K_M \rho \pi A_p^2 \,|\,\grave{U}_{\infty n}\,|}{g_c} \qquad \text{(EQ. 3A-33)}$$

$$|\,F_{sp}\,| = \sqrt{C_D^2 + |\,C_L|^2}\;\frac{\rho A_p\;|\,U_{\infty n}|\,U_{\infty n}}{2g_c} \qquad \text{(EQ. 3A-34)}$$

where:

F_{Ap} = acceleration drag per unit length on p^th cylinder

K_M = $|C_m|/2$ magnification factor and $|C_m|$ is the maximum acceleration drag coefficient

ρ = fluid density

A_p = radius of p^th cylinder

$\mathring{U}_{\infty n}$ = acceleration in the normal (in-line) direction to the cylinder

$U_{\infty n}$ = velocity in the normal (in-line) direction to the cylinder

C_D = standard drag coefficient

$|C_L|$ = maximum lift coefficient

F_{sp} = standard drag per unit length on the p^th cylinder.

The directions of the acceleration and standard drags are the same as those without the interference effect.

However, if the flow field is well defined and the direction of flow known, then the actual acceleration drag and lift coefficients are used. In this case, the lift force is applied in the transverse direction. The equations used are then:

$$F_{Ap} = \frac{2C_m \rho \pi A_p^2 \grave{U}_{\infty n}}{g_c} \qquad \text{(EQ. 3A-35)}$$

$$F_{Lp} = \frac{C_L\;\rho A_p\,|\,U_{\infty n}\;|\,U_{\infty n}}{2g_c} \qquad \text{(EQ. 3A-36)}$$

where:

C_m = acceleration drag coefficient determined through the analysis

C_L = lift coefficient determined through the analysis

F_{Lp} = lift force in the transverse direction

3A.11.3.6 Model/Data Comparisons

The method has been tested numerically as well as experimentally, and the results (Figure 3A-357) indicate excellent agreement with both known numerical values (References 3A-41, 3A-42, and 3A-44) and experimental data (References 3A-43 and 3A-45).

3A.11.4 INTERFERENCE EFFECTS ON STANDARD DRAG

When submerged structures are located closely together in a flow field, they can interfere with one another, causing an effect on the standard drag. Actual data presented in the references can be used, a detailed analysis can be used, or a factor of four can be applied to the standard drag force. For LGS, actual data that are presented in Reference 3A-49 were used to determine the interference effects on standard drag.

Three technical papers (References 3A-48, 3A-49, and 3A-50) have described this phenomenon and presented experimental data on interference effects. Most of the data presented in these references are applicable to interference between two cylinders.

Reference 3A-49 has presented some data for three cylinders whose axes are co-planar. Cylinder spacing, Reynolds number, and the angle between flow direction and the plane containing cylinder axes were varied in the above investigations. In many instances the data obtained from the above references can be applied directly to Mark II suppression pool conditions.

A procedure has been developed to use the above data for interference between more than two cylinders. The results have been compared with measured data of three cylinders and are found to be conservative.

3A.11.4.1 Interference Between Two Cylinders of Equal Diameter

As indicated by the data given in References 3A-48, 3A-49, and 3A-50, the interference between two parallel cylinders alters the flow direction drag and also induces a lift force normal to flow direction. For two cylinders of equal diameter, the interference effect on drag forces is small, and in most cases negative (i.e., the drag is reduced due to interference). The lift force, however, is not always insignificant.

The following bounding values for interference between two cylinders of equal diameter can be used without any further detailed analysis. A bounding value of C_D for a Reynolds number greater than 8,000 and a S/d ratio greater than 0.2 is 1.4, and the bounding value for C_L is 1.0.

3A.11.4.2 Interference Between More than Two Cylinders of Equal Diameter

To evaluate the drag coefficient of a cylinder that is interfered by more than one cylinder, the maximum of C_{Do}, C_{Di}, and $D_{Di,j}$ should be used.

$$C_{Di} - C_{Do} = \sum_{\substack{j=1 \\ j\neq 1}}^{n} (C_{Di,j} - C_{Do}) \qquad \text{(EQ. 3A-37)}$$

where:

C_{Di} = standard drag coefficient for the i^{th} cylinder

C_{D0} = standard drag coefficient for a single cylinder without any interference

$C_{Di,j}$ = drag coefficient of i^{th} cylinder when it is interfered by Cylinder j alone.

Figure 3A-358 illustrates an arrangement of cylinders. The standard drag coefficient of Cylinder 1 would be:

$$C_{D_1} = C_{D_0} + (C_{D_{1/2}} - C_{D_0}) + (C_{D_{1/3}} - C_{D_0}) + (C_{D_{1/4}} - C_{D_0})$$

From this, the maximum value of C_{D_1}, C_{D_0}, $C_{D_{1/2}}$, and $C_{D_{1/4}}$ would be used for the standard drag coefficient.

To evaluate the lift coefficient, the maximum of C_{Li} and $C_{Li,j}$ should be used:

$$C_{Li,j} = \sum_{\substack{j=1 \\ j \neq 1}}^{n} \qquad \text{(EQ. 3A-38)}$$

where:

C_{Li} = lift coefficient of i^{th} cylinder

$C_{Li,j}$ = lift coefficient of i^{th} cylinder when it is interfered by Cylinder j alone.

From Figure 3A-358, the lift coefficient would be determined in the following manner:

$$C_{Li} = C_{L_{1,2}} + C_{L_{1,3}} + C_{L_{1,4}} \qquad \text{(EQ. 3A-39)}$$

The maximum value of C_{L_1}, $C_{L_{1,2}}$, $C_{L_{1,3}}$, and $C_{L_{1,4}}$ would be used for the lift coefficient.

The above described method yielding interference on standard drag between more than two cylinders of equal diameter (bounding procedure) is illustrated in the following examples:

<u>Example 1</u>

Consider the three cylinder arrangement shown in Figure 3A-359.

Let $\frac{S}{d} = 1$, $\theta = 60°$, and Re = 2.78×10^4

For this arrangement:

$C_{D_{1,2}}$ = Drag coefficient of Cylinder 1 when interfered by Cylinder 2 only.

$=$ 1.01 (S/d = 1)

$C_{D_{1,3}}$ $=$ 1.02 (S/d = 3)

C_{D0} $=$ 1.16 [Reference 3A-36, p. 341]

$C_{Di} - C_{D_0} = (C_{D_{1,2}} - C_{D_0}) + (C_{D_{1,3}} - C_{D_1})$

$=$ 0.37

$\therefore$ Maximum of C_{Di}; $C_{D_{1,2}}$; $C_{D_{1,3}}$; C_{D_0} is 1.16

$\therefore$ Use $C_D = 1.16$

From measurements (Reference 3A-49):

C_D $=$ 0.97, which is less than the calculated drag coefficient.

Example 2

Consider the three cylinder side-by-side arrangement shown in Figure 3A-360.

Let S/d = 1 and Re = 2.78×10^4

$C_{D_{1,2}}$ = 1.03(S/d = 1)

$C_{D_{1,3}}$ = 1.05 (S/d = 3)

C_{D_o} = 1.16

$\therefore C_{D_1} - 1.16 = 1.03 - 1.16 + 1.05 - 1.16$

or $C_{D_1} = 0.92$

Maximum of C_{D_o} ; C_{D_1} ; $C_{D_{1,2}}$; $C_{D_{1,3}}$ is 1.16

Use $C_D =$ 1.16

The measured value is 0.98, which is less than the calculated value.

3A.11.4.3 Drag on Small Cylinder Upstream of Large Cylinder

Figure 3A-361 presents the flow around cylinders of unequal diameters.

The coordinates of point A (center of smaller cylinder) are (-a,b). Let R and R_1 be the radii of larger and smaller cylinders, respectively. The velocity potential of flow around the larger cylinder in the absence of smaller cylinder is

$$\phi = Ux\left(1 + \frac{R^2}{x^2 + y^2}\right)$$

where:

ϕ = velocity potential

U = free stream velocity

R = radius of large cylinder.

If u and v are the x and y components of velocity at point "A" (smaller cylinder absent) then,

$$u = U \left[1 + R^2 \left\{\frac{b^2 - a^2}{\left(a^2 + b^2\right)^2}\right\}\right] \qquad \text{(EQ. 3A-40)}$$

and $$v = \frac{2ab\ R^2\ U}{\left(a^2 + b^2\right)^2} \qquad \text{(EQ. 3A-41)}$$

where:

u = the velocity parallel to the free stream velocity at the centerline of the smaller cylinder

v = the velocity perpendicular to the free stream velocity at the centerline of the smaller cylinder.

To use the above velocity correction, it is more convenient to increase the standard drag coefficient and use the corrected standard drag coefficient with the free stream velocity. The standard drag force on the smaller cylinder with interference present is:

$$F_1 = \frac{C_D\ \rho\ A\ \left(u^2 + v^2\right)}{2g_c} \qquad \text{(EQ. 3A-42)}$$

where:

F_1 = standard drag force with interference

C_D = standard drag coefficient

ρ = fluid density

A = projected area of smaller cylinder.

The direction of flow is:

$$\beta = \tan^{-1}\left(\frac{v}{u}\right)$$

The standard drag force without interference is:

$$F = \frac{C_D \ \rho \ A \ U^2}{2g_c} \qquad \text{(EQ. 3A-43)}$$

where:

F = standard drag force without interference

U = free stream velocity.

The ratio of the two standard drag forces yields the following expression for the correction of the standard drag coefficients:

$$\frac{C_D \ (\text{interference})}{C_D \ (\text{without interference})} = m^2 + n^2 \qquad \text{(EQ. 3A-44)}$$

where:

$$m = 1 + R^2\left\{\frac{b^2 - a^2}{(a^2 + b^2)^2}\right\}$$

$$n = \frac{2ab \ R^2}{(a^2 + b^2)^2}$$

If the determined ratio of the standard drag coefficients is less than 1, then a ratio of 1 is used. However, if the determined ratio is greater than 1, then the determined ratio is used.

The standard drag force on the smaller cylinder is then determined by:

$$F_1 = \frac{C_D \ \rho \ A \ U \ |U|}{2g_c} \qquad \text{(EQ. 3A-45)}$$

where:

F_1 = standard drag force on smaller cylinder

C_D = the corrected standard drag coefficient for interference

U = free stream velocity in the in-line direction.

The lift force on the smaller cylinder is determined in the same manner as was the standard drag force:

$$\frac{C_L \text{ (interference)}}{C_L \text{ (without interference)}} = m^2 + n^2 \qquad \text{(EQ. 3A-46)}$$

where m and n are the same as previously described. Once again, if the determined ratio is less that 1, then the ratio of 1 is used. However, if the determined ratio is greater than 1, then the determined ratio is used. The lift force is then determined by:

$$F_L = \frac{C_L \rho A U |U|}{2g_c} \qquad \text{(EQ. 3A-47)}$$

where:

F_L = lift force

C_L = corrected lift coefficient for interference.

The lift force is applied in the transverse direction to the resultant flow.

3A.11.4.4 Standard Drag on Smaller Cylinder Downstream of Large Cylinder

If the smaller cylinder is located downstream of the larger cylinder, then the lift and standard drag coefficients are evaluated corresponding to S/d (where S is the distance between the cylinder surfaces and d is the diameter of the cylinders) ratios of for both cylinders, assuming equal diameters. The coefficients are first determined by assuming both cylinders are equal to the diameter of the smaller cylinder, and then assuming booth cylinders are equal to the diameter of the larger cylinder. When determining the coefficients, the centerline distance between the two submerged structures is maintained at the actual distance.

Afterwards, the larger coefficients are used for determining submerged structure loads. In addition, if the lift and standard drag coefficients are less than the coefficients without interference, then the coefficients without interference are used.

3A.11.4.5 Standard Drag on the Large Cylinder

The method described in Section 3A.11.4.4 is used to determine the standard drag and lift on the large cylinder.

3A.11.4.6 Structures of Noncircular Cross-Section

The methodology of determining an equivalent diameter described in Section 3A.11.4.2 is used to determine the coefficients due to interference effects.

3A.11.4.7 Interference Between Nonparallel Cylinders

To estimate the interference effects between nonparallel structures, the lift and standard drag coefficients are determined by assuming that the structures are parallel. The distance used between them would be the minimum distance between the two structures. In the same manner, the larger coefficients of either with or without interference effects are chosen for submerged structure load determination.

3A.11.5 FLOW BLOCKAGE EFFECTS OF DOWNCOMER BRACING

The downcomer bracing is a flow restriction that increases the fluid velocity and acceleration during pool-swell. As a result, the standard drag, acceleration drag, and lift loads on structures in the pool-swell zone are higher than those which would exist if no downcomer bracing was present. Although the pool-swell loads are not design-controlling criteria, the load calculations were adjusted for blockage effects by introducing a multiplicative factor to the fluid velocity and acceleration.

A method of correction has been developed based on References 3A-51 and 3A-52. A multiplicative factor has been determined based upon Maskell's paper (Reference 3A-52).

$$\frac{C_{Dm}}{C_{Df}} = 1 + n\, C_{Df}\ S/C \qquad \text{(EQ. 3A-48)}$$

where:

C_{Dm}	=	modified drag coefficient of structures in the pool-swell zone
C_{Df}	=	steady flow, free steam drag coefficient
n	=	blockage factor
S	=	total blocked area
C	=	unrestricted flow area.

The value of the blockage factor, n, depends upon the structure's geometry. The blockage ratio varies from 0.96 to 2.77 for structures with aspect ratios, AR, from ∞ to 1.0, respectively. Maskell (Reference 3A-52) recommends a blockage factor of 2.5 for bluff bodies, and this value is considered conservative for the suppression pool bracing system.

The unrestricted flow area, C, is the pool surface area minus the area of the columns, downcomers and MSRV lines. THe blocked area, S, includes all the flanges and members of the bracing system. The drag coefficient used on the right side of Equation 3A-48 is the steady flow, free stream drag coefficient of the particular structure being analyzed.

Equation 3A-48 can be rearranged to obtain

$$C_{Dm} = \left(1 + n\ C_{Df}\ \frac{S}{C}\right) C_{Df} \qquad \text{(EQ. 3A-49)}$$

$$= f\ C_{Df}$$

where (f) is defined as the blockage correction factor. Because (f) is proportional to the drag coefficients, and therefore to the square of the velocity, the fluid velocity and acceleration are multiplied by the square root of (f). For consistency, the same multiplicative factor is used for the velocity and acceleration.

As a result, the pool-swell loads are calculated by the following equations:

Standard Drag Load: $F_X = \frac{1}{2} \rho \, (\sqrt{f}\; V)^2 \, C_D A$ (EQ. 3A-50)

Acceleration Drag Load: $F_A = \rho(\sqrt{f}\; a) \, C_m V_s$ (EQ. 3A-51)

Lift Load: $F_L = \frac{1}{2} \rho \, (\sqrt{f}\; V)^2 \, C_L A$ (EQ. 3A-52)

where:

ρ = fluid density

f = blockage correction factor

V = fluid velocity

C_D = standard drag coefficient which accounts for any interference effects

A = projected cross-sectional area of the structure

C_L = lift coefficient

a = fluid acceleration

C_m = inertial coefficient

V_S = structure's volume.

3A.12 CONTAINMENT AND SUBMERGED STRUCTURE - STRUCTURAL DESIGN ASSESSMENT

3A.12.1 CONTAINMENT STRUCTURE - STRUCTURAL DESIGN ASSESSMENT

Figure 3A-362 indicates the containment structural elements and cross-sections where stresses are determined, and Figures 3A-363 through 3A-386 contain a tabulation of the predicted stresses and allowable stresses for each loading combination considered.

Load Combinations, taken from Table 3A-14, are tabulated to cover all of the critical sections in the containment concrete structures. Load combination equation 2 for all sections and equations 1 and/or 3 and 6 for some sections are not executed because they do not represent the governing cases.

3A.12.2 SUBMERGED STRUCTURE - STRUCTURAL DESIGN ASSESSMENT

The submerged structures in the suppression chamber include the diaphragm slab support columns, the downcomer bracing system, and the downcomers. The bracing system and the columns are assessed in accordance with Table 3A-15. In the column assessment, the dynamic loads are combined by the SRSS method and then combined with the static loads using the absolute sum procedure. In the assessment of the downcomer bracing system, all loads are combined using the absolute sum method. For both the downcomer bracing system and the columns, equation 7 of Table 3A-15 is the most critical combination.

The natural vibration frequencies and shapes of the suppression chamber columns are presented in Figure 3A-387, and the assessment results are summarized in Figure 3A-388. Bolt stresses are not shown in the bottom anchorage because the design is more critical at the connecting flange, which yields a design margin of 10%.

The natural vibration frequencies and mode shapes of the downcomers are presented in Figures 3A-389 through 3A-391. Downcomer design margins are provided in Figure 3A-392. Fatigue usage factors, fatigue cycles, and fatigue histogram are provided in Figures 3A-393, 3A-394 and 3A-395, respectively.

The downcomer bracing system mathematical model is shown in Figure 3A-396, and the design margins for the most critical member in each quadrant are summarized in Figure 3A-397.

3A.13 REACTOR ENCLOSURE AND CONTROL STRUCTURE - STRUCTURAL DESIGN ASSESSMENT

Figure 3A-398 presents the reactor enclosure and control structure general floor plan at el 177' to aid in the location of wall marks.

Figures 3A-399 through 3A-418 identify and locate the selected critical structural elements where stresses are assessed in the reactor enclosure and control structure.

Figures 3A-419 through 3A-428 present diagrams of combined vertical (axial) forces, N-S and E-W shear forces, and N-S and E-W overturning moments, based on the dynamic portion of the load combinations specified in Tables 3A-14 and 3A-15.

Figures 3A-429 through 3A-436 contain tabulations of predicted stresses, stress allowables, and/or stress margins for the reactor enclosure and control structure floor slabs, floor support steel, and shear walls.

3A.14 BOP PIPING DESIGN ASSESSMENT

Table 3A-27 provides maximum cumulative fatigue usage factors for the MSRV discharge lines in the wetwell airspace. Table 3A-28 summarizes the stresses and stress margins for selected BOP piping systems.

The stress reports for the evaluation of the BOP piping will be available for NRC review.

