August 28, 1992

Mr. Giuliano DeGrassi
Building 475C
Brookhaven National Laboratory
Upton, NY 11973

Dear Giuliano:

Enclosed are the ABWR SSAR markups corresponding to the majority of the Piping Design Audit open items. The markups for the outstanding open items will be provided on the following schedule:

Open Item	Date
A-10	9/4/92
A-12	9/15/92
A-17	9/4/92
A-18	10/31/92
A-25	9/15/92
A-28	9/4/92

Sincerely,

J. N. Fox

Jack N. Fox
Advanced Reactor Programs

cc: Chet Poslusny/Shou Hou

see attached distribution ZZZZ 1/1
per: C Poslusny

ABWR SSAR

AUDIT OPEN ITEMS

OPEN ITEM NO.	BRIEF DESCRIPTION OF OPEN ITEM	R.E.	Completion Date	Done
A-3	SRVDL Piping ASME Classification wetwell: Class 2 or 3 (H) weld RT	EOS	8-21-92	✓
A-4	Include in SSAR, description of Quencher fatigue analysis	HLH/EOS	8-21-92	✓
A-5	Table 5.2-4 of SSAR: Specify matl for FW & MS lines up to turb/condenser	MH	8-21-92	✓
A-6	Pipe Support Stiffness: specify min. value & Service level for 1/16" defl. limit	MH	8-21-92	✓
	Frame Supports & Supplementary Steel: Design & Analyze per NF	MH	8-21-92	✓
	Coefficient of Friction: specify in SSAR	EOS/MH	8-21-92	✓
	FS for "Drillco Bolts": spec. in SSAR	MH	8-21-92	✓
	Small Bore Pipe Supp.: Per NF	MH	8-21-92	✓
	Min. gaps @ Supports for Thermal Δr @ hot cond: spec in SSAR	MH	8-21-92	✓
	Pipe Defl. checks to preclude Support failure: spec. in SSAR	EOS/MH	8-21-92	✓

ABWR SSAR Audit Open Items

OPEN ITEM NO.	BRIEF DESCRIPTION OF OPEN ITEM	R.E.	Completion Date	
A-8	Decoupling Criteria: include mass & span length criteria	EOS/MH	8-21-92	✓
A-9	Piping Analysis COF: dependent on f_n	MH	"	✓
↓	TH Direct Integration Analysis damping, Δt, broadening	MH	"	✓
↓	ISM method descrip. in SSAR	MH	"	✓
A-10	SRVDL TH analysis of wetwell loads	HLH		
A-12	SRSS Comb. of "I" & "D" loads provide justification writeup	DKH		
A-13	R/S Amplification @ decoupled pipe connections	EOS/MH	8-21-92	✓
A-17	Thermal Stratification In SSAR, include criteria on when strat. analysis is req'd.	EOS		
A-18	Environmental Fatigue analysis of piping, include descrip. in SSAR	SR		

ABWR SSAR Audit Open Items

OPEN ITEM NO.	BRIEF DESCRIPTION OF OPEN ITEM	R.E.	Completion Date	
A-20	Table 3.9.1 of SSAR: include # of events & cycles for RV1, TSV, RV2$_1$, RV2$_{ALL}$ etc.	MH	8-21-92	✓
	Funct. Capab. Criteria include in SSAR	"	"	✓
A-25	Accel used in HF modes calcs	DKH		
A-26	Below grade & exterior piping State in SSAR that these are enclosed by tunnels or struct	MH	8-21-92	✓
"	Ref. RIs to be used in analysis			
New Item	Separation of Cat. I & II piping Revise SSAR 3.7.3.13(2)	MH	8-21-92	✓
A-28	Thermal Stratif. monitoring Prog Specify in SSAR	ECS		

TABLE 3.2-1

CLASSIFICATION SUMMARY (Continued)

Principal Component[a]	Safety Class[b]	Location[c]	Quality Group Classification[d]	Quality Assurance Requirement[e]	Seismic Category[f]	Notes
2. Vessel - air accumulators (for ADS and SRVs)	3	C	C	B	I	
3. Piping including supports - safety/relief valve discharge and quencher	~~2/3~~ 3	C	~~B/C~~ C	B	I	(h) 210.30

NOTES (Continued)

4. All other instrument lines:

   i Through the root valve the lines shall be of the same classification as the system to which they are attached.

   ii Beyond the root valve, if used to actuate a safety system, the lines shall be of the same classification as the system to which they are attached.

   iii Beyond the root valve, if not used to actuate a safety system, the lines may be Code Group D.

5. All sample lines from the outer isolation valve or the process root valve through the remainder of the sampling system may be Code Group D.

6. All safety-relaed instrument sensing lines shall be in conformance with the criteria of Regulatory Guide 1.151.

h. *Safety/Relief valve discharge line (SRVDL) piping and quenchers shall be Quality Group C and Seismic Category I. In addition, all welds in the SRVDL piping in the wetwell above the surface of the suppression pool shall be non-destructively examined to the requirements of ASME Boiler and Pressure Vessel Code, Section III, Class 2.*

SRVDL piping from the safety/relief valve to the quenchers in the suppression pool consists of two parts: the first part is located in the drywell and is attached at one end to the safety/relief valve and attached at its other end to the diaphragm floor penetration. This first part of the SRVDL is analyzed with the main steam piping as a complete system. The second part of the SRVDL is in the wetwell and extends from the penetration to the quenchers in the suppression pool. Because of the penetration on this part of the line, it is physically decoupled from the main steam piping and the first part of the SRVDL piping and is therefore analyzed as a separate piping system.

i. Electrical devices include components such as switches, controllers, solenoids, fuses, junction boxes, and transducers which are discrete components of a larger subassembly/module. Nuclear safety-related devices are Seismic Category I. Fail-safe devices are non-Seismic Category I.

j. The control rod drive insert lines from the drive flange up to and including the first valve on the hydraulic control unit are Safety Class 2, and non-safety related beyond the first valve.

k. The hydraulic control unit (HCU) is a factory-assembled engineered module of valves, tubing, piping, and stored water which controls two control rod drives by the application of pressures and flows to accomplish rapid insertion for reactor scram.

Although the hydraulic control unit, as a unit, is field installed and connected to process piping, many of its internal parts differ markedly from process piping components because of the more complex functions they must provide. Thus, although the codes and standards invoked by Groups A, B, C, and D pressure integrity quality levels clearly apply at all levels to the interfaces between the HCU and the connection to conventional piping components (e.g., pipe nipples, fittings, simple hand valves etc.), it is considered that they do not apply to the specialty parts (e.g., solenoid valves, pneumatic components, and instruments).