3A.15 SUPPRESSION POOL TEMPERATURE DESIGN ASSESSMENT

3A.15.1 SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM

3A.15.1.1 Suppression Pool Temperature Monitoring System Design Criteria

The SPTMS monitors the suppression pool temperature during normal plant operations and after transient or accidents. Operator monitoring of pool temperature is required to ensure that the suppression pool is operated within the allowable temperature limits set forth in the LGS Technical Specifications. Operation of the pool within the Technical Specifications will provide assurance that the suppression pool temperature will be maintained within the limits specified in NUREG-0783. Section 3A.15.1.1.4 describes the Technical Specification temperature alarm setpoints for pool operation.

The SPTMS is designed in conformance with the acceptance criteria specified in NUREG-0487 (Reference 3A-56) and NUREG-0783 (Reference 3A-58).

3A.15.1.1.1 Sensor Locations

The suppression pool temperature is redundantly monitored by two divisionalized systems. Eight dual element RTDs are provided for each system and are evenly distributed around the pool to provide a reasonable measure of the bulk water temperature. The eight monitoring locations and individual RTD identifications are shown in Figure 3A-437.

The sensors are located at a depth of 4'-4" below the minimum Technical Specification pool water level. This depth ensures a conservative measurement of bulk temperature because the hottest water will rise to the pool surface. This depth also provides adequate sensor submergence to preclude the possibility of sensor uncovery during an accident or transient.

3A.15.1.1.2 Safety Evaluation

The indication of suppression pool temperature in the control room is required to ensure that the plant is always operating within the Technical Specification limits. Manual operator action is required to maintain the plant within the Technical Specifications. Suppression pool temperature is also required for postaccident monitoring. These functions are safety-related.

The system design conforms to all applicable criteria for physical separation, redundancy and divisionalization. Physical and electrical separation is provided for the safety-related instrumentation. The safety-related instrumentation is powered from divisionalized Class 1E power sources.

The suppression pool temperature sensors are qualified to seismic Category I and Class 1E criteria and are energized from onsite emergency power supplies.

The hard copy time plot of suppression pool temperature is for operating history only and is not safety-related.

3A.15.1.1.3 Equipment Design

The signals from the redundant sensors are processed by two independent divisionalized recorders located on a main control room cabinet. The recorders convert the RTD signals into degrees Fahrenheit and compute the average of the eight temperatures. The average value is displayed by the recorders and on the remote indicators located at the main control board. A keypad located on the microprocessor allows the operator to display any individual temperature input.

The SPTMS trouble alarm located in the main control room is generated if the calculated average temperature exceeds any of the four distinct high temperature setpoints that are stored in the microprocessors. (Section 3A.15.1.1.4 provides details on the temperature alarm setpoints.) Also, appropriate high temperature status lights are initiated on the associated recorder and remote indicator. Electrically isolated outputs interface with the SPTMS trouble alarm located in the main control room.

The SPTMS trouble alarm is also initiated if one of the RTDs fails or if non-Class 1E power to the cabinet cooling fans is lost. A keypad allows the operator to remove a failed RTD from the calculated average.

Both elements of each dual element RTD are wired out through containment penetrations. One element of each RTD is connected to the associated recorder inputs. This design provides the capability to easily connect the backup RTD elements in case of a failure, with the exception of the backup RTD elements for TE41-101D and H.

For temperature elements TE41-101D and H only, the second dual element is used for providing suppression pool temperature indication at the remote shutdown panel. This is an independent Division 1 loop to provide the operator with suppression pool water temperature indication when the main control room is inaccessible (Method R shutdown as described in (Appendix 9A).

A printer located on the recorder prints the average temperature, the individual temperature, and the current date and time. Trending information may also be printed at the operator's request. Alarm conditions are printed along with the temperature.

Output signals are provided to interface with other plant information systems including a signal to the PMS computer. The recorder has a self checking diagnostic system that provides an alarm if a failure is detected in any critical part of the system.

3A.15.1.1.4 Alarm Setpoints

The SPTMS provides alarm at four pool temperature setpoints (95°F, 105°F, 110°F, and 120°F) to provide assurance that the suppression pool will be maintained within the temperature limits defined in NUREG-0783. Section 3A.15.2 describes these pool temperature limits and provides LGS analysis for suppression pool temperature response to SRV discharge. This analysis demonstrates the adequacy of these alarm setpoints with regard to alerting the operator to maintain the pool temperature below the NUREG-0783 limit. The alarm setpoints are based on Reference 3A-53 and are defined as follows:

a. 95°F: maximum allowable pool temperature for continuous power operation without suppression pool cooling

b. 105°F: maximum allowable pool temperature during testing at power which adds heat to the pool.

c. 110°F: manual reactor scram setpoint

d. 120°F: manual reactor depressurization setpoint.

3A.15.1.2 SPTMS Adequacy Assessment

As mentioned in Section 3A.15.1.1, the selection of the SPTMS sensor locations conforms with the acceptance criteria specified in NUREG-0487 (Reference 3A-56) and NUREG-0783 (Reference

3A-58). Section 3A.15.1.2 provides data for confirming the adequacy of the SPTMS sensor locations shown on Figure 3A-437, in predicting the bulk pool temperature.

The following assessment is based on a SPTMS sensor location of 2' below minimum Technical Specification water level. Subsequent to the assessment, the sensors were relocated at 4'-4" below the minimum Technical Specification water level to be below the resultant post-LOCA water level.

A sensitivity study as to the effect of the lower SPTMS sensor elevation on the following assessment was performed and the differences were negligible. Therefore, the following assessment, which was originally performed corresponding to SPTMS sensor elevation of 2' below the minimum Technical Specification water level, remains as an adequate representation of the SPTMS prediction capability.

In lieu of conducting LGS unique confirmatory in-plant tests of SRV discharges, analyses were performed using the KFIXTM computer code. KFIXTM is a three-dimensional thermal-hydraulic computer code which was developed to provide an analytical tool for predicting the thermal mixing and temperature response in the LGS suppression pool resulting from SRV actuation. The calculated results from the KFIXTM code have been verified against LaSalle and Caorso SRV extended blowdown in-plant test data. The KFIXTM code verification and methodology have been provided to the NRC (Reference 3A-54).

Section 3A.15.1.2.1 describes the scenarios that were analyzed for assessment of the LGS SPTMS. These scenarios are also used in Section 3A.15.3 to assess the adequacy of the suppression pool local-to-bulk temperature difference (ΔT). Sections 3A.15.1.2.1.1 and 3A.15.1.2.1.2 describe the initial/operating conditions and KFIXTM modeling, respectively. The calculated temperature time histories for the individual SPTMS sensors are discussed in Section 3A.15.1.2.2 The arithmetic average values among these sensors are presented in Section 3A.15.1.2.3. Conclusions of the SPTMS adequacy assessment are provided in Section 3A.15.1.2.4.

3A.15.1.2.1 Stuck Open Relief Valve Scenarios

The KFIXTM code is employed for the simulation of three SORV scenarios to predict the LGS suppression pool thermal mixing and temperature response.

To parallel the scenarios chosen in the LaSalle in-plant tests, two single SORV blowdown scenarios under conditions of high reactor pressure and relatively low pool temperature were selected. This analysis quantifies the thermal mixing effectiveness in the pool due to the large momentum associated with the heated fluid jet induced by high reactor pressure steam discharges through the quencher.

The third scenario considers a single SORV blowdown scenario under conditions of low reactor pressure and high pool temperature. This analysis quantifies the thermal mixing effectiveness in the pool even under conditions of reduced fluid jet momentum associated with steam discharges under low reactor pressure.

The LGS SRV set pressures are provided in Table 3A-3. The associated quencher orientations are shown in Figure 3A-3. Among the 14 SRVs, the two with designations of L and H, which are located along the outer and inner quencher circles, respectively, were selected for the high reactor pressure analysis because these valves have the lowest set pressure values among those on the corresponding quencher circles. SRV-H was chosen for the low reactor pressure analysis. Quenchers H and L have off-radial orientations of 30° and 10° in the counterclockwise direction, respectively. Discharge associated with the end gap of Quencher H is towards the containment wall, while discharge associated with the end cap of Quencher L is towards the pedestal. Figures 3A-438 and 3A-441 show these quencher configurations in the KFIXTM models.

In the KFIXTM code, the LGS suppression pool is subdivided into a large number of computational cells which is on the order of 5500. Among these computational cells, the containment walls, major submerged structures and boundaries are treated as obstruction (or fictitious) cells, the containment walls, major submerged structures, and boundaries are treated as obstruction (or fictitious) cells while the remainder are called fluid cells. The governing conservation equations are solved with respect to the fluid cells. Fluid cells which contain the quencher discharge areas are called special cells. Additional source terms are included in the conservation equations in these special cells to account for the steam blowdown precess. The source terms are derived from various operating conditions, i.e., the reactor pressure, the SRV steam flow rate, the geometrical data of the quencher, and the quencher orientation. Geometrical data of the Mark II T-quencher is provided in Section 3B.4.1.

3A.15.1.2.1.1 Initial and Operating Conditions

The initial and operating conditions pertinent to the high and low reactor pressure SORV scenarios are tabulated below:

Parameter	High Reactor Pressure Analysis	Low Reactor Pressure Analysis
Reactor vessel pressure	1025 psia	90 psia
SRV steam flow rate	239.6 lb_m/sec	21 lb_m/sec
Suppression pool initial water depth	22 ft	23 ft
Initial pool temperature	95° F	199° F
Duration of blowdown	10 minutes or longer	20 minutes or longer

The 1025 psia reactor pressure corresponds to the nominal pressure in the RPV steam dome at 105% of nuclear boiler rated steam flow. The 90 psia reactor pressure corresponds to the lowest pressure just prior to clearing the shutdown cooling pressure interlock. The SRV flow rates correspond to the nominal flow rates adjusted to the specified reactor pressures.

The high pressure analysis initial pool water depth (22 feet) corresponds to the low pool level (Figure 3A-2). The initial pool temperature (95°F) corresponds to the maximum operating temperature without suppression pool cooling.

The low pressure analysis initial pool water depth (23 feet) corresponds to the normal pool level. The normal water level was chosen in lieu of the low level to account for the additional water condensed from the incoming SRV steam during reactor depressurization to 90 psia.

The low pressure analysis initial pool temperature corresponds to the highest temperature at a reactor pressure of 90 psia. From LGS analysis of suppression pool temperature response to SRV discharge presented in Section 3A.15.2, a pool temperature of 199°F exists at 90°F and 10^4 seconds into the transient (Figure 3A-456, Case 3.a).

The blowdown durations selected for the high and low pressure SORV scenarios allow the pool temperature to reach a quasi-steady rate of increase.

In addition to the above initial and operating conditions, several conservative assumptions are made in the high and low reactor pressure analyses. For example, the water in the pedestal is neglected, no RHR operation is considered, the initial pool motion is assumed to be stagnant, and containment wall boundaries are treated adiabatically.

3A.15.1.2.1.2 Geometrical Modeling

The plan and section views of the mesh systems used in the KFIXTM model to simulate the SRV-H and SRV-L blowdown scenarios are shown in Figures 3A-438 through 3A-442. The mesh compositions associated with each scenario are summarized as follows:

Parameter	SRV-H Blowdown (High Reactor Pressure)	SRV-L Blowdown (High Reactor Pressure)	SRV-H Blowdown (Low Reactor Pressure)
Total Cell Number	11x12x39=5148	12x12x40=5760	11x12x39=5148
Grid size variation along radial direction (ΔR)	2 ft to 4.076 ft	2 ft to 3.5 ft	2 ft to 4.076 ft
Grid size variation along Circumferential direction ($\Delta\phi$)	7° to 11.5°	5.5° to 11.5°	7° to 11.5°
Grid size variation along Vertical direction (ΔZ)	2.333 ft to 2.695 ft	2.333 ft to 2.695 ft	2.333 ft to 2.841 ft

The following KFIXTM geometrical modeling aspects apply to the mesh system summarized above and shown in Figures 3A-438 through 3A-442:

- Variable grid sizes are used in the mesh systems. Note that finer mesh sizes in the vicinity of the quencher allow KFIXTM to more accurately predict the pool response in the local region.
- Because the pool normal water level (23') was used in analyzing the SRV-H scenario under the low reactor pressure condition in comparison with the minimum level (22') associated with the high pressure case, the grid sizes along the vertical direction for the low pressure case have to be slightly expanded to account for the additional one foot of water.

- The free surface at the top of the suppression pool is calculated by tracing the surface waves kinematically.
- Because the SPTMS sensors are not located at cell centers, the calculated SPTMS temperatures are interpolated or extrapolated from the temperature values defined at the neighboring cell centers in the code calculations.
- The suppression chamber columns are modeled as stacks of obstruction cells which conservatively approximate the circular cross-section of the actual columns.
- The two T-quencher arms are modeled by means of two special cells separated by an obstruction cell representing the quencher hub/assembly.
- The size of the special cells (i.e., fluid cells which contain the quencher discharge arms) are chosen to be comparable with those used in the LaSalle simulation runs for verifying the KFIXTM code (Reference 3A-54).
- A greater number of fluid cells are needed to model the SRV-L blowdown scenario than that needed for the SRV-H blowdown scenario. This is due to the fact that a better resolution with respect to the outer quenchers (e.g., Quencher L) generally requires more cells in the cylindrical coordinates (compare Figures 3A-438 and 3A-441).
- The obstruction effects of the downcomers are neglected to simplify the geometrical modeling. The downcomers have neglected obstruction effects on SPTMS sensor predictions because of their relative distance from the sensor locations.

3A.15.1.2.2 Individual SPTMS Sensor Predictions

The SPTMS sensor identifications and locations are shown in Figure 3A-437. The SPTMS sensor locations can be classified into two categories: 1) four dual element sensors mounted on columns with approximate azimuthal locations of 0°, 90°, 180°, and 270°, (i.e., TE 101/103-B, D, F, & H); and 2) four dual element sensors mounted on the containment wall with approximate azimuthal locations of 45°, 135°, 225°, and 315° (i.e., TE 101/103-A, C, E, & G).

The calculated sensor predications for each SORV blowdown scenario are shown in Figures 3A-443 through 3A-448 and are discussed in the following sections. The four temperature traces associated with each SPTMS sensor category (as defined above) are shown in the same figure. Sensor temperature traces may vary among each other because of the relative distances between the active quenchers and the various sensor locations. Only division TE 101 predictions are provided. Temperature traces of redundant Division TE 103 are not presented because they are nearly identical. Also shown on these figures is the analytical bulk pool temperature trace which provides a measure of how close the individual sensor predicts the bulk temperature. The bulk pool temperature is calculated by KFIXTM an is based on a mass-energy balance assuming that the pool is a uniform heat sink.

3A.15.1.2.2.1 SRV-H Blowdown Under High Reactor Pressure

Figures 3A-443 and 3A-444 show the KFIXTM calculated temperature time histories of the SPTMS sensors mounted on the columns and the containment wall, respectively, resulting form the SRV-H blowdown under the high reactor pressure condition.

Time delays, or response times, exist before the SPTM sensors start sensing the heat-up process in the suppression pool. These time delays result from the considerable vertical elevation difference between the sensors and the active quencher (i.e., 16.5 feet). However, within this short time delay period, the pool will experience only minor bulk heat-up. Figures 3A-443 and 3A-444 show a bulk pool heat-up on the order of 3□F during a response time ranging from 1-1.5 minutes.

3A.15.1.2.2.2 SRV-L Blowdown Under High Reactor Pressure

Figures 3A-445 and 3A-446 show the KFIXTM calculated temperature time histories of the SPTMS sensors mounted on the columns and the containment wall, respectively, resulting form the SRV-L blowdown under the high reactor pressure condition. The response times range from about 0.5-1 minute.

3A.15.1.2.2.3 SRV-H Blowdown Under Low Reactor Pressure

Figures 3A-447 and 3A-448 show the KFIXTM calculated temperature traces of the SPTMS sensors mounted on the columns and the containment wall, respectively, resulting from the SRV-H blowdown under the low reactor pressure condition. The response times range from 1.5-3 minutes.

Note that Figures 3A-447 and 3A-448 show that the time scale (abscissa) is compressed in comparison to the high pressure cases to accommodate the longer transient (approximately 25 minutes). The temperature scale (ordinate) is stretched to suit the milder temperature variation resulting form a smaller SRV steam flow rate associated with low reactor pressure condition. Note also that the elevated pool temperature reflects the assumption of RHR system not in operation (i.e., no pool cooling or shutdown cooling) during the SORV transient analysis.

3A.15.1.2.3 Average SPTMS Sensor Prediction

The arithmetic average values of the eight traces for the three blowdown cases are presented in Figures 3A-449, 3A-450, and 3A-451. Also shown on these figures are the corresponding analytical bulk pool temperatures (based on a pool mass-energy balance) and code predicted overall average temperatures. The KFIXTM predicted overall average temperature is defined as the average of the entire set of computational fluid cells in the LGS pool model.

In principle, the predicted overall average temperature should adhere closely to the bulk pool temperature to warrant a global calculation. However, due to the accumulated errors in the numerical computation spanning a large number of computational cycles (on the order of 10,000 for the present calculations), the overall average temperature may deviate slightly from the bulk pool temperature.

Figure 3A-449 provides the average SPTMS sensor prediction resulting form SRV-H blowdown under high reactor pressure. The response time is approximately 45 seconds. The SPTMS overpredicts the bulk pool temperature by approximately 1.7°F. The bulk pool temperature and overall average temperature traces are nearly identical, reflecting the adequacy of the overall energy conservation equations in the suppression pool model.

Figure 3A-450 provides the average SPTMS sensor prediction resulting for SRV-L blowdown under high reactor pressure. The response time is about 25 seconds. The SPTMS overpredicts the bulk pool temperature by approximately 2°F. The bulk pool temperature and the overall average temperature traces are nearly identical.

Figure 3A-451 provides the average SPTMS sensor prediction resulting from SRV-H blowdown at low reactor pressure. The response time is about 60 seconds. Both the SPTMS and overall average temperature prediction diverge from and underpredict (by about 1°F) the analytical bulk pool temperature. The apparent inaccuracy in the overall average and SPTMS temperature predictions are due to inherent interpolation errors associated with the large variations in subcooled water properties at elevated pool temperatures amplified by the large number of computational cycles in the code. Regardless of these apparent inaccuracies, the fact that the SPTMS adheres closely to the overall average temperature implies that the in-plant SPTMS sensor average reading will closely follow the actual suppression pool bulk temperature.

Note that the elevated pool temperature shown in Figure 3A-451 reflects the assumption of RHR system not in operation (i.e., no pool cooling or shutdown cooling) during the SORV transient analysis.

3A.15.1.2.4 Conclusion

In light of the code results presented in the preceding sections, it can be concluded that the SPTMS sensor locations are adequate in predicting the bulk pool temperature. The temperature traces indicate that short response times exist for the heated fluid, induced by the quencher discharge at the low pool elevation to rise near the top of the suppression pool where the SPTMS sensors are located. The SPTMS sensor average conservatively overpredicts the pool bulk temperature by 1.7°F to 2°F for the high reactor pressure blowdown scenario.

For the low pressure blowdown scenario, the calculated results for the SPTMS adequately predict the calculated overall average temperature. Because the calculated overall average temperature slightly deviates from the bulk temperature by about 1°F, it is concluded that the code calculated results for the SPTMS predict the bulk pool temperature with an accuracy of 1°F for the low reactor pressure/high pool temperature scenario.

Based on the sensitivity study discussed in Section 3A.15.1.2 to ascertain the effect of lowering the sensors from the original 2' to 4'-4" below the minimum Technical Specification water level, it was concluded that the foregoing results provide an adequate representation of the SPTMS prediction capability.

The SPTMS will adequately monitor the suppression pool bulk temperature in accordance with the requirements of NUREG-0487 (Reference 3A-56) and NUREG-0783 (Reference 3A-58).

3A.15.2 SUPPRESSION POOL TEMPERATURE RESPONSE TO SRV DISCHARGE

The information presented in Section 3A.15.2 is based on the original design basis conditions. The local pool temperature limit for SRV discharge is specified in NUREG-0783 because of concerns resulting from unstable condensation observed at high pool temperatures in plants without quenchers. Reference 3A-62 provides justification for elimination of this limit for plant with quenchers on the SRV discharge lines. Because LGS has quenchers, no evaluation of this limit is necessary, as stated in Supplement 1 of Reference 3A-63. However, the limiting case presented in Section 3A.15.2 (Case 3.a) was reanalyzed at the current plant conditions using the methodology and inputs described in Section 6.2.1.8. The results of this analysis were found to be acceptable.

3A.15.2.1 <u>Introduction</u>

In late 1974, the NRC alerted the BWR Owners to the potential for severe vibratory loads on the containment structure due to SRV discharge at elevated suppression pool temperature (Reference

3A-55). This phenomenon, or condensation instability, was associated with certain SRV discharge device configurations and occurred above given threshold values of pool temperature and steam mass flux. While the condensation instability phenomenon described above has never been exhibited for quencher devices, even in large-scale tests where local temperatures approached saturation, the NRC (Reference 3A-56) has taken the position that a local pool temperature limit of 200°F "will provide additional conservatism and will ensure that unstable steam condensation will not occur with a quencher device" and that "applicants will have to provide plant unique analyses for pool temperature responses to transients involving SRV operations to demonstrate that the plants will operate within the limit of 200°F."

The Mark II Owners Group subsequently prepared a generic report, the "White Paper" (Reference 3A-57), which was used by the utilities, including PECo, as a guideline for plant unique analyses. In conjunction with the development of this report, the Mark II Owners Group proposed alternative suppression pool temperature limits. These alternative acceptance criteria were subsequently accepted by the NRC for plants using the generic Mark II T-Quencher design. The alternative pool temperature limits are defined in NUREG-0783 (Reference 3A-58) as follows:

a. For all plant transients involving SRV operations during which the steam flux through the quencher perforations exceeds 94 lb_m/ft^2-sec, the suppression pool local temperature shall not exceed 200°F.

b. For all plant transients involving SRV operations during which steam flux through the quencher perforations is less than 42 lb_m/ft^2-sec, the suppression pool local temperature shall be at least 20°F subcooled. This is equivalent to a local temperature of 210°F with quencher submergence of 14 feet.

c. For plant transients involving SRV operations during which the steam flux through the quencher perforations exceeds 42 lb_m/ft^2-sec but is less than 94 lb_m/ft^2-sec, the suppression pool local temperature can be established by linearly interpolating the local temperatures established under items a and b above.

The following presentation of the suppression pool temperature analysis for LGS conforms with NUREG-0783 in terms of the pool temperature limit acceptance criteria, assumptions, and pool heatup events required for analysis.

3A.15.2.2 Events for the Analysis of Pool Temperature Transients

The following events have been analyzed on the basis of mass and energy balance on the suppression pool during SRV blowdown. The results of the pool temperature transients demonstrate the history of the pool bulk temperature of for all the events analyzed. Assumptions for the events are discussed in Section 3A.15.2.3. The associated peak pool temperatures calculated for each event are summarized in Table 3A-30.

3A.15.2.2.1 Event 1: Stuck Open SRV at Power Operation

SORV at power cases are analyzed to demonstrate that the spurious opening of an SRV during normal power operation will not result in high pool temperatures.

Two cases of SORV at power are considered separately:

Case 1.a: Single failure of one RHR heat exchanger

Case 1.b: Initiation of the MSIV closure signal at the time of scram and subsequent unavailability of main condenser.

3A.15.2.2.2 Event 2: SRV Discharge Following Isolation/Scram

Isolation/scram cases are analyzed to demonstrate that the loss of the main condenser by the sudden closure of the MSIVs and subsequent scram, SRV openings at set pressure, and manual depressurization will not result in high pool temperature.

Two single failures are considered separately:

Case 2.a: Single failure of one RHR heat exchanger

Case 2.b: Failure of an SRV to reclose (SORV)
(Note: Case 2.b is not required by NUREG-0783 but is presented to maintain consistency with the "White Paper: cases.)

3A.15.2.2.3 Event 3: SRV Discharge Following a Small Break Accident

SBA cases are analyzed to demonstrate that SRV discharge required to depressurize the reactor coolant system following a small break will not result in high pool temperatures. As a result of continued flow through the break, peak pool temperature is not reached until after SRV discharge has terminated.

Two cases of SBA are considered separately:

Case 3.a: Single failure of one RHR heat exchanger

Case 3.b: Loss of shutdown cooling
(Note: Case 3.b is not required by NUREG-0783 but is presented to maintain consistency with the "White Paper" cases.)

3A.15.2.3 Assumptions Used in the Analysis

3A.15.2.3.1 General Assumptions

The following general assumptions and initial conditions have been used for all transients. Table 3A-29 summarizes the values for important system characteristics and input parameters listed below.

a. Power level, decay heat standard, RHR heat exchanger capability (considering design fouling factors), and suppression pool initial temperature (maximum Technical Specification temperature of continuous power operation without pool cooling) are consistent with those used for the analysis of containment pressure and temperature response to a LOCA.

b. The service water temperature is characterized as a transient starting at 88°F (Technical Specification limit for average spray pond temperature).

c. The initial water level of the suppression pool is at the minimum level in the Technical Specifications.

d. MSIV closure is complete 3.5 seconds after the isolation signal (t=0) for transients where isolation occurs.

e. The water volume within the reactor vessel pedestal is not included in the calculation of pool temperature response.

f. To maximize heat addition to the pool, feedwater at the temperature in excess of instantaneous pool temperature is assumed to maintain RPV level rather than CST inventory via RCIC and HPCI. Feedwater injection is terminated when additional feedwater will ultimately result in cooling the pool. (Note: This requirement is more conservative than the NUREG-0783 assumption that "feedwater pumps supply feedwater to the reactor until the feed pumps trip on an automatic signal.") HPCI (From the suppression pool) and CRD (from the CST) systems provide vessel makeup after all the hot feedwater is expended. CRD flow was used for all cases except SBA with one RHR.

g. Offsite power is not available for isolation/scram and SBA events or where MSIV closure is assumed, except SBA Case 3.b Offsite power is available for Case 3.b; however, Case 3.b is conservative due to the conservatism associated with feedwater addition (see assumption "f" above) and the unavailability of the main condenser. Also, Case 3.b is not the controlling event for calculation of peak pool temperature (Table 3A-30).

h. HPCI system is terminated at or before a pool temperature of 170°F.

i. A single electrical division failure may result in the unavailability of RHR shutdown cooling and one loop of RHR pool cooling. The assessment of this single failure assumption on suppression pool temperature response to SRV discharge is provided in Section 3A.15.2.3.2.3.1.

j. The calculation of mass and energy release to the suppression pool due to SRV discharge follows the methodology described in Reference 3A-59.

k. There are no heat losses to the containment atmosphere and structures.

l. The RHR operates in the suppression pool cooling mode 10 minutes after the high pool temperature alarm (95°F).

m. All transients involving one RHR heat exchanger operation assume a minimum controlled depressurization rate and employ a rapid transfer (16 minutes, without flush) from pool cooling to shutdown cooling using the available RHR heat exchanger when the reactor pressure reaches the permissive value (89.7 psia). Shutdown cooling is not used in the analyses for those transients having both RHR trains available.

n. In accordance with the LGS Technical Specifications, manual depressurization at a rate of 100°F/hour begins at a pool temperature of 120°F unless the depressurization rate for the event itself (e.g., SORV, SBA) exceeds the required rate at that time. Manual depressurization is terminated upon initiation of shutdown cooling.

o. SRV flow rate = 122.5% of ASME rated.

3A.15.2.3.2 Assumptions for Specific Events

This section describes the specific assumptions used for the events described in Section 3A.15.2.2. Operator actions are also described for justification of the assumptions.

3A.15.2.3.2.1 Event 1: SORV at Power

This initiating event postulates that an SRV is inadvertently actuated while the plant is operating at power. Following actuation, the SRV fails to reseat and remains open throughout the transient. As a result of this malfunction, steam from the primary systems is discharged through the SRV and released to the suppression pool.

Two independent systems will generate alarms and displays in the control room so as to give the operator immediate and unambiguous indications of an SORV. First, the SRVPI system (Section 7.6.1.5.1) provides positive indication and alarm of SRV position through the use of acoustic sensors (two per valve) which detect noise generated by steam flow through an open SRV. Secondly, the SPTMS will indicate a rise in the suppression pool temperature and alert the operator to initiate corrective action. A control room alarm is generated when the average pool temperature increases to 95°F, 105°F, 110°F, and 120°F. Further details of the SPTMS are provided in Section 3A.15.1.

In accordance with the EOPs, the operator will manually scram the reactor prior to suppression pool temperature reaching 110°F by turning the mode switch to "shutdown" if the SRV cannot be reclosed immediately.

For analysis purposes, it is conservatively assumed that manual scram does not occur until the Technical Specification limit on pool temperature for power operation is reached (110°F).

Case 1.a: Single Failure - One RHR Heat Exchanger Unavailable

- Manual scram at pool temperature = 110°F.
- Offsite power is available.
- One RHR system is placed in pool cooling mode 10 minutes after the SORV.
- The MSIVs remain open because the mode switch has been taken out of the "run" position.
- Following scram, the reactor steam generation will decrease so that the TCV will mechanistically close as the RPV pressure drops, thus isolating the turbine from the reactor. The turbine bypass valves are also mechanistically closed. The SJAE will continue to maintain vacuum in the main condenser.
- The operator manually depressurizes the reactor by reestablishing the main condenser as a heat sink through the main turbine bypass system. It is assumed that the operator will manually open the turbine bypass valve 20 minutes after scram.

- The main condenser is available using full bypass capacity until the reactor vessel pressure permissive for RHR shutdown cooling is reached (89.7 psia).

- RHR out of pool cooling when pressure permissive for RHR shutdown cooling is reached; 16 minute delay for RHR transfer to shutdown cooling.

Case 1.b: Single Failure - Spurious Main Steam Line Isolation at Scram

- Manual scram at pool temperature - 110°F

- Nonmechanistic main steam line isolation occurs at scram (t = 0)

- LOOP

- Two RHR systems are placed in the pool cooling mode 10 minutes after the SORV.

- When the pool temperature = 120°F, the operator begins manual depressurization to maintain 100°F/hour cooldown rate by opening additional SRVs as needed.

- RHR shutdown cooling is not initiated.

3A.15.2.3.2.2 Event 2: SRV Discharge Following Isolation/Scram

Case 2.a: Single Failure - One RHR Heat Exchanger Unavailable

- Nonmechanistic main steam line isolation and automatic scram at t=0

- LOOP

- One RHR system placed in pool cooling mode 10 minutes after the event.

- When the pool temperature = 120°F, the operator begins manual depressurization at a rate of 100°F/hour by opening SRVs as needed.

- RHR out of pool cooling when pressure permissive for RHR shutdown cooling is reached; 16 minute delay for RHR transfer to shutdown cooling.

Case 2.b: Single Failure - SORV

- Nonmechanistic main steam line isolation and automatic scram at t=0.

- SORV occurs at t=0

- LOOP

- Two RHR systems are placed in the pool cooling mode 10 minutes after the event.

- When the pool temperature = 120°F, the operator begins manual depressurization to maintain 100°F/hour cooldown rate by opening additional SRVs as needed.

- RHR shutdown cooling is not initiated.

3A.15.2.3.2.3 Event 3: SRV Discharge Following SBA

Case 3.a: Single Failure - One RHR Heat Exchanger Unavailable

- Automatic scram on high drywell pressure at t=0.
- Nonmechanistic main steam line isolation at t=0.
- LOOP
- One RHR system is placed in the pool cooling mode 10 minutes after event.
- When the pool temperature = 120°F, the operator begins manual depressurization at a rate of 100°F/hour by opening SRVs as needed.
- Automatic RHR switch-over to the LPCI system mode on LPCI initiation signal. (LPCI signal occurs at (a) low reactor level or (b) high drywell pressure combined with low reactor pressure.) The operator manually converts back to the pool cooling mode in 10 minutes.
- RHR out of pool cooling when pressure permissive for RHR shutdown cooling is reached; 16 minute delay for RHR transfer to shutdown cooling.

Case 3.b: Single Failure - Shutdown Cooling Unavailable

- Automatic scram on high drywell pressure at t=0.
- Nonmechanistic main steam line isolation at t=0.
- Offsite power is available.
- Two RHR systems are placed in the pool cooling mode 10 minutes after event.
- When the pool temperature = 120°F, the operator begins manual depressurization at a rate of 100°F/hour by opening SRVs as needed.
- Automatic RHR switch-over to the LPCI system mode on LPCI initiation signal. The operator manually converts back to the pool cooling mode in 10 minutes.
- RHR shutdown cooling is not initiated. The operator will ultimately reach cold shutdown by establishing the alternate shutdown cooling path as outlined in Section 15.2.9.

3A.15.2.3.2.3.1 SRV Discharge Following SBA: Single Electrical Division Failure

In response to NUREG-0783, sections 5.7.1(8) and 5.7.2.3(2), LGS has evaluated the effect of a most limiting single failure on the suppression pool peak temperature. It was concluded that a worst case single failure of an electrical division power source may result in the unavailability of RHR shutdown cooling and one loop of RHR pool cooling. However, the peak pool temperature resulting from this single failure will be bounded by the peak temperature calculated for limiting SBA Case 3.a when taking credit for manual operator action to regain the lost loop of pool cooling.

Approximately 2½ hours are available to the operator for manual realignment of affected valves to obtain additional pool cooling capability from the second RHR heat exchanger. This available time is conservatively derived from the pressure-temperature time history for comparable Case 3.a (Figure 3A-456). Limiting Case 3.a is similar to the single electrical division failure case because only one loop of RHR pool cooling is available during the depressurization phase of the event.

The time is based on the conservative assumption that LOOP (and subsequent operator awareness of loss of both RHR shutdown cooling and one loop of pool cooling) occurs at a pool temperature of 120°F (Technical Specification limit for manual depressurization). From Figure 3A-456 (Case 3.a), the pool temperature reaches 120°F at approximately 1000 seconds. The time available for manual operator action after t=1000 seconds without the pool exceeding the peak calculated temperature is limited to the same point in time in Case 3.a where shutdown cooling was initiated (89.7 psia), i.e, approximately 10,000 seconds. Therefore, the total time available based on limiting Case 3.a is approximately 9,000 seconds or 2½ hours.

A study of required manual operator actions has concluded that a second RHR heat exchanger could be available in the pool cooling mode in less than 2½ hours (the time when Case 3.a peak pool temperature is reached). The pool temperature will decrease following the initiation of the second RHR loop in the pool cooling mode because the heat removal rate of both RHR exchangers will exceed the heat addition rate to the pool at this time in the event.

Because the RHR shutdown cooling mode is not initiated, the operator will ultimately reach cold shutdown by establishing the alternative shutdown cooling path as outlined in Section 15.2.9. The heat addition rate to the pool resulting from this alternate path of shutdown cooling will be controlled to preclude the possibility of additional pool heatup.

If manual operator actions are required in case of a worst case single electrical division failure, the plant operator could actually reduce the blowdown rate to extend the time before the peak pool temperature is reached. This scenario allows additional time for operator actions and would result in a peak pool temperature which is lower than Case 3.a.

3A.15.2.4 Analysis Results and Conclusions

Table 3A-30 lists the peak bulk suppression pool temperatures that were calculated using the GE computer code HEX for the scenarios described in Sections 3A.15.2.2 and 3A.15.2.3. Figures 3A-452 through 3A-457 provide plots of the suppression pool temperature and the respective reactor pressure versus time.

As stated earlier, the pool temperatures summarized in Table 3A-30 represent "bulk" temperatures, i.e., they were calculated assuming a homogeneously mixed suppression pool. In reality, pool mixing will not be perfect and differences will exist between the "local" temperature of the water in the immediate vicinity of the quencher and the calculated "bulk" temperature. However, because of the special design features of quenchers and their predominantly radial orientation in the suppression pool to optimize pool thermal mixing (Figure 3A-3), the local-to-bulk ΔT is expected to be small and not exceed the value that was previously derived for ramshead discharge devices in Mark I plants (10°F, Reference 3A-56). This number has been verified to be conservative for LGS using in-plant tests and analysis (Section 3A.15.3).