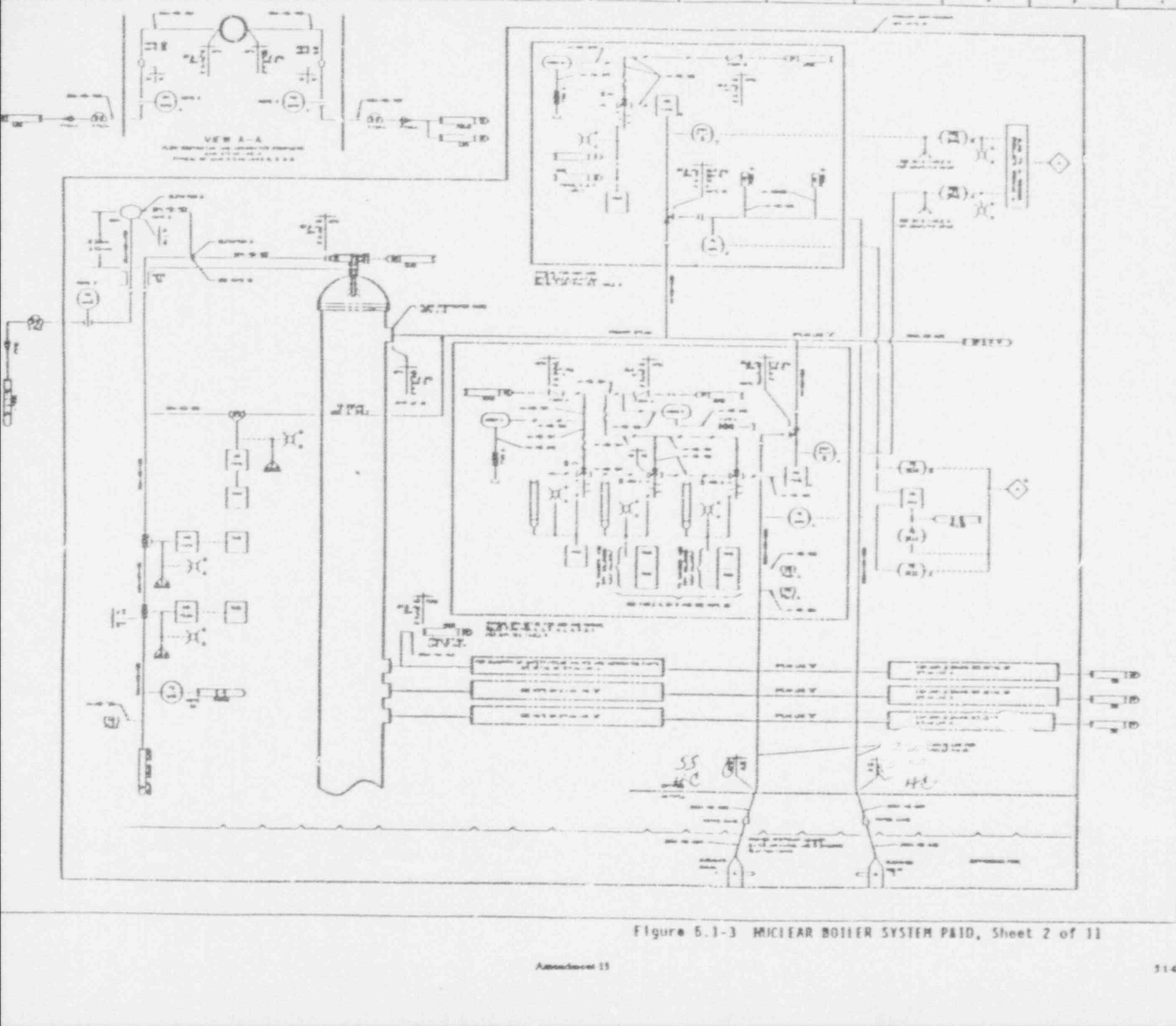


Figure 5.1-3 NUCLEAR BOILER SYSTEM P&ID, Sheet 2 of 11

SECTION 3.6

CONTENTS

SECTION 3.6

CONTENTS (Continued)

SECTION 3.6

CONTENTS (Continued)

SECTION 3.6

TABLES

ILLUSTRATIONS

3.6 PROTECTION AGAINST DYNAMIC EFFECTS ASSOCIATED WITH THE POSTULATED RUPTURE OF PIPING

This Section deals with the structures, systems, components and equipment in the ABWR Standard Plant.

Subsections 3.6.1 and 3.6.2 describe the design bases and protective measures which ensure that the containment; essential systems, components and equipment; and other essential structures are adequately protected from the consequences associated with a postulated rupture of high-energy piping or crack of moderate-energy piping both inside and outside the containment.

Before delineating the criteria and assumptions used to evaluate the consequences of piping failures inside and outside of containment, it is necessary to define a pipe break event and a postulated piping failure:

Pipe break event: Any single postulated piping failure occurring during normal plant operation and any subsequent piping failure and/or equipment failure that occurs as a direct consequence of the postulated piping failure.

Postulated Piping Failure: Longitudinal or circumferential break or rupture postulated in high-energy fluid system piping or throughwall leakage crack postulated in moderate-energy fluid system piping. The terms used in this definition are explained in Subsection 3.6.2.

Structures, systems, components and equipment that are required to shut down the reactor and mitigate the consequences of a postulated piping failure, without offsite power, are defined as essential and are designed to Seismic Category I requirements.

The dynamic effects that may result from a postulated rupture of high-energy piping include missile generation; pipe whipping; pipe break reaction forces; jet impingement forces; compartment, subcompartment and cavity pressurizations; decompression waves within the ruptured pipes and seven types of loads identified with loss of coolant accident (LOCA) on Table 3.9-2.

Subsection 3.6.3 and Appendix 3E describe the implementation of the leak-before-break (LBB) evaluation procedures as permitted by the broad scope amendment to General Electric Criterion 4 (GDC-4) published in Reference 1. It is anticipated, as mentioned in Subsection 3.6.4.2, that a COL applicant will apply to the NRC for approval of LBB qualification of selected piping by submitting a technical justification report. The approved piping, referred to in this SSAR as the LBB piping, will be excluded from pipe breaks, which are required to be postulated by Subsection 3.6.1 and 3.6.2, for design against their potential dynamic effects. However, such piping are included in postulation of pipe cracks for their effects as described in Subsections 3.6.1.3.1, 3.6.1.2.1.5 and 3.6.2.1.6.2. It is emphasized that an LBB qualification submittal is not a mandatory requirement; a COL applicant has an option to select from none to all technically feasible piping systems for the benefits of the LBB approach. The decision may be made based upon a cost-benefit evaluation (Reference 6).

3.6.1 Postulated Piping Failures In Fluid Systems Inside and Outside of Containment

This subsection sets forth the design bases, description, and safety evaluation for determining the effects of postulated piping failures in fluid systems both inside and outside the containment, and for including necessary protective measures.

3.6.1.1 Design Bases

3.6.1.1.1 Criteria

Pipe break event protection conforms to 10CFR50 Appendix A, General Design Criterion 4 *Environmental and Missile Design Bases*. The design bases for this protection is in compliance with NRC Branch Technical Positions (BTP) ASB 3-1 and MEB 3-1 included in Subsections 3.6.1 and 3.6.2, respectively, of NUREG-0800 (Standard Review Plan).

MEB 3-1 describes an acceptable basis for selecting the design locations and orientations of postulated breaks and cracks in fluid systems piping. Standard Review Plan Sections 3.6.1 and 3.6.2 describe acceptable measures that could be taken for protection against the breaks and cracks and for restraint against pipe whip that may result from breaks.

The design of the containment structure, component arrangement, pipe runs, pipe whip restraints and compartmentalization are done in

consonance with the acknowledgment of protection against dynamic effects associated with a pipe break event. Analytically sized and positioned pipe whip restraints are engineered to preclude damage based on the pipe break evaluation.

3.6.1.1.2 Objectives

Protection against pipe break event dynamic effects is provided to fulfill the following objectives:

(1) Assure that the reactor can be shut down safely and maintained in a safe cold shutdown condition and that the consequences of the postulated piping failure are mitigated to acceptable limits without offsite power.

(2) Assure that containment integrity is maintained.

(3) Assure that the radiological doses of a postulated piping failure remain below the limits of 10CFR100.

3.6.1.1.3 Assumptions

The following assumptions are used to determine the protection requirements.

(1) Pipe break events may occur during normal plant conditions (i.e., reactor startup, operation at power, normal hot standby* or reactor cooldown to a cold shutdown conditions but excluding test modes).

210.23

(2) A pipe break event may occur simultaneously with a seismic event, however, a seismic event does not initiate a pipe break event. This applies to Seismic Category I and non-Seismic Category I piping. Insert B

(3) A single active component failure (SACF) is assumed in systems used to mitigate consequences of the postulated piping failure and to shut down the reactor, except as noted in item (4) below. A SACF is malfunction or loss of function of a component of electrical or fluid systems. The failure of an active component of a fluid system is considered to be a loss of component function as a result of mechanical, hydraulic, or electrical malfunction but not the loss of component structural integrity. The direct consequences of a SACF are considered to be a part of the single active failure. The single active component failure is assumed to occur in addition to the postulated piping failure and any direct consequences of the piping failure.

(4) Where the postulated piping failure is assumed to occur in one of two or more redundant trains of a dual-purpose moderate-energy essential system (i.e., one required to operate during normal plant conditions as well as to shut down the reactor and mitigate the consequences of the piping failure), single active failure of components in the other train or trains of that system only are not assumed, provided the system is designed to Seismic Category I standards, is powered from both offsite and onsite sources, and is constructed, operated, and inspected to quality assurance, testing and inservice inspection standards appropriate for nuclear safety-related systems. Residual heat removal system is an example of such a system.

(5) If a pipe break event involves a failure of non-Seismic Category I piping, the pipe break event must not result in failure of essential systems, components and equipment to shut down the reactor and mitigate the consequences of the pipe break event considering a SACF in accordance with items (3) and (4) above.

(6) If loss of offsite power is a direct consequence of the pipe break event (e.g., trip of the turbine-generator producing a power

* *Normal hot standby is a normally attained zero power plant operating state (as opposed to a hot standby initiated by a plant upset condition) where both feedwater and main condenser are available and in use.*

For BWRs, the reactor coolant system extends to and includes the outermost primary containment isolation valve in the main steam and feedwater piping.

required systems and components.[3] Systems and components (structures, equipment, component of a system or total system) required for safe shutdown following an associated postulated pipe rupture.

safe shutdown. The shutdown with (1) the reactivity of the reactor is kept to a margin below criticality consistent with technical specifications, (2) the core decay heat is being removed at a controlled rate sufficient to prevent core and reactor coolant system thermal design limits from being exceeded, (3) components and systems necessary to maintain these conditions operating within their design limits, and (4) components and systems necessary to keep doses within prescribed limits operating properly.

safe shutdown earthquake (SSE). That earthquake which is based upon evaluation of the maximum earthquake potential considering regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to perform their nuclear safety function.

page 3.6-2 Insert B

seismic category I. The category of nuclear safety-related structures, systems and components that are required to perform their nuclear safety function during or after an SSE as necessary to accommodate any event involving an SSE.

seismically analyzed ANSI B31.1 piping. ASME Code for Pressure Piping, B31, "Power Piping," ANSI/ASME B31.1-1986 [4], piping which is not required to be Seismic Category I but is designed to accommodate seismic loadings.

shall, should, or may. The word "shall" is used to denote a requirement; the word "should" is used to denote a recommendation; and the word "may" is used to denote permission, neither a requirement nor a recommendation.

terminal end. That section of piping originating at a structure or component (such as a vessel or component nozzle or structural piping anchor) that acts as an essentially rigid constraint to the piping thermal expansion. Typically, an anchor assumed for the piping code stress analysis would be a terminal end. The branch connection to the main run is one of the terminal ends of a branch run, except for the special case where the branch pipe is classified as part of a main run (see definition for branch run). In-line fittings, such as valves, not assumed to be anchored in the piping code stress analysis, are not terminal ends.

4. Postulated Rupture Locations and Configurations

4.1 General Requirements. Postulated pipe ruptures shall be considered in all plant piping systems and the associated potential for damage to required systems and components evaluated on the basis of the energy in the system. System piping shall be classified as high energy or moderate energy, and postulated ruptures shall be classified as circumferential breaks, longitudinal breaks, leakage cracks, or through-wall cracks. Each postulated rupture shall be considered separately as a single postulated initiating event.