The suppression pool temperature limits defined in NUREG-0783 and listed in Section 3A.15.2.1 are specified in terms of "local" pool temperature and quencher mass flux criteria. Because Figures 3A-452 through 3A-457 specify the LGS time histories in terms of "bulk" pool temperature and reactor pressure, it is necessary to convert the NUREG-0783 local pool temperature limit criteria to bulk pool temperature and reactor pressure criteria. Applying a local-to-bulk ΔT of 10°F as described above and calculating the LGS reactor pressures corresponding to steam fluxes of 42 lb_m/ft^2 sec and 94 lb_m/ft^2 sec, respectively, a bulk suppression pool temperature limit curve is developed. These curves are shown on Figures 3A-452 through 3A-457 and demonstrate that the LGS suppression pool temperatures due to SRV discharge comply with the temperature limits defined in NUREG-0783.

3A.15.3 SUPPRESSION POOL LOCAL-TO-BULK TEMPERATURE DIFFERENCE ADEQUACY ASSESSMENT

3A.15.3.1 Introduction

NUREG-0783 (Reference 3A-58) defines the suppression pool temperature limits for steam discharges through the Mark II T-quenchers (e.g., those used in the LGS suppression pool). These limits stem from the NRC's concern that, for certain combinations of pool temperatures and quencher mass fluxes, the steam condensation in the vicinity of the quencher exit may lead to higher vibratory loads on the submerged structures within the suppression pool. These pool temperature limits depend on the quencher steam mass flux and the saturation temperature at the quencher centerline submergence. The NUREG-0783 local pool temperature limits are expressed in terms of a local pool temperature. According to NUREG-0783, the local pool temperature is defined as the average water temperature in the vicinity of the quencher discharge device and represents the relevant temperature which controls the condensation process occurring at the quencher exit.

To confirm that LGS will not exceed the pool temperature limits stipulated in NUREG-0783 for all design basis scenarios which involve T-quencher operation, the LGS mass and energy analysis has been performed as reported in Section 3A.15.2. The analysis calculates a bulk pool temperature, defined as the pool temperature obtained by an energy balance on the pool assuming the pool acts as a uniform heat sink (i.e., no thermal stratification).

If ideal pool mixing would occur during steam discharges through the quenchers, the bulk temperature calculated by the mass and energy analysis would become the local pool temperature, and could be used directly to confirm that the LGS suppression pool will not exceed the NUREG-0783 temperature limits. In reality, thermal stratification occurs in the suppression pool, resulting in higher values of local pool temperature in comparison with the bulk pool temperature. The difference between these two temperatures in the local-to-bulk pool temperature difference (ΔT). Therefore, once the LGS unique local-to-bulk ΔT is determined, it can be used with the results of the mass and energy analysis (Section 3A.15.2) to confirm that the LGS suppression pool conforms to the local pool temperature criteria provided in NUREG-0783.

In conjunction with the SPTMS adequacy assessment provided in Section 3A.15.1.2, the KFIXTM code is used to calculate the local-to-bulk ΔT in the LGS suppression pool for the SORV blowdown scenarios described in Section 3A.15.1.2.1. Sections 3A.15.1.2.1.1 and 3A.15.1.2.1.2. provide the initial/operating conditions and KFIXTM geometrical models associated with these scenarios, respectively. Summarizing, these scenarios consist of two single SORV blowdowns under the high reactor pressure condition (SRV-H and SRV-L) and one single SORV blowdown under the low reactor pressure condition (SRV-H).

The two conditions of high and low reactor pressures correspond to the early and late stages of the SORV transient, respectively. The magnitude of the local-to-bulk ΔT gains significance at the later stages of the transient due to the smaller margin between the elevated bulk pool temperature and NUREG-0783 pool temperature limits. The results from the KFIXTM analysis, to be delineated in the following sections, indicate that the low reactor pressure analysis yields a lower local-to-bulk ΔT than that associated with the high pressure analysis.

NUREG-0783 provides a specific definition of local pool temperature stated as follows:

> "To define the local pool temperature, a qualitative picture of the flow pattern during quencher discharge can be evolved by a combination of physical reasoning and experimental evidence...., it is apparent that the temperature which controls the condensation process (that is, the "local" temperature) is best characterized by that which would occur at a point directly above and below the quencher arms (perhaps one or two arms diameters distant), with the former providing a more conservative measure of this parameter."

Based on this definition, the local pool temperature can be calculated for both the high and low reactor pressure cases by mass averaging the temperature traces from the four fluid cells located directly above and below the two special cells representing the quencher arms. From Figures 3A-439, 3A-440, and 3A-442, the distances from the centers of these four cells to the centerline of the quencher arm varies from 2.333' to 2.47', or approximately twice the quencher arm diameter. The distances from the centers of these four cells to the top or bottom surface of the quencher arm is about 1½ times the quencher arm diameter. Thus, the methodology for calculating the local temperature conforms to the NUREG-0783 criteria.

Sections 3A.15.3.2, 3A.15.3.3, and 3A.15.3.4 discuss the KFIXTM calculated local and bulk pool temperature traces and corresponding local-to-bulk ΔTs for the SORV scenarios. Concluding remarks regarding the LGS local pool temperature and the related NUREG-0783 pool temperature limits are presented in Section 3A.15.3.5.

3A.15.3.2 SRV-H Blowdown Under High Reactor Pressure

Figure 3A-458 shows that the quasi steady-state local-to-bulk ΔT is about 8.6°F for SRV-H blowdown under high reactor pressure. The calculation of the local temperature is described in Section 3A.15.3.1. The bulk pool temperature is calculated by KFIXTM and is based on a mass-energy balance assuming that the pool is a uniform heat sink.

3A.15.3.3 SRV-L Blowdown Under High Reactor Pressure

Figure 3A-459 illustrates that the predicted local pool temperature follows the bulk pool temperature closely for SRV-L blowdown under high reactor pressure (i.e., local-to-bulk ΔT is minimal). The favorable thermal mixing characteristics associated with this analysis result from the combination of the quencher location (outer ring) and its orientation.

3A.15.3.4 SRV-H Blowdown Under Low Reactor Pressure

Section 3A.15.3.2 shows that a peak local-to-bulk ΔT of approximately 8.6°F is calculated for the high reactor pressure and relatively low pool temperature conditions. At this time in the transient, the steam flux through the active quencher is greater than 94 lb_m/ft^2 sec. As discussed in Section 3A.15.2.1, the NUREG-0783 local pool temperature limit at this flux is 200°F. Because the bulk pool temperature is much lower than 200°F at high reactor pressures (Figures 3A-452 through 3A-457), the local-to-bulk ΔT is relatively unimportant at these conditions.

As the reactor depressurizes and SRV flow rate decreases, the momentum transfer to the pool (i.e., pool mixing) decreases. The bulk pool temperature continues to increase and the local-to-bulk ΔT gains significance. Therefore, the KFIXTM code is used to quantify the local-to-bulk ΔT calculated earlier is conservative with respect to the low reactor pressure ΔT.

Figure 3A-460 shows the bulk temperature trace along with the code predicted local temperature trace and overall average temperature trace (of all fluid cells) for SRV-H blowdown under low reactor pressure. The slight deviations between the bulk pool temperature and the KFIXTM predicted overall average temperature are due to the minor inaccuracies of KFIXTM temperature predications under low reactor pressure and elevated pool temperature conditions (Section 3A.15.1.2.3). Regardless of the apparent inaccuracy, the local pool temperature adheres closely to the overall average temperature and the local-to-bulk ΔT for the low pressure scenario is both minimal and bounded by the ΔT for the high pressure scenario.

3A.15.3.5 Conclusion

The local pool temperature limits stipulated in NUREG-0783 have been restated in Section 3A.15.2.1. Figures 3A-452 to 3A-457 plot these pool temperature limits relative to the bulk temperature time histories for the six mass and energy cases described in Section 3A.15.2.2. The local temperature limits have been converted to bulk limits by applying a local-to-bulk ΔT equal to 10°F. A local-to-bulk ΔT of 10°F was previously derived for ramshead discharge devices in Mark I plants (Reference 3A-56). Figures 3A-452 to 3A-457 indicate that adequate margin exists between the NUREG-0783 local limits (converted to bulk limits by 10°F ΔT) and the calculated bulk temperatures from the mass and energy analyses. The minimum margin occurs for Case 3.a near the end of the transient at low reactor pressure when the maximum bulk temperature peaks at 202°F (Figure 3A-456).

The peak calculated local-to-bulk ΔT has been established to be 8.6°F for SRV-H blowdown under high reactor pressure (Section 3A.15.3.2) and is adequately bounded by 10°F ΔT. In addition, the results of the low reactor pressure analysis (Section 3A.15.3.4) confirm that the low reactor pressure ΔT is much lower than the high pressure ΔT. Therefore, LGS has demonstrated that the NUREG-0783 maximum local pool temperature specification will not be exceeded.

3A.16 WETWELL-TO-DRYWELL VACUUM BREAKER AND DOWNCOMER CAPPING ADEQUACY ASSESSMENT

3A.16.1 INTRODUCTION

In April 1981, the ACRS expressed concern regarding the potential pool bypass from a stuck open wetwell-to-drywell vacuum breaker. This concern stems from the fact that following the onset of a LOCA about 20 seconds into the transient, the chugging phenomenon takes place. This rapid steam condensation will cause repeated and strong dynamic under and overpressure conditions in the downcomer. As a result of this pressure variation, the vacuum breaker attached to the downcomer may open.

Because chugging is a repetitive phenomenon, the vacuum breaker may be called on to function in a cyclic manner during these intermittent steam condensation events. These potential opening and closing impact loads could exceed the original design basis of the vacuum breakers. Failure of a vacuum breaker to close during this time could result in steam bypass of the suppression pool and subsequent pressurization of the wetwell air space, thus jeopardizing the integrity of the containment.

In July 1981, the NRC staff was informed that the Mark II owners who have vacuum breakers attached to the downcomer were conducting a joint qualification test program to demonstrate the operability of the vacuum breaker under this intermittent steam condensation loading. The Mark II owners also identified the potential adverse effect of pool-swell on the performance of vacuum breakers. Because the wetwell air space will pressurize during the pool-swell event, the resulting differential pressure will cause the vacuum breaker to cycle open and then cycle closed when he pool falls back to the normal water level. The potential opening and closing impact load could exceed the potential opening and closing impact load could exceed the original design basis of the vacuum breakers.

3A.16.2 DESIGN ASSESSMENT

3A.16.2.1 Vacuum Breaker Cycling During Pool-Swell

To qualify the LGS vacuum breakers to withstand the dynamic effects of pool-swell, design modifications to the vacuum breakers have been implemented based on results from the Anderson Greenwood Company vacuum breaker test program. The modifications and test program results have been transmitted to the NRC (References 3A-60 and 3A-61).

3A.16.2.2 Vacuum Breaker Cycling During Chugging

To qualify the LGS vacuum breakers to withstand the dynamic effects of chugging, the four downcomers on which the wetwell-to-drywell vacuum breakers are counted have been capped. Capping the downcomers will eliminate the dynamic under and overpressures caused by the sudden steam condensation at the downcomer exit and eliminate the vacuum breaker cyclic actuation due to chugging phenomena. The locations of these capped downcomers are shown in Figure 3A-461.

3A.16.2.2.1 Downcomer Capping Design Assessment

3A.16.2.2.1.1 Downcomer Modifications

Figure 3A-462 shows a configuration of a modified downcomer with vacuum breaker (typical of four). The modifications include installation of a cap, a 3 inch drain line, and a 1 inch weir at the drywell entrance of the downcomer.

The capping design incorporates a 3 inch Schedule 160 drain line. Water motion in the 3 inch drain line has been modeled. As a result of this work, the drain has been extended 9'-7¾" above the downcomer exit plane. This extended length will prevent water from streaming into the downcomer during the rapid drywell depressurization caused by the gross chugging at the downcomer exits. In addition, to prevent water from exiting the drain line during the chugging/CO phase of a LOCA, the drain line is extended 4 feet below the downcomer exit plane. Therefore, potential chugging/CO dynamic loading phenomena at the drain exit are precluded.

The addition of a 1 inch weir at the drywell entrance of each capped downcomer is designed to limit the maximum ECCS flow into these downcomers during the recirculation mode after a LOCA. The 3 inch drain line is capable of passing this limited flow of ECCS water while preventing the downcomers from being filled to the vacuum breaker elevation.

3A.16.2.2.1.2 Containment Evaluation

Capping 4 out of 87 downcomers requires an evaluation to determine its effect on the containment design basis LOCA loading conditions and safety margins. To resolve this concern, Bechtel's computer program COPDA was used to evaluate the drywell conditions based on 83 and 87 downcomers, respectively. The results indicate that there is no significant change in either drywell pressure and temperature or steam blowdown rate through the downcomers for the capped and uncapped situations.

Based on this analysis, capping 4 out of 87 downcomers will have no adverse effects on the LGS containment safety margins resulting from design basis LOCA loads, as defined in Section 3A.4.2, including pool-swell loads, containment functional pressure, submerged structure loads, boundary loads, and asymmetric effects.

3A.17 REFERENCES

3A.17.1 REFERENCES

3A-1 "Mark II Containment Dynamic Forcing Function Information Report", NEDO-21061, Revision 4, GE, (November 1981).

3A-2 "Mark II Containment Lead-Plant Program Load Evaluation and Acceptance Criteria", NUREG-0487, NRC, (October 1978).

3A-3 "Mark II Containment Lead-Plant Program Load Evaluation and Acceptance Criteria", NUREG-0487, Supplement 1, NRC, (September 1980).

3A-4 "Mark II Containment Lead-Plant Program Load Evaluation and Acceptance Criteria", NUREG-0487, Supplement 2, NRC, (February 1981).

3A-5 "Mark II Containment Program Load Evaluation and Acceptance Criteria", NUREG-0808, NRC, (August 1981).

3A-6 "Safety/Relief Valve Quencher Loads: Evaluation for BWR Mark II and III Containments", NUREG-0802, NRC, (October 1982).

3A-7 A.J. James, "The General Electric Pressure-Suppression Containment Analytical Model", GE, (July 1971).

3A-8 R.J. Ernst, "Mark II Pressure-Suppression Containment Systems: An Analytical Model of the Pool Swell Phenomenon", NEDE 21544-P, (December 1976).

3A-9 Letter MFN-080-79, L.J. Sobon (GE) to J.F. Stolz (NRC), "Vent Clearing Pool Boundary Loads for Mark II Plants," (March 20, 1979).

3A-10 F.J. Moody, "Analytical Model for Liquid Jet Properties for Predicting Forces on Rigid Submerged Structures," NEDE-21472, GE, (September 1977).

3A-11 R.J. Ernst, et al, "Mark II Pressure-Suppression Containment Systems: Loads on Submerged Structures - An Application Memorandum," NEDE-21730, GE, (September 1977).

3A-12 "Dynamic Forcing Function Information Report (DFFR)," Revision 3, NEDO-21061, GE and Sargent and Lundy Engineers, (June 1978).

3A-13 "Generic Condensation Oscillation Load Definition Report," NEDE-24288-P, GE, (May 1980).

3A-14 "Mark II Improved Chugging Methodology," GE, NEDE-24822-P, (May 1980).

3A-15 "4T Condensation Oscillation Test Program Final Test Report," NEDE-24811-P, GE, (May 1980).

3A-16 "Generic Chugging Load Definition," NEDE-24302-P, GE, (April 1981).

3A-17 R.L. Kian and B.J. Grossi, "Dynamic Modeling of a Mark II Pressure-Suppression System," EPRI NP-441, Palo Alto, (April 1977).

3A-18 ASME B&PV Code, Section III, Division 2, (1975 Edition).

3A-19 ASME B&PV Code, Section III, Division 1, (1974).

3A-20 ACI 318, "Building Code Requirements for Reinforced Concrete", (1971 Edition).

3A-21 "Seismic Analyses of Structures and Equipment for Nuclear Power Plants," BC-TOP-4A, Bechtel Power Corporation, (November 1974).

3A-22 E. L Wilson, "A Computer Program for the Dynamic Stress Analysis of Underground Structures," USAEWES, Control Report 1-175, (January 1968).

3A-23 Desai and Abel, "Introduction to the Finite-Element Method," Van Nostroid Reinold Co., (1972).

3A-24 "Technical Bases for the Use of SRSS Method for Combining Dynamic Loads for Mark II Plants," NEDE-24010-P, GE, (July 1977).

3A-25 M.K. Caldwell, and J.J. Whittle, "In-Plant Test Report for Adjacent Structure Response to Hydrodynamic (Mark II) Loads", PECo, (July 28, 1982).

3A-26 W.M. Davis, "MK II Main Vent Lateral Loads Summary Report," NEDE-23806-P, GE, (October 1978).

3A-27 T.E. Johnson, et al., "Containment Building Liner Plate Design Report," BC-TOP-1, Bechtel Corporation, San Francisco, (December 1972).

3A-28 "Seismic Analysis of Piping Systems," BP-TOP-1, Revision 3, Bechtel Power Corporation, San Francisco, (January 1976).

3A-29 IEEE 344, "Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations", (1975).

3A-30 AISC, "Manual of Steel Construction", 7th Edition, (1970).

3A-31 "Cable Tray and Conduit Raceway Seismic Test Program - Release 4", Test Report #1053-21.1-4, Volumes 1 and 2, ANCo Engineers, Inc., (December 15, 1978).

3A-32 "Development of Analysis and Design Techniques from Dynamic Testing of Electrical Raceway Support Systems", Technical Report, Bechtel Power Corporation, (July 1979).

3A-33 "Analytical Model for Estimating Drag Forces on Rigid Submerged Structures Caused by LOCA and Safety/Relief Valve Ramshead Air Discharges," NEDO-21471, (September 1977).

3A-34 T. Sarpkaya and C.J. Garrison, "Vortex Formation and Resistance in Unsteady Flow," Journal of Applied Mechanics, pp. 16-24, (March 1963).

3A-35 T. Sarpkaya, "Forces on Cylinders and Spheres in a Sinusoidally Oscillating Fluid," Transactions of the ASME, pp. 32-37, (March 1975).

3A-36 G.K. Batchelor, "An Introduction to Fluid Dynamics", p. 341, Cambridge, England, (1967).