For each postulated circumferential and longitudinal break, an evaluation shall be made of the effects of pipe whip, jet impingement, compartment pressurization, environmental conditions, and flooding, in accordance with Sections 6 through 10, respectively. Also, if required to demonstrate safe plant shutdown, an internal fluid system load evaluation shall be performed of the effects of fluid forces on components within or bounding the fluid system. However, only general guidance for this evaluation, for components other than piping, is provided in this standard. If a postulated break results in missile generation, an additional evaluation shall be performed of the effect of the missile; however, specific guidance for the evaluation is not provided in this standard. For each postulated leakage crack, an evaluation shall be made of the effects of compartment pressurization, en-

[3] This definition is equivalent to the definition of "Essential Systems and Components" in NUREG-0800, "Standard Review Plan," Sections 3.6.1 and 3.6.2. "Required" is used in place of "essential" because the word "essential" may have similar but different meanings outside the context of postulated pipe rupture design.

surge which in turn trips the main breaker), then a loss of offsite power occurs in a mechanistic time sequence with a SACF. Otherwise, offsite power is assumed available with a SACF.

Replace with Insert c

(7) A whipping pipe is not capable of rupturing impacted pipes of equal or greater nominal pipe diameter, but may develop throughwall cracks in equal or larger nominal pipe sizes with thinner wall thickness.

(8) All available systems, including those actuated by operator actions, are available to mitigate the consequences of a postulated piping failure. In judging the availability of systems, account is taken of the postulated failure and its direct consequences such as unit trip and loss of offsite power, and of the assumed SACF and its direct consequences. The feasibility of carrying out operator actions are judged on the basis of ample time and adequate access to equipment being available for the proposed actions.

Although a pipe break event outside the containment may require a cold shutdown, up to eight hours in hot standby is allowed in order for plant personnel to assess the situation and make repairs.

(10) Pipe whip occurs in the plane ~~defined~~ determined by the piping geometry and causes movement in the direction of the jet reaction. If unrestrained, a whipping pipe with a constant energy source forms a plastic hinge and rotates about the nearest rigid restraint, anchor, or wall penetration. If unrestrained, a whipping pipe without a constant energy source (i.e., a break at a closed valve with only one side subject to pressure) is not capable of forming a plastic hinge and rotating provided its movement can be defined and evaluated.

using fluid dynamic forces responding inside the pipe

(11) The fluid internal energy associated with the pipe break reaction can take into account any line restrictions (e.g., flow limiter) between the pressure source and break location and absence of energy reservoirs, as applicable.

3.6.1.1.4 Approach

To comply with the objectives previously described, the essential systems, components, and equipment are identified. The essential systems, components, and equipment, or portions thereof, are identified in Table 3.6-1 for piping failures postulated inside the containment and in Table 3.6-2 for outside the containment.

3.6.1.2 Description

The lines identified as high-energy per Subsection 3.6.2.1.1 are listed in Table 3.6-3 for inside the containment and in Table 3.6-4 for outside the containment. Moderate-energy piping defined in Subsection 3.6.2.1.2 is listed in Table 3.6-~~5~~6 for outside the containment. Pressure response analyses are performed for the subcompartments containing high-energy piping. A detailed discussion of the line breaks selected, vent paths, room volumes, analytical methods, pressure results, etc., is provided in Section 6.2 for primary containment subcompartments.

The effects of pipe whip, jet impingement, spraying, and flooding on required function of essential systems, components, and equipment, or portions thereof, inside and outside the containment are considered.

In particular, there are no high-energy lines near the control room. As such, there are no effects upon the habitability of the control room by a piping failure in the control building or elsewhere either from pipe whip, jet impingement, or transport of steam. Further discussion on control room habitability systems is provided in Section 6.4.

3.6.1.3 Safety Evaluation

3.6.1.3.1 General

An analysis of pipe break events is performed to identify those essential systems, components, and equipment that provide protective actions required to mitigate, to acceptable limits, the consequences of the pipe break event.

Pipe break events involving high-energy fluid

, with rapid motion of a pipe resulting from a postulated pipe break,

Insert C page 3.6-3

Pipe whip shall be considered capable of causing circumferential and longitudinal breaks, individually, in impacted pipes of smaller nominal pipe size, irrespective of pipe wall thickness, and developing through-wall cracks in equal or larger nominal pipe sizes with equal or thinner wall thickness. Analytical or experimental data, or both, for the expected range of impact energies may be used to demonstrate the capability to withstand the impact without rupture; however, loss of function due to reduced flow in the impacted pipe should be considered.

systems are evaluated for the effects of pipe whip, jet impingement, flooding, room pressurization, and other environmental effects such as temperature. Pipe break events involving moderate-energy fluid systems are evaluated for wetting from spray, flooding, and other environmental effects.

By means of the design features such as separation, barriers, and pipe whip restraints, a discussion of which follows, adequate protection is provided against the effects of pipe break events for essential items to an extent that their ability to shut down the plant safely or mitigate the consequences of the postulated pipe failure would not be impaired.

3.6.1.3.2 Protection Methods

3.6.1.3.2.1 General

The direct effects associated with a particular postulated break or crack must be mechanistically consistent with the failure. Thus, actual pipe dimensions, piping layouts, material properties, and equipment arrangements are considered in defining the following specific measure for protection against actual pipe movement and other associated consequences of postulated failures.

(1) Protection against the dynamic effects of pipe failures is provided in the form of pipe whip restraints, equipment shields, and physical separation of piping, equipment, and instrumentation.

(2) The precise method chosen depends largely upon limitations placed on the designer such as accessibility, maintenance, and proximity to other pipes.

3.6.1.3.2.2 Separation

The plant arrangement provides physical separation to the extent practicable to maintain the independence of redundant essential systems (including their auxiliaries) in order to prevent the loss of safety function due to any single postulated event. Redundant trains (e.g., A and B trains) and divisions are located in separate compartments to the extent possible. Physical separation between redundant essential systems with their related auxiliary supporting features, therefore, is the basic protective measure incorporated in the design to protect against the dynamic effects of postulated pipe failures.

Due to the complexities of several divisions being adjacent to high-energy lines in the drywell and reactor building steam tunnel, specific break locations are determined in accordance with Subsection 3.6.2.1.4.3 for possible spatial separation. Care is taken to avoid concentrating essential equipment in the break exclusion zone allowed per Subsection 3.6.2.1.4.2. If spatial separation requirements (distance and/or arrangement to prevent damage) cannot be met based on the postulation of specific breaks, barriers, enclosures, shields, or restraints are provided. These methods of protection are discussed on Subsections 3.6.1.3.2.3 and 3.6.1.3.2.4.

For other areas where physical separation is not practical, the following high energy line-separation analysis (HELSA) evaluation is done to determine which high- energy lines meet the spatial separation requirement and which lines require further protection:

(1) For the HELSA evaluation, no particular break points are identified. Cubicles or areas through which the high-energy lines pass are examined in total. Breaks are postulated at any point in the piping system.

(2) Essential systems, components, and equipment at a distance greater than thirty feet from any high energy piping are considered as meeting spatial separation requirements. No damage is assumed to occur due to jet impingement since the impingement force becomes negligible beyond 30 feet. Likewise, a 30 ft evaluation zone is established for pipe breaks to assure protection against potential damage from a whipping pipe. Assurance that 30 feet represents the maximum free length is made in the piping layout.

(3) Essential systems, components, and equipment at a distance less than 30 feet from any high-energy piping are evaluated to see if damage could occur to more than one essential division, preventing safe shutdown of the plant. If damage occurred to only one division of a redundant system, the

requirement for redundant separation is met. Other redundant divisions are available for safe shutdown of the plant and no further evaluation is performed.

(4) If damage could occur to more than one division of a redundant essential system within 30 ft of any high energy piping, other protection in the form of barriers, shields, or enclosures is used. These methods of protection are discussed in Subsection 3.6.1.3.2.3. Pipe whip restraints as discussed in Subsection 3.6.1.3.2.4 are used if protection from whipping pipe is not possible by barriers and shields.

3.6.1.3.2.3 Barriers, Shields, and Enclosures

Protection requirements are met through the protection afforded by the walls, floors, columns, abutments, and foundations in many cases. Where adequate protection is not already present due to spatial separation or existing plant features, additional barriers, deflectors, or shields are identified as necessary to meet the functional protection requirements.

Barriers or shields that are identified as necessity by the use of specific break locations in the drywell are designed for the specific loads associated with the particular break location.

The steam tunnel is made of reinforced concrete 2m thick. A steam tunnel subcompartment analysis was performed for the postulated rupture of a mainsteam line and for a feedwater line (see Subsection 6.2.3.3.1). The peak pressure from a mainsteam line break was found to be 11 psig. The peak pressure from a feedwater line break was found to be 3.9 psig. The steam tunnel is designed for the effects of an SSE coincident with high energy line break inside the steam tunnel. Under this conservative load combination, no failure in any portion of the steam tunnel was found to occur; therefore, a high energy line break inside the steam tunnel will not effect control room habitability.

The MSIVs and the feedwater isolation and check valves located inside the tunnel shall be designed for the effects of a line break. The details of how the MSIV and feedwater isolation and check valves functional capabilities are protected against the effects of these postulated pipe failures will be provided by the applicant referencing the ABWR design (see Subsection 3.6.4.1, item 4 and 6).

Barriers or shields that are identified as necessary by the HELSA evaluation (i.e., based on no specific break locations), are designed for worst-case loads. The closest high-energy pipe location and resultant loads are used to size the barriers.

3.6.1.3.2.4 Pipe Whip Restraints

Pipe whip restraints are used where pipe break protection requirements could not be satisfied using spatial separation, barriers, shields, or enclosures alone. Restraints are located based on the specific break locations determined in accordance with Subsections 3.6.2.1.4.3 and 3.6.2.1.4.4. After the restraints are located, the piping and essential systems are evaluated for jet impingement and pipe whip. For those cases where jet impingement damage could still occur, barriers, shields, or enclosures are utilized.

The design criteria for restraints is given in Subsection 3.6.2.3.3.

3.6.1.3.3 Specific Protection Measures

(1) Nonessential systems and system components are not required for the safe shutdown of the reactor, nor are they required for the limitation of the offsite release in the event of a pipe rupture. However, while none of this equipment is needed during or following a pipe break event, pipe whip protection is considered where a resulting failure of a nonessential system or component could initiate or escalate the pipe break event in an essential system or component, or in another nonessential system whose failure could affect an essential system.

(2) For high energy piping systems penetrating through the containment, isolation valves are located as close to the containment as possible.

(3) The pressure, water level, and flow sensor instrumentation for those essential systems,

which are required to function following a pipe rupture, are protected.

(4) High-energy fluid system pipe whip restraints and protective measures are designed so that a postulated break in one pipe could not, in turn, lead to a rupture of other nearby pipes or components if the secondary rupture could result in consequences that would be considered unacceptable for the initial postulated break.

(5) For any postulated pipe rupture, the structural integrity of the containment structure is maintained. In addition, for those postulated ruptures classified as a loss of reactor coolant, the design leak tightness of the containment fission product barrier is maintained.

(6) Safety/relief valves (SRV) and the reactor core isolation cooling (RCIC) system steamline are located and restrained so that a pipe failure would not prevent depressurization.

(7) Separation is provided to preserve the independence of the low-pressure flooder (LPFL) systems.

(8) Protection for the FMCRD scram insert lines is not required since the motor operation of the FMCRD can adequately insert the control rods even with a complete loss of insert lines (See Subsection 3.6.2.1.6.1).

(9) The escape of steam, water, combustible or corrosive fluids, gases, and heat in the event of a pipe rupture do not preclude:

(a) Accessibility to any areas required to cope with the postulated pipe rupture;

(b) Habitability of the control room; or

(c) The ability of essential instrumentation, electric power supplies, components, and controls to perform their safety-related function.

Insert D

3.6.2 Determination of Break Locations and Dynamic Effects Associated with the Postulated Rupture of Piping

Information concerning break and crack location criteria and methods of analysis for dynamic effects is presented in this Subsection. The location criteria and methods of analysis are needed to evaluate the dynamic effects associated with postulated breaks and cracks in high- and moderate-energy fluid system piping inside and outside of primary containment. This information provides the basis for the requirements for the protection of essential structures, systems, and components defined in introduction of Section 3.6.

3.6.2.1 Criteria Used to Define Break and Crack Location and Configuration

The following subsections establish the criteria for the location and configuration of postulated breaks and cracks.

3.6.2.1.1 Definition of High-Energy Fluid Systems

High-energy fluid systems are defined to be those systems or portions of systems that, during normal plant conditions (as defined in Subsection 3.6.1.1.3(1)),are either in operation or are maintained pressurized under conditions where either or both of the following are met:

(1) maximum operating temperature exceeds 200°F, or

(2) maximum operating pressure exceeds 275 psig.