3A-37 T. Sarpkaya, "In-Line and Transverse Forces on Cylinders in Oscillatory FLow at High Reynolds Numbers," Journal of Ship Research, Vol. 21, No. 4, pp. 200-216, (December 1977).

3A-38 T. Sarpkaya, "Vortex Shedding and Resistance in Harmonic Flow About Smooth and Rough Circular Cylinders at High Reynolds Numbers," NPS-59SL76021, (February 1976).

3A-39 J.P. Den Hartog, "Mechanical Vibrations", Fourth edition, pp. 305-306, McGraw-Hill Book Co., Inc., New York, (1956).

3A-40 J.A. Roberson and C.T. Crowe, "Engineering Fluid Mechanics", pp. 338-340, Houghton Mifflin Co., Illinois, (1975).

3A-41 T. Yamamoto, "Hydrodynamic Forces on Multiple Circular Cylinders," Journal of the Hydraulics Division, ASCE, pp. 1193-1210, (September 1976).

3A-42 T. Yamamoto and J.H. Nath, "Hydrodynamic Forces on Groups of Cylinders," Paper No. OTC 2499, presented at the Offshore Technology Conference, Houston, Texas, (May 3-7, 1976).

3A-43 T. Yamamoto and J.H. Nath, "Forces on Many Cylinders Near a Plane Boundary," Preprint 2633, presented at the ASCE National Water Resources and Ocean Engineering Convention, San Diego, California, (April 5-8, 1976).

3A-44 C. Dalton and R.A. Helfinstein, "Potential Flow Past a Group of Circular Cylinders," Journal of Basis Engineering, ASME, pp. 636-642, (December 1971).

3A-45 T. Yamamoto, J.H. Nath, and L.S. Slotta, "Wave Forces on Cylinder Nearby a Plane Boundary," ASCE Journal of Waterways, Harbors and Coastal Engineering Division, pp. 345-349, (November 1974).

3A-46 T. Sarpkaya, "Forces on Cylinders Near a Plane Boundary in a Sinusoidally Oscillating Fluid," Journal of Fluids Engineering, ASME, pp. 499-505, (September 1976).

3A-47 T. Sarpkaya, "In-Line and Transverse Forces on Cylinders Near a Wall in Oscillatory Flow at High Reynolds Numbers," Paper No. OTC 2898, presented at the Offshore Technology Conference, Houston, Texas, (May 2-5, 1977).

3A-48 E.I. Hori, "Experiments on Flow Around a Pair of Parallel Circular Cylinders," proceedings of the 9th Japan National Congress for Applied Mechanics, pp. 231-234, (1959).

3A-49 C. Dalton and J.M. Szabo, "Drag on a Group Cylinders," Transactions of the ASME, Journal of Pressure Vessel Technology, pp. 152-157, (February 1977).

3A-50 M.M. Zdravkovich, "Review of Flow Interference Between Two Circular Cylinders in Various Arrangements," Transactions of the ASME, Journal of Fluids Engineering, pp. 618-633, (December 1977).

3A-51 R.W.F. Gould, "Wake Blockage Corrections in a Closed Wind Tunnel One or Two Wall-Mounted Models Subject to Separated Flow," Aerodynamics Division, N.P.L., Reports and Memoranda 3649, (February 1969).

3A-52 E.C. Maskell, "A Theory of the Blockage Effects on Bluff Bodies and Stalled Wings in a Closed Wind Tunnel," British ARC, Reports and Memoranda 3400, (November 1963).

3A-53 "General Electric Service Information Letter No. 106", SIL-106, (October 25, 1974).

3A-54 Letter, N.W. Curtis (PP&L) to A. Schwencer (NRC), "Evaluation of NUREG-0783 Local Pool Temperature Limits for the Susquehanna Steam Electric Station," (November 28, 1983).

3A-55 RO Bulletin 74-14, "BWR Relief Valve Discharge to Suppression Pool," (November 15, 1974).

3A-56 NUREG-0487, "Mark II Containment Lead-Plant Program - Load Evaluation and Acceptance Criteria," (October 1978).

3A-57 Mark II Owners Group, "Assumptions for Use in Analyzing Mark II BWR Suppression Pool Temperature Response to Plant Transients Involving Safety/Relief Valve Discharge," (March 24, 1980).

3A-58 NUREG-0783, "Suppression Pool Temperature Limits for BWR Containments," (November 1981).

3A-59 Letter report, R.H. Bucholz to Karl Kniel, "Mark II Containment Program Method for Calculating Mass and Energy Release for Suppression Pool Temperature Response to Safety/Relief Valve Discharges," (March 12, 1981).

3A-60 Letter, D.M. O'Connor (Mark II Owners Group) to Dr. R.W. Houston (NRC), "AGCo Vacuum Breaker Test Program," (June 17, 1983).

3A-61 Letter, J.S. Kemper (PECo) to A. Schwencer (NRC), "AGCo Wetwell/Drywell Vacuum Breaker Test Program," (July 6, 1983).

3A-62 NEDO-30832, "Elimination of Limit On Local Suppression Pool Temperature for SRV Discharge With Quenchers," Class I, December 1984.

3A-63 GE Nuclear Energy, "Generic Evaluations of General Electric Boiling Water Reactor Power Uprate," Licensing Topical Report NEDC-31984P, Class III (Proprietary), July 1991; NEDO-31984, Class I (Non-Proprietary), March 1992; and Supplements 1 & 2.

3A-64 GE Nuclear Energy, “Quencher Water Jet Loads Analytical Model”, Topical Report NEDE-23539-P, Class III (Proprietary), August 1979.

3A.17.2 REFERENCES (Proprietary - See Appendix 3B)

Table 3A-1

LGS LICENSING BASIS

I. MARK II GENERIC PROGRAM

A. LOCA-RELATED TASKS

TASK NUMBER	ACTIVITY	ACTIVITY TYPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
A.1	"4T" PROGRAM	Phase I Test Report	NEDE-13442-01-P NEDO-13442-01	5/76 6/76	Yes Yes
		Phase I Application Memorandum	Application Memorandum	6/76	Yes
		Phase II & III Test Report	NEDE-13468-P NEDO-13468	12/76 3/77	Yes Yes
		Application Memorandum	NEDE-23678-P NEDO-23678	1/77 1/77	Yes Yes
A.2	POOL-SWELL MODEL REPORT	Model Report	NEDE-21544-P NEDO-21544	12/76 2/77	Yes Yes
A.3	IMPACT TESTS	PSTF 1/3 Scale Tests	NEDE-13426-P NEDO-13426	8/75 8/75	Yes Yes
		Mark I 1/12 Scale Tests	NEDC-20989-2P NEDO-20989-2	9/75 9/75	No No
A.4	IMPACY MODEL	PSTF 1/3 Scale Tests	NEDE-13426-P NEDO-13426	8/75 8/75	Yes Yes
		Mark I 1/12 Scale Tests	NEDE-20989-2P NEDO-20989-2	9/75 9/75	No No
A.5	LOADS ON SUBMERGED STRUCTURES	LOCA/RH Air Bubble Model	NEDE-21471-P NEDO-21471	9/77 9/77	Yes Yes
		LOCA/RH Water Jet Model	NEDE-21472-P NEDO-21472	9/77 9/77	Yes Yes
		Appplications Memorandum	NEDE-21730-P NEDO-21730	12/77 7/78	Yes Yes
		¼ Scaling Tests	NEDE-23817-P	9/78	No
A.5.5	RING VORTEX MODEL, PHASE I	Model Development	Letter Report	5/79	No

Table 3A-1 (Cont'd)

TASK NUMBER	ACTIVITY	ACTIVITY TYPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
A.5.7	RING VORTEX MODEL, PHASE II	Model Extension Steam Condensation Methods	Burns & Roe Proprietary Report, Plant DARs	9/80	No
		Steam Condensation Methods	Burns & Roe Non Proprietary Report,	9/80	No
A.6	CHUGGING ANALYSIS AND TESTING	Single Cell Report	NEDE-23703-P NEDO-23703	9/77 9/77	Yes Yes
		Multivent Model	NEDO-21669-P NEDO-21669	2/78 2/78	Yes Yes
		4T FSI Report	NEDE-23710-P NEDO-23710	4/78 9/78	Yes Yes
A.7	CHUGGING SINGLE VENT	CREARE Report	NEDE-21851-P NEDO-21851	6/78 6/78	Yes Yes
A.9	EPRI TEST EVALUATION	EPRI-4T Comparison	NEDO-21667	8/77	Yes
	EPRI 1/13 SCALE TESTS	3 D Tests	EPRI NP-441	4/77	Yes
	EPRI SINGLE CELL TESTS	Unit Cell Tests	EPRI NP-1353	3/80	Yes
A.11	MULTIVENT SUBSCALE TESTING AND ANALYSIS	Preliminary MV Program Plan	NEDO-23697	12/77	Yes
		MV Test Program Plan & Procedures – Phase I	NEDO-23697A, Rev. 1	1/79	Yes
		Phase I Test Report	NEDE-24781-1-P	1/80	Yes
		MV Test Progress Plan & Procedures – Phase II	NEDO-23697A, Rev. 1, Supp. 1	8/79	Yes
		Phase II Test Report	NEDE-25289-1-P NEDO-25289-1	8/80 11/80	Yes Yes
		CONMAP Tests	CREARE Report TN-297	6/79	Yes
		MHM Verification 1/10 Scale	NEDE-25116-P NEDO-25116	5/79 8/79	Yes Yes
		Scaling and Data Correlation	NEDE-24300-P NEDO-24300	4/81 7/81	Yes Yes
A.13	SINGLE VENT LATERAL LOADS	Dynamic Analysis	NEDE-24106-P NEDO-24106	3/78 3/78	Yes Yes
		Summary Report	NEDE-23606-P NEDO-23606	10/78 12/78	Yes Yes
		Responses to NRC Questions	Letter Report	1/81	Yes

Table 3A-1 (Cont'd)

TASK NUMBER	ACTIVITY	ACTIVITY TYPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
A.13	NEW LATERAL LOADS	Dynamic Analysis Report	NEDE-24794-P NEDE-24794-P Errata NEDO-24794	3/80 9/80 3/80	Yes Yes Yes
		Method of Mulitple Application	Vent Letter Report	4/80	Yes
A.16	IMPROVED CHUGGING LOAD DEFINITION	Impulse Evaluation Improved Chug Load	Letter Report NEDE-24822-P NEDE-24822-P Errata NEDO-24822 NEDO-24822 Errata	6/78 5/80 8/80 6/80 8/80	No Yes Yes Yes Yes
A.17	CONDENSATION OSCILLATION TESTING AND IMPROVED CO LOAD DEFINITION	4TCO Test	NEDE-24811-P NEDE-24811-P Errata NEDO-24811 NEDO-24811 Errata	5/80 9/80 7/80 9/80	Yes Yes Yes Yes
		Improved CO Load Definition	NEDE-24288-P NEDO-24288	11/80 2/81	Yes Yes
A.22	A.16 SOURCE EVALUATION	Confirm/Revise Source based on 4TCO Data	NEDE-24302-P	4/81	Yes
		4TCO Chugging Data – Six key runs	NEDE-24285-P NEDO-24285	1/81	Yes Yes
A.29	V.B. MODEL	Methodology Report	NEDE-22178-P	8/82	Yes
A.30	RESPONSE TO BIENKOWSKI/NRC CHUGGING QUESTION	Load Evaluation for frequency	Letter Report	4/82	Yes
B. SRV-RELATED TASKS					
B.1	QUENCHER EMPIRICAL MODEL	DFFR Model	NEDE-21061-P NEDE-21061	9/76 9/76	No No
		Supporting Data	NEDE-21061-P NEDO-21078	5/75 10/75	No No

Table 3A-1 (Cont'd)

TASK NUMBER	ACTIVITY	ACTIVITY TYPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
B.2	RAMSHEAD MODEL	DFFR MODEL	NEDE-21061-P NEDO-21062	9/76 9/76	No No
		Supporting Data	NEDE-21061-P NEDO-21062	7/75 7/75	No No
		Analysis	NEDE-20942-P NEDO-20942	5/75 5/75	No No
B.3	MONITCELLO IN-PLANT SRV TESTS	Preliminary Test Report	NEDC-21465-P NEDO-21465	12/76 12/76	No No
		Hydrodynamic Report	NEDC-21581-P NEDO-21581	8/77 8/77	No No
B.5	SRV QUENCHER IN-PLANT	Test Plan	NEDM-20988 Rev. 2	12/76	No
	CAORSO TESTS	Test Plan Addendum 1	NEDM 20988 Rev. 2 Add. 1	10/77	No
		Test Plan Addendum 2	NEDM 20988 Rev. 2 Add. 2	4/78	No
		Test Summary	Letter Report	3/79	No
	Phase I	Test Report	NEDE-25100-P NEDE-25100-P Errata NEDO-25100-P NEDO-25100-P Errata	5/79 2/81 8/79 2/81	No No No No
	Phase II	Test Report	NEDE-24757-P NEDO-24757	5/80 7/80	No No
	Re-evaluate	AMN Report	NEDE-24835-P	3/81	No
B.5.1	EXTENDED BLOWDOWN	Test Report	NEDE-24798-P NEDO-24798	7/80 8/80	No No
B.6	THERMAL MIXING BOWL	Analytical Model	NEDC-23689-P NEDO-23689	3/78 3/78	No No
B.10	MONITCELLO FSI	Analysis of FSI	NEDO-23834	6/78	No
B.11	DFFR RAMSHEAD MODEL TO MONITCELLO DATA	Data/Model Comparison	NSC-GEN 0394	9/77	No
B.12	RAMSHEAD SRV METHODOLOGY SUMMARY	Analytical Methods	NEDO-24070	10/77	N0

Table 3A-1 (Cont'd)

TASK NUMBER	ACTIVITY	ACTIVITY TYPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
C. MISCELLANEOUS TASKS					
C.0	SUPPORTING PROGRAM	Supp Prog Report	NEDO-21297	5/76	No
		Supp Prog Report Rev. 1	NEDO-21297 Rev. 1	4/78	No
C.1	DFTR REVISIONS (See also TASK C.18)	Revision 1	NEDE-21061-P Rev. 1 NEDO-21061 Rev. 1	9/75 9/75	No No
		Revision 2	NEDE-21061-P Rev. 2 NEDO-21061 Rev. 2	9/76 9/76	No No
		Revision 3	NEDE-21061-P Rev. 3 NEDO-21061 Rev.3	6/78 6/78	Yes Yes
C.3	NRC ROUND 1 QUESTIONS	DFFR Rev 2	NEDO-21061 Rev. 2	9/76	Yes
		DFFR Rev 2 Amendment 1	NEDO-21061 Rev. 2 Amendment 1	12/76	Yes
		DFFR Round 1 Questions	Letter Report	6/78	Yes
C.5	SRSS JUSTIFICATION	Interim Report	(NEDE-24010)	4/77	Yes
		SRRS Report	NEDE-24010-P NEDE-24010	7/77 7/77	Yes Yes
C.5.1	SRSS PROGRAM SUMMARY	SRSS Executive Summary	Summary Report	4/78	Yes
C.5.2	SRSS APPLICATION CRITERIA	SRSS Criteria Application	NEDO-24010, Supp. 1	10/78	Yes
		SRSS Criteria Basis	NEDO-24010, Supp. 2	12/78	Yes
C.5.3	SRSS JUSTIFICATION CRITERIA	SRSS Justification Supp	NEDO-24010, Supp. 3	8/79	Yes
		SRSS Criteria Evaluation	Letter Report	1/80	Yes
C.5.4	BROOKHAVEN REPORT CRITIQUE	BNL Critique	EDAC 134-242-03	1/80	Yes

Table 3A-1 (Cont'd)

TASK NUMBER	ACTIVITY	ACTIVITY TYPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
C.6	NRC ROUND 2 QUESTIONS	DFFR Amend 2	NEDE-21061-P Rev 2 Amend.2	6/77	Yes
			NEDE-21061 Rev 2 Amend.2	6/77	Yes
		DFFR Amend 2, Supp 1	NEDE-21061 Rev 2 Amend.2 Supp.1	8/77	Yes
		DFFR Amend 2, Supp 2	NEDE-21061-P Rev 2 Amend.2 Supp.2	9/77	Yes
		DFFR Rev. 3, Appendix A-2	NEDE-21061-P Rev 3 Appendix A-2		Yes
			NEDE-21061 Rev 3 Appendix A-2		Yes
C.7	JUSTIFICATION OF "4T" BOUNDING LOADS	Chugging Loads Justification	NEDE 23617-P NEDO 23617 NEDE 24013-P NEDO 24013 NEDE 24014-P NEDO 24014 NEDE 24015-P NEDO 24015 NEDE 24016-P NEDO 24016 NEDE 24017-P NEDO 24017 NEDE 23627-P NEDO 23627	7/77 7/77 6/77 7/77 6/77 7/77 6/77 7/77 6/77 7/77 6/77 7/77 6/77 7/77	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes
C.8	SRV AND CHUGGING FSI	Prestressed Concrete, Reinforced Concrete, Steel	NEDE 21936-P NEDE 21936-P	7/78 7/78	Yes Yes
C.9	MONITOR WORLD TESTS	Monitor Tests	None		No
C.11	MASS-ENERGY RELEASE	SRV Pool Temperature Analysis Assumption	White Paper – Revision 0 White Paper – Revision 1	4/80 1/81	Yes No
		Methods for calculating mass and energy release for SRV discharges	Letter Report	5/81	Yes

Table 3A-1 (Cont'd)

TASK NUMBER	ACTIVITY	ACTIVITY TYPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
C.13	LOAD COMBINATIONS AND FUNCTIONAL CAPABILITY CRITERIA	Criteria Justification	NEDO 21985	9/78	Yes
C.14	NRC ROUND 3 QUESTIONS	Letter Report	Letter Report	6/78	Yes
		DFFR Round 3 Questions	Letter Report	6/78	Yes
C.15	SUBMERGERD STRUCTURE CRITERIA	NRC Question Responses	Letter Report	4/80	Yes
C.16	QUENCHER MASS ENERGY CUTOFF	Quencher Temperature Limit	Letter Report	1/81	Yes
C.18	DFFR REVISION	Revision 4	NEDO-21061-4	12/81	Yes

Table 3A-1 (Cont'd)