3.6.2.1.2 Definition of Moderate-Energy Fluid Systems.

Moderate-energy fluid systems are defined to be those systems or portions of systems that, during normal plant conditions (as defined in Subsection 3.6.1.1.3.(1)), are either in operation or are maintained pressurized (above atmospheric pressure) under conditions where both of the following are met:

(1) maximum operating temperature is 200°F or less, and

(2) maximum operating pressure is 275 psig or less.

Piping systems are classified as moderate-energy systems when they operate as high-energy piping for only short operational periods in performing their system function but, for the major operational period, qualify as moderate-energy fluid systems. An operational period is considered short if the total fraction of time that the system operates within the pressure-temperature conditions specified for high-energy fluid systems is less than two percent of the total time that the system operates as a moderate-energy fluid system.

3.6.2.1.3 Postulated Pipe Breaks and Cracks

A postulated pipe break is defined as a sudden gross failure of the pressure boundary either in the form of a complete circumferential severance (guillotine break) or a sudden longitudinal split without pipe severance, and is postulated for high-energy fluid systems only. For moderate-energy fluid system, pipe failures are limited to postulation of cracks in piping and branch runs. These cracks affect the surrounding environmental conditions only and do

{Insert D)

3.6.1.4

~~add title except capital~~

9) BREAK LOCATION AND PIPE WHIP RESTRAINT

The procedure of determinating a break location and sizing a pipe whip restraint is as follows:

(1) Use break criteria in SRP 3.6.2 June 1987, Rev. 2 to find the break location.

(2) Use ANS 58.2-1[illegible] [illegible]ndix B and break type (longitudinal or circumferential [illegible] [illegible]r limited separation) to get the thrust load of the broken pipe.

(3) Use GE pipe whip restraint (PWR) data (REDEP file) to select applicable rod size, quantity, bend, straight length, force and deflection, clearance, elastic and plastic displacements. Use other PWR design and characterics as required for the calculation.

(4) Use pipe stress/strain curve, pipe mechanical properties and pipe dimensions for piping model.

(5) Use PDA computation program and a joystick model to confirm the adequate selection of PWR in capacity, dispacement, time at peak load and lapsed time toward static state.

(6) Perform one dimensional wave propagation calculation to find the time history thrust load of each pipe segment (limited to 5 segments in one model) beyond the first one.

(7) Model a piping, apply thrust and retrain the pipe movement by using PWR as selected in step 3.

(8) Use ANSYS or equivalent program with input preparation (step 7).

(9) Check displacements at broken end and PWR; stresses in holy pipe against ASME Code, Section III, Equation 9 (NB3650) with 2.25 Sm limitaiton.

(10) Check operability of MSIV using limitation of bonnet flange bolt load and limits of acceleration.

not result in whipping of the cracked pipe. High-energy fluid systems are also postulated to have cracks for conservative environmental conditions in a confined area where high- and moderate-energy fluid systems are located.

The following high-energy piping systems (or portions of systems) are considered as potential candidates for a postulated pipe break during normal plant conditions and are analyzed for potential damage resulting from dynamic effects:

(1) All piping which is part of the reactor coolant pressure boundary and subject to reactor pressure continuously during station operation;

(2) All piping which is beyond the second isolation valve but subject to reactor pressure continuously during station operation; and

(3) All other piping systems or portions of piping systems considered high-energy systems.

Portions of piping systems that are isolated from the source of the high-energy fluid during normal plant conditions are exempted from consideration of postulated pipe breaks. This includes portions of piping systems beyond a normally closed valve. Pump and valve bodies are also exempted from consideration of pipe break because of their greater wall thickness.

3.6.2.1.4 Locations of Postulated Pipe Breaks

Postulated pipe break locations are selected as follows:

3.6.2.1.4.1 Piping Meeting Separation Requirements

Based on the HELSA evaluation described in Subsection 3.6.1.3.2.2, the high-energy lines which meet the spatial separation requirements are generally not identified with particular break points. Breaks are postulated at all possible points in such high-energy piping systems. However, in some systems break points are particularly specified per the following subsections if special protection devices such as barriers or restraints are provided.

3.6.2.1.4.2 Piping in Containment Penetration Areas

No pipe breaks or cracks are postulated in those portions of piping from containment wall to and including the inboard or outboard isolation valves which meet the following requirement in addition to the requirement of the ASME Code, Section III, Subarticle NE-1120:

(1) The following design stress and fatigue limits are not exceeded:

For ASME Code, Section III, Class 1 Piping

(a) The maximum stress range between any two loads sets (including the zero load set) does not exceed 2.4 S_m, and is calculated* by Eq. (10) in NB-3653, ASME Code, Section III.

If the calculated maximum stress range of Eq. (10) exceeds 2.4 S_m, the stress ranges calculated by both Eq. (12) and Eq. (13) in Paragraph NB-3653 meet the limit of 2.4 S_m.

(b) The cumulative usage factor is less than 0.1

(c) The maximum stress, as calculated by Eq. (9) in NB-3652 under the loadings resulting from a postulated piping failure beyond these portions of piping does not exceed the lesser of 2.25 S_m and 1.8 S_y except that following a failure outside containment, the pipe between the outboard isolation valve and

* *For those loads and conditions in which Level A and Level B stress limits have been specified in the Design Specification.*

the first restraint may be permitted higher stresses provided a plastic hinge is not formed and operability of the valves with such stresses is assured in accordance with the requirement specified in Section 3.9.3. Primary loads include those which are deflection limited by whip restraints.

For ASME Code, Section III, Class 2 Piping

(d) The maximum stress as calculated by the sum of Eqs. (9) and (10) in Paragraph NC-3652, ASME Code, Section III, considering those loads and conditions thereof for which level A and level B stress limits are specified in the system's Design Specification (i.e., sustained loads, occasional loads, and thermal expansion) including an OBE event does not exceed $0.8(1.8\ S_h + S_A)$. The S_h and S_A are allowable stresses at maximum (hot) temperature and allowable stress range for thermal expansion, respectively, as defined in Article NC-3600 of the ASME Code, Section III.

(e) The maximum stress, as calculated by Eq. (9) in NC-3653 under the loadings resulting from a postulated piping failure of fluid system piping beyond these portions of piping does not exceed the lesser of $2.25\ S_h$ and $1.8\ S_y$.

Primary loads include those which are deflection limited by whip restraints. The exceptions permitted in (c) above may also be applied provided that when the piping between the outboard isolation valve and the restraint is constructed in accordance with the Power Piping Code ANSI B31.1, the piping is either of seamless construction with full radiography of all circumferential welds, or all longitudinal and circumferential welds are fully radiographed.

(2) Welded attachments, for pipe supports or other purposes, to these portions of piping are avoided except where detailed stress analyses, or tests, are performed to demonstrate compliance with the limits of item (1).

(3) The number of circumferential and longitudinal piping welds and branch connections are minimized. Where penetration sleeves are used, the enclosed portion of fluid system piping is seamless construction and without circumferential welds unless specific access provisions are made to permit inservice volumetric examination of longitudinal and circumferential welds.

(4) The length of these portions of piping are reduced to the minimum length practical.

(5) The design of pipe anchors or restraints (e.g., connections to containment penetrations and pipe whip restraints) do not require welding directly to the outer surface of the piping (e.g., flued integrally forged pipe fittings may be used) except where such welds are 100 percent volumetrically examinable in service and a detailed stress analysis is performed to demonstrate compliance with the limits of item (1).

(6) Sleeves provided for those portions of piping in the containment penetration areas are constructed in accordance with the rules of Class MC, Subsection NE of the ASME Code, Section III, where the sleeve is part of the containment boundary. In addition, the entire sleeve assembly is designed to meet the following requirements and tests:

(a) The design pressure and temperature are not less than the maximum operating pressure and temperature of the enclosed pipe under normal plant conditions.

(b) The Level C stress limits in NE-3220, ASME Code, Section III, are not exceeded under the loadings associated with containment design pressure and temperature in combination with the safe shutdown earthquake.

(c) The assemblies are subjected to a single pressure test at a pressure not less than its design pressure.

(d) The assemblies do not prevent the access required to conduct the inservice examination specified in item (7).

(7) A 100% volumetric inservice examination of all pipe welds would be conducted during each inspection interval as defined in IWA-2400, ASME Code, Section XI.

3.6.2.1.4.3 ASME Code Section III Class 1 Piping In Areas Other Than Containment Penetration

With the exception of those portions of piping identified in Subsection 3.6.2.1.4.2, breaks in ASME Code, Section III, Class 1 piping are postulated at the following locations in each piping and branch run:

(a) At terminal ends*

(b) At intermediate locations where the maximum stress range ~~(see Subsection 3.6.2.1.4.2, Paragraph (1)(a))~~ as calculated by Eq. (10) ~~in NB-3653, ASME Code, Section III~~ exceeds 2.4 Sm.

If the calculated maximum stress range of Eq.(10) exceeds the stress range calculated by both Eq.(12) and Eq.(13) in Paragraph NB-3653 should meet the limit of 2.4 Sm.

(c) At intermediate locations where the cumulative usage factor exceeds 0.1.

* *Extremities of piping runs that connect to structures, components (e.g., vessels, pumps, valves), or pipe anchors that act as rigid constraints to piping motion and thermal expansion. A branch connection to a main piping run is a terminal end of the branch run, except where the branch run is classified as part of a main run in the stress analysis and is shown to have a significant effect on the main run behavior. In piping runs which are maintained pressurized during normal plant conditions for only a portion of the run (i.e., up to the first normally closed valve) a terminal end of such runs is the piping connection to this closed valve.*

As a result of piping re-analysis due to differences between the design configuration and the as-built configuration, the highest stress or cumulative usage factor locations may be shifted; however, the initially determined intermediate break locations need not be changed unless one of the following conditions exists:

(i) The dynamic effects from the new (as-built) intermediate break locations are not mitigated by the original pipe whip restraints and jet shields.

(ii) A change is required in pipe parameters such as major differences in pipe size, wall thickness, and routing.

3.6.2.1.4.4 ASME Code Section III Class 2 and 3 Piping in Areas Other Than Containment Penetration

With the exceptions of those portions of piping identified in Subsection 3.6.2.1.4.2, breaks in ASME Codes, Section III, Class 2 and 3 piping are postulated at the following locations in those portions of each piping and branch run:

(a) At terminal ends (see Subsection 3.6.2.1.4.3, Paragraph (a))

(b) At intermediate locations selected by one of the following criteria:

(i) At each pipe fitting (e.g., elbow, tee, cross, flange, and nonstandard fitting), welded attachment, and valve. Where the piping contains no fittings, welded attachments, or valves, at one location at each extreme of the piping run adjacent to the protective structure.

(ii) At each location where stresses calculated (see Subsection 3.6.2.1.4.2, Paragraph (1)(d)) by the sum of Eqs. (9) and (10) in NC/ND-3653, ASME Code, Section III, exceed 0.8 times the sum of the stress limits given in NC/ND-3653.

As a result of piping re-analysis due to differences between the design configuration and the as-built configuration, the highest stress

locations may be shifted; however, the initially determined intermediate break

locations may be used unless a redesign of the piping resulting in a change in the pipe parameters (diameter, wall thickness, routing) is required, or the dynamic effects from the new (as-built) intermediate break location are not mitigated by the original pipe whip restraints and jet shields.

3.6.2.1.4.5 Non-ASME Class Piping

Breaks in seismically analyzed non-ASME Class (not ASME Class 1, 2 or 3) piping are postulated according to the same requirements for ASME Class 2 and 3 piping above. Separation and interaction requirements between Seismically analyzed and non-seismically analyzed piping are met as described in Subsection 3.7.3.13.

3.6.2.1.4.6 Separating Structure With High-Energy Lines

If a structure separates a high energy line from an essential component, the separating structure is designed to withstand the consequences of the pipe break in the high-energy line at locations that the aforementioned criteria require to be postulated. However, as noted in Subsection 3.6.1.3.2.3, some structures that are identified as necessary by the HELSA evaluation (i.e., based on no specific break locations), are designed for worst-case loads.

3.6.2.1.5 Locations of Postulated Pipe Cracks

Postulated pipe crack locations are selected as follows:

3.6.2.1.5.1 Piping Meeting Separation Requirements

Based on the HELSA evaluation described in Subsection 3.6.1.3.2.2, the high- or moderate-energy lines which meet the separation requirements are not identified with particular crack locations. Cracks are postulated at all possible points that are necessary to demonstrate adequacy of separation or other means of protections provided for essential structures, systems and components.

3.6.2.1.5.2 High-Energy Piping

With the exception of those portions of piping identified in Subsection 3.6.2.1.4.2, leakage cracks are postulated for the most severe environmental effects as follows:

(1) For ASME Code, Section III Class 1 piping, at axial locations where the calculated stress range (see Subsection 3.6.2.1.4.2, Paragraph (1)(a)) by Eq. (10) and either Eq. (12) or Eq. (13) in NB-3653 exceeds 1.2 S_m.