Document Number	Title	Documentation	Document Date	Used for LGS Licensing
II. KWU Tests and Reports				
1	Formation and oscillation of spherical gas bubble	AEG – Report 2241	12/72	Yes
2	Analytical model for clarification or pressure pulsation in the wetwell after vent clearing	AEG – Report 2208	3/72	Yes
3	Tests on mixed condensation with model quenchers	KWU – Report 2593	5/73	Yes
4	Condensation and vent clearing tests at GKM with quenchers	KWU – Report 2594	5/73	Yes
5	Concept and design of the pressure relief system with quenchers	KWU – Report 2703	7/73	Yes
6	KKB vent clearing with quencher	KWU – Report 2796	10/73	Yes
7	Experimental approach to vent clearing in a model tank	KWU – Report 3129	7/75	Yes
8	Anticipated data for blowdown tests with pressure relief system during the non-nuclear hot functional test at KKB	KWU – Report 3141		Yes
9	Results of the non-nucleat hot functional tests with the pressure relief system in the nuclear power station Brunsbuttel	KWU - Report 3267	12/74	Yes

Table 3A-1 (Cont'd)

Document Number	Title	Documentation	Document Date	Used for LGS Licensing
10	Analysis of the loads measured on the pressure relief system during the non-nuclear hot functional test at KKB	KWU – Report 3346	4/75	Yes
11	KKB – Listing of test parameters and important test data of the non-nuclear hot functional tests with the pressure relief system	KWU – Working Report R 521/40/77	8/77	Yes
12	KKB – Results from nuclear startup testing of pressure relief system	KWU – Working Report R 142-136/76	9/76	Yes
13	Results of non-nuclear hot functional tests with pressure relief system in KKPI	KWU – Working Report R 142-38/77	3/77	Yes
14	KKPI – Listing of test parameters and important test data of the non-nucleat hot functional tests with the pressure relief system	KWU – Working Report R 521/41/77	8/77	Yes
15	KKB hot functional test results, loads on internals in pool of the suppression chamber during pressure relief processes	KWU – Working Paper R 113/203	11/74	Yes

Table 3A-2

COMPARISON OF LGS LICENSING BASIS WITH NRC ACCEPTANCE CRITERIA

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
I. LOCA-Related Hydrodynamic Loads			
A. Submerged Boundary Loads During Vent Clearing	24 psi overpressure added to local hydrostatic pressure below vent exit (walls and basemat) – linear attenuation to pool surface	NUREG-0487 Supplement 1	Acceptable
B. Pool-swell Loads			
1. Pool-swell Analytical Model			
a. Air Bubble Pressure	Calculated by the pool swell analytical model (PSAM) used in calculation of submerged boundary loads.	NUREG-0487	Acceptable
b. Pool-swell Elevation	Use PSAM with polytropic exponent of 1.2 to a maximum swell height which is the greater of 1.5x vent submergence or the corresponding to the drywell floor uplift ΔP = 2.5 psid.	NUREG-0808	Acceptable. Used NUREG-0487, Supplement 1

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
c. Pool-swell Velocity	Velocity history vs. pool elevation predicted by the PSAM used to compute impact loading on small structures and drag on gratings between initial pool surface and maximum pool elevation and steady-state drag between vent wxit and maximum pool elevation. Analytical velocity variation is used up to maximum velocity. Maximum velocity applies thereafter up to maximum pool-swell. PSAM predicted velocities multiplied by a factor of 1.1.	NUREG-0808	Acceptable. Used NUREG-0487. PSAM calculated velocity without 1.1 multiplier However multiplied by 1.1 when used in force code.
d. Pool-swell Acceleration	Acceleration predicted by the PSAM. Pool acceleration is used in the calculation of acceleration loads on submerged components during pool-swell.	NUREG-0487	Acceptable
e. Wetwell Air Compression	Wetwell air compression is calculated by PSAM consistent with maximum pool-swell elevation calculated in B.1.b above.	NUREG-0487 Supplement 1	Acceptable. Maximum pool-swell elevation calculated in accordance with NUREG-0487, Supplement 1.
f. Drywell Pressure	Methods of NEDM-10320 and NEDO-20533 Appendix B. Used in PSAM to calculate pool-swell loads.	NUREG-0487	Acceptable.

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
2. Loads on Submerged Boundaries	Maximum bubble pressure predicted by the PSAM added uniformly to local hydrostatic pressure below vent exit (walls and basemat) – linear attenuation to pool surface. Applied to walls up to maximum pool-swell elevation.	NUREG-0487	Acceptable
3. Impact Loads			
a. Small Structures	1.35 x Pressure-Velocity correlation for pipes and I-beams based on PSTF impulse data and flat pool assumption. Variable pulse duration.	NUREG-0808	Acceptable
b. .Large Structures	None – Plant unique laod where applicable.	NUREG-0487	Not Applicable. No large structures.
c. Grating	Pool-swell drag vs. grating area correlation and pool velocity vs. elevation. Pool velocity from the PSAM. Pool-swell drag multiplied by dynamic laod factor.	NUREG-0808	Acceptable
4. Wetwell Air Compression			
a. Wall Loads	Direct application of the PSAM calculated pressure due to wetwell compression.	NUREG-0487	Acceptable

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
b. Diaphragm Upward Loads	5.5 psid diaphragm loadings only.	NREG-0808	Acceptable. Calculated diaphragm uplift ΔP = 10.6 psid (Figures 3A-6 and 3A-7) Design diaphragm uplift ΔP = 20 psid.
5. Asymetric LOCA Pool	Use 20 percent of maximum bubble pressure statiscally applied to ½ of the submerged boundary.	NUREG-0808	Acceptable
C. Steam Condensation and Chugging Loads			
1. Downcomer Lateral Loads			
a. Single Vent Loads (24 in.)	Dynamic load to end of vent. Half sine wave with a duration of 3-6 ms and corresponding maximum amplitudes of 65-10 k-lb_{f}.	NUREG-0808	Acceptable
b. Multiple Vent Loads (24 in.)	Prescribed variation of load per vent vs. number of vents. Determined from single vent dynamic load specification and multivent reduction factor.	NUREG-0808	Acceptable
c. Single/Mulitple vent loads (28 in)	Multiply basic vent loads by factor f = 1.34	NUREG-0808	Not Acceptable

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
2. Submerged Boundary Loads			
a. High/Medium Steam Flux Condensation Oscillaiton Load	Bounding CO pressure histories observed in 4TCO tests. In-phase application.	NUREG-0808	Acceptable
b. Low Steam Flux Chugging Load	Conservative set of 10 sources derived from 4TCO tests. Applied to plants using the IEWGS/MAPS acoustic model. Source desynchronization of 50 ms or alternate load using 7 sources derived from 4TCO key chugs without averaging.	NUREG-0808	Acceptable
- Symmetric Load	All vents use source of equal strength for each of the sources.		
- Asymmetric Load Case	Source strengths $S\pm = S\ (1\pm\alpha)$ applied to all vents on + and – side of containment. Sources based on the symmetric sources. Asymmetric parameter α based on rms moment method of interpreting experimental 4TCO single vent and JAERI multivent data.		

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
II. SRW Related Hydrodynamic Loads			
A. Pool Temperature Limits	For plants using a discharge device with the exact hole pattern as described in the SSES DAR Section 4.1, the following limits shall apply:	NUREG-0783	
	1. For all plant transients involving SRV operations during which steam flux exceeds 94 lb_m/ft^2-sec, the local pool temperature shall not exceed 200°F.	NUREG-0783	Acceptable
	2. For all plant transients involving SRV operations during which steam flux is less than 42 lb_m/ft^2-sec, the local pool temperature shall be at least 20°F subcooled. This is equivalent to a temperature of 210°F with quencher submergence of 14 feet.	NUREG-0783	Acceptable

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	3. For all plant transients involving SRV operations during which steam flux is between 42 lb_m/ft^2-sec and 94 lb_m/ft^2-sec, the local pool temperature can be determined by linear interpolation between the temperatures defined in items 1 and 2 above.	NUREG-0783	Acceptable
B. Evaluation of Air Cleaning Load Definition Procedures	The T-quencher load specification described in section 4.1 of the SSES DAR may be applied for evaluation of SRV containment boundary pressure loads with the following restrictions:	NUREG-0802	Acceptable
	1. All valves load case The DLV and DLWL combinations must lie below the limit line of figure A.1 defined in the criteria where: a. DLV shall be equal to the arithmetic average of all discharge line volumes (m^3)	NUREG-0802	Acceptable

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	b. DLW shall be equal to the quencher submergence at high water level (m).		
	2. ADS Load Case The DLV and DLWL combinations must lie below the limit line of figure A.2 defined in the criteria where: a. DLV shall be equal to the arithmetic average of all ADS discharge line volumes (m^3) b. DLWL shall be equal to the differences between the plant downcomer exit elevation and the quencher center line elevation (m)	NUREG-0802	Acceptable
	3. Frequency Range For the single valve and asymmetric load cases, the time-wise compression of the design pressure signatures shall be increased to provide an overall dominant frequency range that extends to 11 Hz.	NUREG-0802	Acceptable (Section 3B.4.1.4.1)

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	4. Vertical Pressure Distribution The maximum pressure amplitudes shall be applied uniformly to the containment and pedestal walls up to an el 2.5' above the quencher centerline followed by linear attenuation to zero at pool surface.	NUREG-0802	Acceptable
C. T-Quencher Tie-Down Loads	The T-Quencher load specification described in SSES DAR section 4.1.2, as interpreted in sections 2.2.3 and 2.3.3 of NUREG-0802, may be applied for evaluation of quencher and quencher support.	NUREG-0802	Acceptable
D. SRV Boundary Loads	The acceptance criteria specified in NUREG-0802. Appendix A (A.1.1 through A.1.7), are recommended for plants following the "alternate" load methodology (i.e., T-Quencher load specification described in SSES DAR section 4.1)	NUREG-0802	Acceptable Section 3B.4.1.1.1 demonstrates the acceptability of using the SSES SRV load specification for LGS.

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
III. LOCA/SRV Submerged Structure Loads			
A. LOCA Downcomer Jet Load	Alternate methodology presented in Zimmer DAR may be applied.	NUREG-0487 Supplement 1	Acceptable
B. SRV T-Quencher Jet	SRV T-quencher jet loads may be neglected betond a 5 ft cylindrical zone of influence. Cyliner should be extended 10 hole diameters on the arm with holes in the end cap.	NUREG-0487	Acceptable
C. LOCA Air Bubble Drag Loads	Calculate based on methods described in NEDE-21471 subject to the following constraints and modifications:	NUREG-0487	Applying plant unique methodology defined in Section 3A.4.2.1.5
	1. To account for bubble asymmetry, accelerations and velocities shall be increased 10 %.	NUREG-0487	Acceptable
	2. For standard drag in accelerating flow fields, use draft coefficients presented in Zimmer FSAR Attachement 1.k with following modifications:	NUREG-0487 Supplement 1	Acceptable

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	a. Use $C_H = C_m^{-1}$ in the F_A formula b. For noncylindrical structures, use lift coefficient for appropriate shape or $C_L = 1.6$ c. The standard drag coefficient for pool-swell and SRV oscillating bubbles should be based on data for structures with sharp edges.		
	3. For equivalent uniform flow velocity and acceleration calculations, structures are segmented into small sections such that $1.0 \leq L/D \leq 1.5$. The loads are then applied to the geometric center of each segment. This approach, as presented in Zimmer FSAR Attachment 1.k. may be applied.	NUREG-0487 Supplement 1	Acceptable
	4. A detailed methodology on the approach for considering effects as presented in Zimmer FSAR Attachment 1.k may be applied.	NUREG-0487 Supplement 1	Acceptable

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	5. Formula 2-23 of NEDE-21739 shall be modified by replacing M_H by ρ_{FB} V_A where V_A is obtained from tables 2-1 & 2-2.	NUREG-0487	Acceptable
D. SRV Air Bubble Drag Load	No criteria specifiec for T-quencher		Applying plant unique methodology defined in Section 3B.4.1.4 and applying the Mark II Submerged structure load methodology for SRV - bubbles described in Section 3A.11
E. Steam Condensation Drag Load	No criteria specifiec		Applying plant unique methodology defined in Section 3A.4.2
IV. Secondary Loads			
1. Sonic Wave Load	Negligible Load	NUREG-0487	Acceptable
2. Comprehensive Wave Load	Negligible Load	NUREG-0487	Acceptable
3. Fallback Load on Submerged Boundary	Negligible Load	NUREG-0487	Acceptable
4. Thrust Load	Negligible Load	NUREG-0487	Acceptable
5. Friction Load on Submerged Boundary	Negligible Load	NUREG-0487	Acceptable
6. Vent Clearing Loads	Negligible Load	NUREG-0487	Acceptable

Table 3A-2 (Cont'd)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
7. Postswell Wave Load	Methodology for establishing loads resulting from postswell waves to be evaluated on a plant unique basis	NUREG-0487	Load is negligible when compared to design basis loads (Section 3A.4.2.3.6)
8. Seismic Slosh Load	Methodology for establishing loads resulting from seismic slosh to be evaluated on a plant unique basis	NUREG-0487	Load is negligible when compared to design basis loads (Section 3A.4.2.3.7)
V. Confirmatory In-plant Tests of SRV Discharge			
A. SRV Load Specification	In the event that an applicant cannot demonstrated to the staff's satisfaction, equivalence in any of the areas cited in acceptance criteria A.1.1 through A.1.7 of confirmatory testing may be employed to demonstrate the applicability of the acceptance criteria for individual plants. Such testing if proposed should conform to the guidelines set down in NUREG-0763	NUREG-0802 Appendix A	Acceptable. No In-plant test is required. Section 3B>4.1.1.1 demonstrates the acceptability of using SSES SRV load specification for LGS.
B. Pool Temperature Specification (Thermal Mixing)	The acceptability of the safety/relief valve in-plant confirmatory test program shall be based on conformance guidelines specified in sections 6, 7, and 8 of NUREG-0763. I f the applicant/licensee elects not to perform the SRV in-plant tests, justification should be provided following the guidelines specified in section 4 of NUREG-0763.	NUREG-0763	Acceptable. The LGS pool thermal mixing capability has been adequately demonstrated by in-plant testing at LaSalle and analysis (Sections 3A.15.1.2 and 3A.15.3).

Table 3A-3

CONTAINMENT DESIGN PARAMETERS

	Drywell	Suppression Chamber
DRYWELL AND SUPPRESSION CHAMBER		
Internal design pressure, psig	55	55
External to internal design differential pressure, psid	5	5
Drywell deck design differential pressure, psid	30 downward	20 upward
Design temperature, ^{o}F	340	220
Drywell net free volume, at suppression pool low water level, including downcomers, ft^3	243,580[(3)]	
Suppression chamber free volume including pedestal interior, ft^3		
Low water level		159,540[(3)]
High water level		147,670[(3)]
Suppression pool water volume including pedestal interior, ft^3		
Low water level		122,120[(3)(5)]
High water level		134,600[(3)]
Suppression pool net surface area, ft^2		
Outside pedestal		4974
Inside pedestal		293
Suppression pool depth, ft		
Low level		22'
Normal level		23'
High level		24'-3"

Table 3A-3 (Cont'd)

	Drywell	Suppression Chamber
VENT SYSTEM		
Number of downcomers		87[(4)]
Nominal downcomer diameter, ft		2[(5)]
Downcomer area (each), ft^2		2.95
Downcomer submergence, ft		
Low water level		10'
Normal water level		11'
High water level		12'-3"
Downcomer loss coefficient (including exit loss)		2.23[(3)]
SAFETY/RELIEF VALVES		
Number		14
Spring Set Pressures, Mass Flow Rates:		

Valve	Set Pressure (psig)	Mass Flow (lb_m/hr) at 103% of Spring Set Pressure
A	1190	948,785
B	1190	948,785
C	1190	948,785
D	1180	940,906
E*	1180	940,906
F	1190	948,785
G	1190	948,785
H*	1170	933,028
J	1170	933,028

Table 3A-3 (Cont'd)

Valve	Set Pressure (psig)	Mass Flow (lb_m/hr) at 103% of Spring Set Pressure
K*	1180	940,906
L	1170	933,028
M*	1180	940,906
N	1170	933,028
S*	1180	940,906

*ADS Valves

SAFETY/RELIEF VALVE DISCHARGE LINES

Nominal Diameter 12"

Length, Number of Bends, and Air Volume for each SRV Pipe:

Valve	Bends	Length(1) (ft)	Volume(2) (ft^3)
A	9	144.5	94.3
B	7	116.4	74.2
C	7	118.2	75.7
D	9	144.9	94.8
E	9	137.4	89.1
F	11	136.3	88.3
G	11	136.6	88.5
H	11	140.5	91.2
J	7	118.6	76.0
K	12	134.0	86.2
L	10	134.3	86.5
M	13	137.0	88.2
N	10	144.5	93.8
S	12	142.3	93.2

Table 3A-3 (Cont'd)

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(1) Line lengths are measured from the valve to the quencher inlet.

(2) Air volume is calculated up to pool normal water level.

(3) These values vary slightly from those actually used in the analysis. The difference in analysis results is negligible.

(4) Four of 87 downcomers are capped (Section 3A.16).

(5) These values were used in the original design basis analyses. Refer to Table 6.2-4A for the values used in the containment analyses for the current plant conditions.

Table 3A-4

LGS CONTAINMENT DIMENSIONS

SUPPRESSION CHAMBER	
Inside Diameter	88'-0"
Height	52'-6"
DRYWELL	
Inside Diameter of Base	86'-4"
Inside Diameter of Top	36'-4.5"
Height	87'-9"
REACTOR PEDESTAL	
Inside Diameter Below Diaphragm Slab	20'-0.5"
Inside Diameter Above Diaphragm Slab	20'-3"
Wall Thickness Below Diaphragm Slab	4'-9.5"
Wall Thickness Above Diaphragm Slab	4'-5"
Height	82'
REINFORCED CONCRETE THICKNESS	
Base Foundation Slab	8'-0"
Containment Wall	6'-2"
Diaphragm Slab	3'-6"
STEEL LINER PLATE THICKNESS	
Base Foundation, Containment Wall, and Diaphragm Slab)	0.25"
SUPPRESSION CHAMBER COLUMNS	
Outside Diameter	3'-6"
Wall Thickness	1.25"
Height	52'-3"

Table 3A-5

SHORT-TERM LOCA LOADS ASSOCIATED WITH POOL-SWELL

Load

1. Wetwell/drywell pressures during pool-swell
2. Pool-swell impact loads
3. Pool-swell drag loads
4. Downcomer clearing loads
5. Downcomer water jet load
6. Pool-swell air bubble load
7. Pool-swell fallback load

Table 3A-6

SHORT-TERM DRYWELL PRESSURES DURING POOL-SWELL

Time (sec)	Pressure (psia)
0.0000[1]	36.11
0.0600	36.29
0.1000	36.82
0.1200	37.08
0.1600	37.57
0.2000	38.04
0.2400	38.49
0.2800	38.91
0.3200	39.30
0.3600	39.67
0.4000	40.01
0.5000	40.75
0.6000	40.75
0.7000	41.39
0.8000	42.07
0.9000	42.80
1.0000	43.56
1.1000	44.603
1.2000	45.36
1.3000	46.08
1.4000	46.75

(1) Represents the beginning of the pool-swell phase, which starts 0.7107 seconds after the break.

NOTE: The information presented in this table is historical and is based on the original design basis conditions. The initial drywell pressurization rate is negligibly affected by the current plant conditions. The results presented here reasonably represent the general characteristics of the drywell pressure response.

Table 3A-7

LGS PLANT UNIQUE POOL-SWELL CODE INPUT DATA

Downcomer area (each)	2.95 ft^2
Suppression pool free surface area (outside pedestal)	4973.89 ft^2
Maximum downcomer submergence	12.25 ft
Downcomer loss coefficient (without exit loss)	1.23
Number of downcomers	87
Initial wetwell pressure	15.45 psia
Wetwell free air volume	149,425 ft^3
Vent clearing time	0.7107 sec
Slug velocity in downcomer at vent clearing	3.096 ft/sec
Initial drywell temperature	135°F
Initial drywell relative humidity	0.20
Downcomer friction coefficient, f	0.0115 (nominal)
Bubble initialization parameter (nominal)	50

NOTE: The information presented in this table is based on the original design basis conditions. Refer to Table 6.2.4A for input values used in the containment analyses for the current plant conditions.

Table 3A-8

INCLUDED LOCA WATER JET DRAG LOADS

Largest vertical downward force density acting on RHR pump suction line strainer	49 psi
Largest horizontal force density acting on RHR pump suction line strainer	29 psi
Largest vertical force on closest MSRV discharge line (distance = 2 ft)	1207 lb/ft
Largest horizontal force on closest MSRV discharge line (distance = 2 ft)	1394 lb/ft

NOTE: The information presented in this table is pertains to the original design basis. At current plant conditions, the LOCA water jet loads are approximately 2% higher than the load values shown in the table. However, margin between the design limits and the resulting component stress calculations exists to accommodate the increase in the LOCA jet loads.

Table 3A-9

POOL-SWELL AIR BUBBLE LOADS

Water volume in downcomers	3142.16 ft^3
Pool surface area (outside pedestal)	4973.89 ft^2
Maximum pool-swell after water discharge	18.88 ft
Height of downcomer water in the pool	7.58 in (0.632 ft)
Maximum pool-swell height (18.88 ft + 0.632 ft)	19.51 ft
Basemat hydrostatic pressure	10.51 psig
Downcomer tip hydrostatic pressure	5.20 psig
Maximum air bubble pressure	48.25 psia
Maximum pressure at basemat	58.76 psia
Maximum pressure at downcomer tip	48.25 psia
Maximum pool-swell inside the pedestal	212'-9" (6.62 ft above the high water level)

NOTE: The information presented in this table is based on the original design basis conditions. Refer to Sections 3A.4.2.1.4 and 3A.4.2.1.7 for the air bubble loads evaluation at the current operating conditions.

Table 3A-10

POOL-SWELL WATER FRICTION DRAG LOADS

Friction drag loads on columns	
Number of columns	12
Surface area per column	214.55 ft^2
Friction force for 12 columns	5098 lb_f
Shear stress	0.01375 lb/in^2
Friction drag load on downcomers	
Number of downcomers	87
Surface area of downcomer	122.6 ft^2
Frictional drag coefficient	0.00216
Friction force for 87 downcomers	2112.2 lb
Friction drag load on MSRV pipes	1806 lb
Air friction drag inside downcomers	303 lb
Downcomer bracing fallback loads	
Vertical load (12" nominal diameter)	3720 lb/ft
Horizontal load (12" nominal diameter)	2823 lb/ft
Vertical load (10" nominal diameter	2616 lb/ft
Horizontal load (10" nominal diameter	2046 lb/ft

NOTE: The information presented in this table is based on the original design basis conditions. Refer to Section 3A.4.2.1.8 for the pool swell drag load evaluation at the current operating conditions.

Table 3A-11

MAXIMUM LOAD ON SUBMERGED STRUCTURES

Submerged Structure	Max CO Load (lb/in)	Max Chugging Load (lb/in)
MSRV Discharge Line	3.8	24.0
Downcomer	22.0	41.0
Bracer	0.8	10.2
Core spray discharge line	0.22	6.6
HPCI discharge line	22.0	22.0
RHR discharge line	2.2	16.0
Column	51.6	190.0

Table 3A-12

COMPONENT LOCA LOAD CHART FOR LGS

Structure Directly Affected	Load 1	2	3	4	5	6	7	8	9	10	11	12	13
Containment Wall	X					X		X	X	X	X	X	X
Pedestal (incl. Interior)	X					X		X	X	X	X	X	X
Basemat	X				X	X		X	X	X	X	X	X
Liner plate	X				X	X		X	X	X	X	X	X
Drywell floor	X										X	X	X
Drywell	X										X	X	X
Columns			X			X	X	X	X	X			
Downcomers			X	X		X	X	X	X	X			
Downcomer bracing			X			X	X	X	X	X			
Wetwell piping		X	X		X	X	X	X	X	X			

Load Legend

1	Wetwell/drywell pressure during pool-swell
2	Pool-swell impact load
3	Pool-swell drag load
4	Downcomer clearing load
5	Downcomer water jet load
6	Pool-swell air bubble load
7	Fallback load
8	High mass flux condensation load
9	Medium mass flux condensation load
10	Chugging load
11	Wetwell/drywell P and T during DBA
12	Wetwell/drywell P and T during IBA
13	Wetwell/drywell P and T during SBA

Table 3A-13

WETWELL PIPING LOCA LOADING SITUATIONS

Piping Configuration	LOCA Load to be Applied
1. Completely Submerged	
(a) vertical	skin drag load only (C_f)
(b) horizontal	drag load (C_D)
2. Partially Submerged	
(a) vertical	skin drag load only (C_f)
3. Initially Uncovered	
(a) vertical	skin drag load only (C_f)
(b) horizontal	impact load, then drag load (C_D)

Table 3A-14

LOAD COMBINATIONS FOR CONCRETE DESIGN IN CONTAINMENT, REACTOR ENCLOSURE, AND CONTROL STRUCTURES
(CONSIDERING HYDRODYNAMIC LOADS)

Equa-tion	Load Condition	D	L	P_o	T_o	R_o	E_o	E_{ss}	P_B	P_A	T_A	B_A	R_V	SRV	AOT(1)	ADS	ASYM	Single Valve	LOCA(3)
1	Normal w/o Temp.	1.4	1.7	1.0	-	-	-	-	-	-	-	-	-	1.5	X(2)	X	X	-	-
2	Normal w/Temp.	1.0	1.3	1.0	1.0	1.0	-	-	-	-	-	-	-	1.3	X	-	X	-	-
3	Normal Sev. Env.	1.0	1.0	1.0	1.0	1.0	1.25	-	-	-	-	-	-	1.25	X	-	X	-	-
4	Abnormal	1.0	1.0	-	-	-	-	-	1.25	-	1.0	1.0	-	1.25	-	X	X	-	X
4a	Abnormal	1.0	1.0	-	-	-	-	-	-	1.25	1.0	1.0	-	1.0	-	-	-	X	X
5	Abnormal Sev. Env.	1.0	1.0	-	-	-	1.1	-	1.1	-	1.0	1.0	-	1.1	-	X	X	-	X
5a	Abnormal Sev. Env.	1.0	1.0	-	-	-	1.1	-	-	1.1	1.0	1.0	-	1.0	-	-	-	X	X
6	Normal Ext. Env.	1.0	1.0	1.0	1.0	1.0	-	1.0	-	-	-	-	-	1.0	X	-	X	-	-
7	Abnormal Ext. Env.	1.0	1.0	-	-	-	-	1.0	1.0	-	1.0	1.0	1.0	1.0	-	X	X	-	X
7a	Abnormal Ext. Env.	1.0	1.0	-	-	-	-	1.0	-	1.0	1.0	1.0	1.0	1.0	-	-	-	X	X

Table 3A-14 (Cont'd)

Load Description

D	=	Dead Loads
L	=	Live Loads
P_o	=	Operating Pressure Loads
T_o	=	Operating Temperature Loads
R_o	=	Operating Pipe Reactions
SRV	=	Safety Relieve Valve Loads
E_o	=	Operating Basis Earthquake
E_{ss}	=	Safe Shutdown Earthquake
P_B	=	SBA or IBA (LOCA) Pressure Load
B_A	=	Pipe Break Temperatures Reaction Loads
P_A	=	DBA (LOCA) Pressure Load
T_A	=	Pipe Break temperature Load
R_V	=	Reaction and jet forces associated with the pipe break
AOT	=	Abnormal Operating Transient
ADS	=	Automatic Depressurization System
ASYM	=	Asymmetric

(1) For columns designated AOT, ADS, ASYM, and Single Valve, only one of the four possible columns may be included in the load combination for any one equation. For example, in Equation 1, either AOT or ASYM may be considered with the other loads but not both AOT and ASYM simultaneously.

(2) X indicates applicability for the designated load combination.

(3) LOCA includes chugging, condensation oscillation, and large air bubble loads.

Table 3A-15

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR STRUCTURAL STEEL COMPONENTS
(Suppression Chamber Columns, Downcomer Bracing, and Reactor Enclosure Structural Steel)

Equation	Condition	Load Combination	Allowable Stress
1	Normal w/o Temp.	$D+L+P_o+SRV$	F_s
2	Normal w/ Temp.	$D+L+P_o+T_o+SRV$	F_s
3	Normal/ Severe	$D+L+P_o+T_o+E+SRV$	$1.25\ F_s$
4	Normal/ Extreme	$D+L+P_o+T_o+E'+SRV$	(1)
5	Abnormal	$D+L+P+(T_o+T_a)+R+SRV+LOCA$	(1)
6	Abnormal/ Severe	$D+L+P+(T_o+T_a)+R+E+SRV+LOCA$	(1)
7	Abnormal/ Extreme	$D+L+P+(T_o+T_a)+R+E'+SRV+LOCA$	(1)

(1) In no case shall the allowable stress exceed 0.90 F_y in bending, 0.85 F_y in axial tension or compression, and 0.50 F_y in shear. Where the design is governed by requirements of stability (local or lateral buckling), the actual stress shall not exceed 1.5 F_s.

Table 3A-15 (Cont'd)

Notations:

F_s	=	Allowable stress according to the AISC, "Specification for the Design, Fabrication, and Erection of Structural Steel for Building," dated 1969, Part 1
F_y	=	Minimum specified yield strength
D	=	Dead load
L	=	Live load
T_o	=	Thermal effects during normal operating conditions including temperature gradients and equipment and pipe reactions
T_a	=	Added thermal effects (over and above operating thermal effects) that occur during a design accident
P_o	=	Operating Pressure Load
P	=	Design basis accident pressure load
R	=	Local force or pressure on structure due to postulated pipe rupture including the effects of steam/water jet impingement, pipe whip, and pipe reaction
E	=	Load due to operating basis earthquake
E'	=	Load due to safe shutdown earthquake
SRV	=	Safety relief valve loads
LOCA	=	Loads due to loss-of-coolant accident conditions (chugging, condensation oscillation, or large air bubble loads)

Table 3A-16

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR
ASME CLASS MC COMPONENTS

The drywell head assembly, equipment hatches, personnel lock suppression chamber access hatches, CRD removal hatch, and piping and electrical penetrations are designed for the following loading combinations and allowable stresses:

Equation	Condition	Load Combination	Stress Limits
1	Normal	$D+L+1.15P$	1.15 times ASME Section III, Class B
2	Normal	$D+L+T_A+P$	ASME Section III, Class B
3	Emergency	$D+L+T_A+P+H_A+R+E$	ASME Section III, Summer 1970 Addenda, Figure N-414
4	Faulted	$D+L+T_A+P+H_A+R+E'$	ASME Section III, Summer 1970 Addenda, Figure N-414
5	Normal w/Temp.	$D+L+T_o+SRV$	ASME Section III, Class MC Components
6	Abnormal/ Severe	$D+L+T_A+P+H_A+R+E$ $+SRV+LOCA$	ASME Section III, Fig. NB-3224-1 for "Emergency Conditions"
7	Abnormal/ Extreme	$D+L+T_A+P+H_A+R+E'$ $+SRV+LOCA$	ASME Section III, Fig. NB-3225-1 for "Faulted Conditions"

Definitions

D = Dead load

L = Live Load

T_o = Thermal effects due to temperature gradient through the wall, under operating conditions

T_A = Thermal effects due to temperature gradient through the wall, under accident conditions

P = Design basis accident pressure load

Table 3A-16 (Cont'd)

R	=	Steam/water jet forces or reactions resulting from the rupture of process piping
E	=	Load due to the operating basis earthquake
E'	=	Load due to the design basis earthquake
B	=	Hydrostatic loading due to postaccident flooding of the primary containment to the level of the reactor core
H_A	=	Force on the structure due to thermal expansion of pipes, under accident conditions
SRV	=	Safety/relief valve loads
LOCA	=	Loads due to loss-of-coolant accident conditions (chugging, condensation oscillation, annulus pressurization or large air bubble loads)

Table 3A-17

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR DOWNCOMERS

Equation	Condition	Load Combination	Allowable Stress
1	Upset	$D+P_o+SRV_{ALL}$	1.5 S_m
2	Emergency	$D+P_o+SRV_{ALL}+E$	2.25 S_m
3	Emergency	$D+P_{SBA}+SRV_{ADS}+E+LOCA(SBA)$	2.25 S_m
4	Faulted	$D+P_o+SRV_{ALL}+E'$	3 S_m
5	Faulted	$D+P_{IBA}+SRV_{ADS}+E+LOCA(IBA)$	3 S_m
6	Faulted	$D+P_{SBA}$ (or P_{IBA}) $+SRV_{ADS}+E'+LOCA$(SBA or IBA)	3 S_m
7	Faulted	$D+P_A+E'+LOCA(DBA)$	3 S_m

Notations:

S_m = Maximum allowable stress

D = Dead weight of the downcomer

P_o = Pressure differential between drywell and suppression chamber during normal operating condition

P_{SBA} = Pressure differential between drywell and suppression chamber during SBA.

P_{IBA} = Pressure differential between drywell and suppression chamber during IBA.

P_A = Pressure differential between drywell and suppression chamber during DBA.

SRV_{ALL} = Dynamic lateral pressure and inertia load due to the discharge of all 14 safety/relief valves simultaneously.

Table 3A-17 (Cont'd)

SRV_{ADS}	=	Dynamic lateral pressure and inertia load due to the discharge of all 5 ADS safety/relief valves simultaneously.
E	=	Load due to operating basis earthquake
E'	=	Load due to safe shutdown earthquake
LOCA	=	Loads due to chugging, condensation oscillation, or air bubble loads. The governing applicable loading case should be considered. The loads should include:

1. Lateral load at the tip of the downcomer
2. Horizontal and vertical inertial loads
3. Submerged structure loads

Table 3A-18

LOAD COMBINATIONS AND STRESS LIMITS FOR BOP PIPING SYSTEMS

Equation	Condition	Load Combination	Stress Limit
1	Design	PD	NB-3652 NC-3600, ND-3600
2	Normal	PD + DW	NB-3654, NC-3600, ND-3600
3	Upset	(a) $PO+DW+(OBE^2+SRV_x^2)^{1/2}$ (b) $PO+DW+(RVC^2+OBE^2)^{1/2}$ (c) PO+DW+FV (d) PO+DW+OBE+RVO	NB-3654, NC-3600, ND-3600
4	Emergency	(a) $PO+DW+(OBE^2+SRV_{ADS}^2+SBA^2)^{1/2}$ (b) $PO+DW+(FV^2+OBE^2)^{1/2}$	NB-3655, NC-3600, ND-3600
5	Faulted	(a) $PO+DW+(OBE^2+SRV_{ADS}^2+IBA^2)^{1/2}$ (b) $PO+DW+(SSE^2+SRV_{ADS}^2+IBA^2)^{1/2}$ (c) $PO+DW+(SSE^2+DBA^2)^{1/2}$	NB-3656 ASME Code Case 1606

Notations:

PD = Design pressure

PO = Operating pressure

DW = Dead weight

OBE = Operating basis earthquake (inertia portion)

SSE = Safe shutdown earthquake (inertia portion)

SRV_x = Loads due to safety/relief valve blow, axisymmetric or asymmetric

Table 3A-18 (Cont'd)

SRV_{ADS}	=	Load due to automatic depressurization SRV blow, axisymmetric
SBA	=	Small break accident[1]
IBA	=	Intermediate break accident[1]
DBA	=	Design basis accident[1]
FV	=	Transient response of the piping system associated with fast valve closure (transients associated with valve closure times less than 5 seconds are considered)
RVC	=	Transient response of the piping system associated with relief valve opening in a closed system
RVO	=	Sustained load or response of the piping system associated with relief valve opening in an open system or last segment of the closed system with steady-state load

---

(1) SBA, DBA, and IBA include all event-induced loads, as applicable, such as chugging, condensation oscillation, pool-swell, annulus pressurization, etc.

Table 3A-19

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA FOR
ASME CLASS 1, 2, AND 3 NSSS PIPING, EQUIPMENT, AND SUPPORTS

LOAD COMBINATION	DESIGN BASIS	EVALUATION[3] BASIS	SERVICE LEVEL
N + $SRV_{(ALL)}$	Upset	Upset	(B)
N + OBE	Upset	Upset	(B)
N + OBE + $SRV_{(ALL)}$	Emergency	Upset	(B)
N + SSE + $SRV_{(ALL)}$	Faulted	Faulted	(D)[1]
N + SBA + SRV	Emergency	Emergency	(C)[1]
N + SBA + $SRV_{(ADS)}$	Emergency	Emergency	(C)[1]
N + SBA/IBA + OBE + $SRV_{(ADS)}$	Faulted	Faulted	(D)[1]
N + SBA/IBA + SSE + $SRV_{(ADS)}$	Faulted	Faulted	(D)[1]
N + LOCA[2] + SSE	Faulted	Faulted	(D)[1]

LOAD DEFINITION LEGEND

N	-	Normal loads (e.g., weight, pressure, temperature, etc)
OBE	-	Operating basis earthquake loads
SSE	-	Safe shutdown earthquake loads
SRV	-	Safety/relief valve discharge induced loads from two adjacent valves (one valve actuated when adjacent valve is cycling)
SRV_{ALL}	-	Loads induced by actuation of all 14 safety/relief valves that activate within milliseconds of each other (e.g., turbine trip operational transient)
SRV_{ADS}	-	Loads induced by the actuation of all 5 safety/relief valves associated with automatic depressurization system that actuate within milliseconds of each other during the postulated small or intermediate size pipe rupture.
LOCA	-	Loss-of-coolant accident associated with the postulated pipe rupture of large pipes (e.g., main steam, feedwater, recirculation piping)

Table 3A-19 (Cont'd)

$LOCA_1$ -	Pool-swell drag/fallback loads on piping and components located between the main vent discharge outlet and the suppression pool water upper surface
$LOCA_2$ -	Pool-swell impact loads on piping and components located above the suppression pool water upper surface
$LOCA_3$ -	Oscillating pressure induced loads on submerged piping and components during condensation oscillations
$LOCA_4$ -	Building motion induced loads from chugging
$LOCA_5$ -	Building motion induced loads from main vent air clearing
$LOCA_6$ -	Vertical and horizontal loads on main vent piping
$LOCA_7$ -	Annulus pressurization loads
SBA -	Abnormal transients associated with a small break accident
IBA -	Abnormal transients associated with an intermediate break accident.

(1) All ASME Class 1, 2 and 3 piping that are required to function for safe shutdown under the postulated events are designed to meet the requirements described in NEDO-21985 (Sept. 1978).

(2) The most limiting case of load combinations among $LOCA_1$ through $LOCA_7$.

(3) Evaluation basis in accordance with NRC requirements.

Table 3A-20

LOAD COMBINATIONS AND DAMPING VALUES FOR SAFETY-RELATED BOP EQUIPMENT IN THE PRIMARY CONTAINMENT, REACTOR ENCLOSURE, AND CONTROL STRUCTURES

Equation	Condition	Load Combination	Damping[1]
1	Upset	a. $N+[OBE^2 + SRV^2]^{1/2}$	2%
		b. N+OBE	0.5%
2	Emergency	a. $N+[OBE^2 + SRV^2 + SBA^2]^{1/2}$	2%
3	Faulted	a. $N+[OBE^2 + SRV^2 + IBA^2]^{1/2}$	2%
		b. $N+[SSE^2 + SRV^2 + IBA^2]^{1/2}$	2%
		c. $N+[SSE^2 + DBA^2]^{1/2}$	2%
		d. Envelope of a, b & c	2%
		e. N+SSE	1%
4	Worst	a. Envelope of 1a, 2 and 3d	2%

Notations:

N = Normal loads (dead weight + operating temp + operating pressure, etc.

OBE = Operating basis earthquake loads

SSE = Safe shutdown earthquake loads

SRV = Safety/relief valve discharge loads

SBA = Small break accident loads

IBA = Intermediate break accident loads

DBA = Design basis accident loads

---

(1) Where justified, a higher damping value may be used.

Table 3A-21

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR ELECTRICAL RACEWAY SYSTEM

Equation	Condition	Load Combination	Allowable Stress
1	Normal	D+L+SRV	F_s
2[1]	Normal/Severe	D+E	[2]
3	Abnormal/Extreme	D+E'+SRV+LOCA	[2,3]

Notations:

F_s = Allowable stress for normal condition

D = Dead weight of raceway and cables

L = A 200 lb concentrated live load is applied at any point on cable trays only between supports

E = Load due to operating basis earthquake

E' = Load due to safe shutdown earthquake

SRV = Safety/relief valve loads

LOCA = Loss-of-coolant accident loads

F_y = Minimum specified yield strength

Table 3A-21 (Cont'd)

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(1) Applies only to connections for fatigue considerations.

(2) The following equation is applicable for connections:

$$\frac{5n_{EQ}}{N_{OBE}} + \frac{n_{EQ}}{N_{SSE}} \leq 1.0$$

where:

n_{EQ} = Total number of load/stress cycles per earthquake.

N_{OBE} = Allowable number of load/stress cycles per OBE event.

N_{SSE} = Allowable number of load/stress cycles per SSE event.

Allowable shear and normal loads on proprietary connection fittings shall be determined from the manufacturer's data or from code allowable stresses, whichever is applicable and as provided by Specification C-98.

(3) In no case shall the allowable stress exceed 0.90 F_y in bending, 0.85 F_y in axial tension or compression, and 0.50 F_y in shear. Where the design is governed by requirements of stability (local or lateral buckling), the actual stress shall not exceed 1.5 F_s.

Table 3A-22

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR
HVAC DUCT SYSTEMS

DUCTS

Equation	Condition	Load Combination	Allowable Stress
1	Normal	D+L+SRV	F_s
2	Normal	$D+P_M+SRV$	F_s
3	Abnormal	$D+P_T$	1.25 F_s
4	Normal/Severe	$D+P_M+E$	1.25 F_s
5	Normal/Severe	$D+P_M+E+SRV$	1.25 F_s
6	Normal	D+Po	F_s
7	Normal/Severe	D+Po+E	1.25 F_s
8	Normal/Extreme	D+Po+E'	(2)
9	Normal/Extreme	$D+P_M+E'+SRV$	(2)
10	Normal/Abnormal	$D+P_O+P_A+E'+SRV+LOCA$	(2)
11	Normal/Abnormal	When protection against tornado depressurization is required:	
		$D+P_O+W_D+SRV+LOCA$	(2)
12	Extreme/Abnormal	For ducts inside drywell of containment, the following additional load combination is also applicable:	
		$D+H_A+P_O+P_A+E'+SRV+LOCA$	(2)

Table 3A-22 (Cont'd)

DUCT SUPPORTS

Equation	Condition	Load Combination	Allowable Stress
1	Normal	D+L+SRV	F_s
2	Normal/Severe	D+E	1.25 F_s (1)
3	Normal/Severe	D+E+SRV	1.25 F_s
4	Extreme/Abnormal	D+E'+SRV+LOCA	(2)

Notations:

D	=	Dead load
L	=	Live load
P_O	=	Duct normal operating pressure load
P_T	=	Duct test pressure load
P_A	=	Design basis accident pressure load
P_M	=	Duct maximum operating pressure load, excluding P_A & P_T, e.g., fan cutoff pressure load
E	=	Load due to operating basis earthquake
E'	=	Load due to safe shutdown earthquake
W_D	=	Tornado depressurization load
H_A	=	Forces due to thermal expansion of HVAC ducts under accident conditions
SRV	=	Safety/relief valve loads
LOCA	=	Loss-of-coolant accident loads
F_s	=	Allowable stress for steel, governed by AISI or AISC Codes, as applicable
F_y	=	Yield strength for steel (ASTM specification minimum)

Table 3A-22 (Cont'd)

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(1) This value shall be F_s for transverse and longitudinal bracing and their connections.

(2) In no case shall be allowable stress exceed 0.90 F_y in bending, 0.85 F_y in axial tension or compression, and 0.50 F_y in shear. Where the design is governed by requirements of stability (local or lateral buckling), the actual stress shall not exceed 1.5 F_s.

Table 3A-23

REACTOR ENCLOSURE AND CONTROL STRUCTURE:
SUMMARY OF HYDRODYNAMIC ANALYSES AND
CORRESPONDING MATHEMATICAL MODELS

Load Case	SRV		CO		CHUGGING	
MODEL (Figure Number)	AXISYMMETRIC	ASYMMETRIC	BASIC	ADS	AXISYMMETRIC	ASYMMETRIC
Axisymmetric "FESS" Vertical Coupled Model (Figure 3A-33)	X		X	X	X	
Vertical Flexible Base Stick Model (Figure 3A.34)		X				X
Horizontal Flexible Base Sticl Model (Figure 3A-35)		X				X
Control Structure Floor Half-Model (Figure 3A-36)	X	X			X	X
Control Structure Floor Quarter Model (Figure 3A.37)			X	X		

Table 3A-24

CONTROL STRUCTURE FLOOR MODEL MATERIAL PROPERTIES

Control Structure Floor Elevation (ft)	Slab Thickness t (ft)	Equiv. Floor Element Thickness, t_{eff}	Floor Element Mass Density ρ' kip-s^2/ft^4
el 217	1.25	2.66	.002554
	2.125, 2.5	3.26	.003334
el 239	1.0	2.93	.003241
el 253	1.0	2.61	.002538
el 269	1.5	2.63	.003219
el 289	1.5	2.96	.002610
el 304	1.0	2.50	.002145
el 331	2, 1.5	3.595	.0040821
		2.965	.0044573

(1) Equivalent floor element thickness and mass density ρ' to take into account the beam-slab system action.

Table 3A-25

MAXIMUM SPECTRAL ACCELERATIONS OF CONTAINMENT DUE TO
SRV AND LOCA LOADS AT 1% DAMPING

Type of Load	Direction	Elevation	Maximum Spectral Acceleration (g)	Structural Frequency (Hz)
SRV				
Axisymmetric	Vertical	312'-8"	1.09	14
	Horizontal	198'-9"	1.88	38
Asymmetric	Vertical	236'-2"	0.917	40
	Horizontal	207'-1"	1.15	25
CO	Vertical	236'-2"	3.2	40
	Horizontal	198"-9"	6.0	40
CO-ADS	Vertical	236'-2"	0.75	38
	Horizontal	205'-11"	1.16	42
Chugging	Vertical	236"-2"	1.76	40
	Horizontal	189'-5"	3.13	75

Table 3A-26

EXAMPLE COMPARISON OF SEISMIC FORCES ACTING ON FULLY LOADED AND EMPTY CABLE TRAYS

	Fully Loaded Tray (10% Damping)	Empty Tray (7% Damping)
Acceleration	a	4a
Weight	8w	w
Seismic Force (= Acceleration X Weight)	8aw	4aw

Table 3A-27

MAXIMUM CUMULATIVE USAGE FACTORS
FOR MSRV DISCHARGE LINES IN WETWELL AIR SPACE

Component	Calculated Cumulative Usage Factors	Code Cumulative Usage Factors
Flued head	0.401	1.0
Flush weld (weld between process pipe and flued head)	0.059	1.0
Short radius elbow	0.110	1.0
Long radius elbow	0.179	1.0
Tapered transition (thin end)	0.868	1.0
Tapered transition (thick end)	0.084	1.0
Tee	0.106	1.0
Flush weld for pipe anchor	0.870	1.0

Table 3A-28

SUMMARY OF BOP PIPING STRESSES

(UNIT 1)

Stress Ratio[1] = Maximum Stress / Allowable Stress

Maximum Calculated Stress (PSI)[3]

Piping System	I.C./[2] O.C	Reference Stress Calculation[4]
RWCU	I.C.	1-10-11B
	O.C.	P1-37-52
	O.C.	R1-37-53
RHR	I.C.	1-10-05
	O.C.	1-10-65B
	O.C.	P1-10-75
CS	I.C.	1-20-02
	O.C.	P1-20-54
	O.C.	P1-20-56
FPCC	I.C.	1-33-01
	I.C.	1-33-02
	O.C.	1-33-62
HPCI	I.C.	1-01-03
	O.C.	P1-10-72

Table 3A-28 (Cont'd)

SUMMARY OF BOP PIPING STRESSES
(UNIT 2)

Stress Ratio[1] = Maximum Stress / Allowable Stress

Maximum Calculated Stress (PSI)[3]

Piping System	I.C./[2] O.C	Reference Stress Calculation[4]
RWCU	I.C.	2-10-11
	O.C.	2-37-63
RHR	I.C.	2-10-05
	O.C.	2-10-84
	O.C.	2-10-83
CS	I.C.	2-20-02
	O.C.	2-20-64
	O.C.	2-20-63
FPCC	I.C.	2-33-02
	I.C.	2-33-01
	O.C	2-43-02
HPCI	I.C.	2-01-03
	O.C.	2-10-83

(1) Design Margin = 1 - Max. Stress / Allowable Stress

(2) I.C. = Inside Containment
O.C. = Outside Containment

(3) Calculated stresses are based on original analysis. Changes due to re-rate are small and stress ratios are less than 1.0. Changes due to "A" RWCU pump replacement result in stress ratios that are less than 1.0.

(4) Calculated stresses are maintained within the Reference Stress Calculation from the Table.

Table 3A-29

SYSTEM CHARACTERISTICS AND INPUT PARAMETERS

REACTOR

Initial core power (105% Rated)	3.26×10^6 Btu/sec
Initial RPV liquid mass	608,142 lb_m
Initial RPV steam mass	24,669 lb_m
RPV and internals mass	2.772×10^6 lb_m
Initial vessel pressure	1025 psia
Initial steam flow (105% Rated)	4129 lb_m/sec

REACTOR MAKEUP

Initial CRD flow	8.89 lb_m/sec
CRD flow after scram (P_{RPV} = 0 psig)	23.6 lb_m/sec
CRD enthalpy (from CST)	108 Btu/lb_m
Feedwater flow rate	as required to maintain RPV level

Feedwater mass/enthalpy

Mass (lb_m)	Enthalpy (Btu/lb_m)
165,385	402
256,919	342
370,885	235
359,442	156
235,746	126

HPCI "on" volume (RPV level 2)	12,675 ft^3
HPCI "off" volume (RPV level 8)	15,281 ft^3

VALVES

MSIV closure time	3.5 sec
SRV flow rate (122.5% ASME)	390 lb_m/sec at 1500 psia
SRV setpoints	See Table 3A-29A

NOTE: The information presented in this table is based on the original design bais conditons. Refer to Section 6.2.1.8 for the initial conditions and methodology used to analyze current plant conditions.

Table 3A-29 (Cont'd)

<u>RHR SYSTEM</u>	
RHR heat exchanger effectiveness, K (shutdown cooling)	288.9 Btu/sec °F
RHR heat exchanger effectiveness, K (pool cooling)	288.9 Btu/sec °F
RHR flow rate in pool cooling	1390 lb_m/sec
RHR flow rate in shutdown cooling	1390 lb_m/sec
RHR pump horsepower	1250 hp/pump
RHRSW temperature	88°F at time = 0 sec 91.2°F at time = 18,000 sec 92.5°F at time = 36,000 sec
RHRSW flow rate	9000 gpm
Maximum reactor pressure for switch-over from RHR pool cooling to shutdown cooling	89.7 psia
<u>WETWELL/SUPPRESSION POOL</u>	
Wetwell airspace pressure	15.45 psia
Initial suppression pool water mass (at low water level, without water mass inside pedestal)	$7.194 x 10^6$ lb_m
Initial suppression pool temperature	95°F
Suppression pool temperature Technical Specification limits for:	
a. Continuous operation without suppression pool cooling	95°F
b. Continuous testing at power	105°F
c. Power operation (Scram Technical Specification temperature	110°F
d. Hot standby (Depressurization Technical Specification temperature)	120°F
Quencher submergence (at low water level)	18.5 feet

NOTE: The information presented in this table is based on the original design bais conditons. Refer to Section 6.2.1.8 for the initial conditions and methodology used to analyze current plant conditions.

Table 3A-29A

SRV SETPOINTS USED FOR SUPPRESSION POOL TEMPERATURE RESPONSE ANALYSIS

SAFETY/RELIEF VALVES

Number 14

Spring Set Pressures, Mass Flow Rates:

Valve	Set Pressure (psig)	Mass Flow (lb_m/hr) at 103% of Spring Set Pressure
A	1150	917,00
B	1150	917,000
C	1150	917,000
D	1140	909,000
E*	1140	909,000
F	1150	917,000
G	1150	917,000
H*	1130	301,500
J	1130	901,500
K*	1140	909,000
L	1130	901,500
M*	1140	909,000
N	1130	901,500
S*	1140	909,000

* ADS Valves

NOTE: The information presented in this table is historical and is based on the original design bais conditons. Refer to Table 3A-3 for the current SRV setpoints.

Table 3A-30

PEAK SUPPRESSION POOL TEMPERATURES[1]

EVENT	TEMPERATURE
1. SORV at Power	
Case 1.a	169°F
Case 1.b	187°F
2. Isolation/Scram	
Case 2.a	201°F
Case 2.b	183°F
3. SBA	
Case 3.a	202°F[2]
Case 3.b	182°F

(1) The information presented in this table for the suppression pool temperature response is based on the original design basis conditions. The current suppression pool temperature results are discussed in Section 3A.15.2. The results shown in this table reasonably represent the general characteristics and relative differences between the cases.

(2) The limiting case (Case 3.a) was reanalyzed for the current plant conditions and the resulting peak suppression pool temperature was 203°F.

Table 3A-31

MATERIAL PROPERTIES FOR ANALYTICAL ELEMENTS
OF THE AXISYMMETRIC SRV ANALYSIS MODEL

Element Material Type	Young's Modulus, E kip/ft^2	Material Density, ρ kip-s^2/ft^4	Poisson's Ratio	Shear Wave, V_s (ft/s)
Concrete	0.0936E+6*	0.00446	0.22	-
Steel	0.4176E+7	0.01524	0.33	-
Soil Medium	0.432E+6	0.00481	0.30	5950**

*The modulus represents a dynamic modulus of elasticity.
**The shear-wave velocity, V_s, is used to simulate a soil shear modulus ($G = V_s^2\rho$), equal to 0.166×10^6 kip/ft^2.