(2) For ASME Code, Section III Class 2 and 3 or non-ASME class piping, at axial locations where the calculated stress (see Subsection 3.6.2.1.4.4, Paragraph (b)(ii)) by the sum of Eqs. (9) and (10) in NC/ND-3653 exceeds 0.4 times the sum of the stress limits given in NC/ND-3653.

(3) Non-ASME class piping which has not been evaluated to obtain stress information have leakage cracks postulated at axial locations that produce the most severe environmental effects.

3.6.2.1.5.3 Moderate-Energy Piping

3.6.2.1.5.3.1 Piping In Containment Penetration Areas

Leakage cracks are not postulated in those portions of piping from containment wall to and including the inboard or outboard isolation valves provided they meet the requirements of the ASME Code, Section III, NE-1120, and the stresses calculated (See Subsection 3.6.2.1.4.4, Paragraph (b)(ii)) by the sum of Eqs. (9) and (10) in ASME Code, Section III, NC-3653 do not exceed 0.4 times the sum of the stress limits given in NC-3653.

3.6.2.1.5.3.2 Piping In Areas Other Than Containment Penetration

(1) Leakage cracks are postulated in piping located adjacent to essential structures, systems or components, except:

(a) Where exempted by Subsections 3.6.2.1.5.3.1 and 3.6.2.1.5.4.

(b) For ASME Code, Section III, Class 1 piping the stress range calculated ~~(see Subsection 3.6.2.1.4.2, Paragraph (1)~~

~~(a))~~ by Eq. (10) ~~and either Eq. (12) or Eq.~~ ~~(13)~~ in NB-3653 is less than 1.2 S_m.

(c) For ASME Code, Section III, Class 2 or 3 and non-ASME class piping, the stresses calculated (see Subsection 3.6.2.1.4.4, Paragraph (b)(ii)) by the sum of Eqs. (9) and (10) in NC/ND-3653 are less than 0.4 times the sum of the stress limits given in NC/ND-3653.

(2) Leakage cracks, unless the piping system is exempted by item (1) above, are postulated at axial and circumferential locations that result in the most severe environmental consequences.

(3) Leakage cracks are postulated in fluid system piping designed to nonseismic standards as necessary to meet the environmental protection requirements of Subsection 3.6.1.1.3.

3.6.2.1.5.4 Moderate-Energy Piping in Proximity to High-Energy Piping

Moderate-energy fluid system piping or portions thereof that are located within a compartment of confined area involving considerations for a postulated break in high-energy fluid system piping are acceptable without postulation of throughwall leakage cracks except where a postulated leakage crack in the moderate-energy fluid system piping results in more severe environmental conditions than the break in the proximate high-energy fluid system piping, in which case the provisions of Subsection 3.6.2.1.5.3 are applied.

3.6.2.1.6 Types of Breaks and Cracks to be Postulated

3.6.2.1.6.1 Pipe Breaks

The following types of breaks are postulated in high-energy fluid system piping at the locations identified by the criteria specified in Subsection 3.6.2.1.4.

(1) No breaks are postulated in piping having a nominal diameter less than or equal to one inch. Instrument lines one inch and less nominal pipe or tubing size meet the provision of regulatory Guide 1.11 (See Table 3.2-1). Additionally, the 1-1/4-inch hydraulic control unit fast scram lines do not require special protection measure because of the following reasons:

(a) The piping to the control rod drives from the hydraulic control units (HCUs) are located in the containment under reactor vessel, and in the reactor building away from other safety-related equipment; therefore should a line fail, it would not affect any safety-related equipment but only impact on other HCU lines. As discussed in Subsection 3.6.1.1.3, Paragraph (7), a whipping pipe will only rupture an impacted pipe of smaller nominal pipe size or cause a through wall crack in the same nominal pipe size but with thinner wall thickness.

(b) The total amount of energy contained in the 1-1/4" piping between normally closed scram insert valve on the HCU module and the ball-check valve in the control rod housing is small. In the event of a rupture of this line, the ball-check valve will close to prevent reactor vessel flow out of the break.

(c) Even if a number of the HCU lines ruptured, the control rod insertion function would not be impaired since the electrical motor of the fine motion control drive would drive in the control rods.

(2) Longitudinal breaks are postulated only in piping having a nominal diameter equal to or greater than four inches.

(3) Circumferential breaks are only assumed at all terminal ends.

(4) At each of the intermediate postulated break locations identified to exceed the stress and usage factor limits of the criteria in Subsections 3.6.2.1.4.3 and 3.6.2.1.4.4, considerations is given to the occurrence of either a longitudinal or circumferential break. Examination of the state of stress in the vicinity of the postulated break location is used to identify the most

probably type of break. If the maximum stress range in the longitudinal direction is greater than 1.5 times the maximum stress range in the circumferential direction, only the circumferential break is postulated. Conversely, if the maximum stress range in the circumferential direction is greater than 1.5 times the stress range in the longitudinal direction, only the longitudinal break is postulated. If no significant difference between the circumferential and longitudinal stresses is determined, then both types of breaks are considered.

(5) Where breaks are postulated to occur at each intermediate pipe fitting, weld attachment, or valve without the benefit of stress calculations, only circumferential breaks are postulated.

(6) For both longitudinal and circumferential breaks, after assessing the contribution of upstream piping flexibility, pipe whip is assumed to occur in the plane defined by the piping geometry and configuration for circumferential breaks and out of plane for longitudinal breaks and to cause piping movement in the direction of the jet reactions. Structural members, piping restraints, or piping stiffness as demonstrated by inelastic limit analysis are considered in determining the piping movement limit (alternatively, circumferential breaks are assumed to result in pipe severance and separation amounting to at least a one-diameter lateral displacement of the ruptured piping sections).

(7) For a circumferential break, the dynamic force of the jet discharged at the break location is based upon the effective cross sectional flow area of the pipe and on a calculated fluid pressure as modified by an analytically or experimentally determined thrust coefficient. Limited pipe displacement at the break location, line restrictions, flow limiters, positive pump-controlled flow, and the absence of energy reservoirs are used, as applicable, in the reduction of the jet discharge.

(8) Longitudinal breaks in the form of axial split without pipe severance are postulated in the center of the piping at two diametrically opposed points (but not concurrently) located so that the reaction force is perpendicular to the plane of the piping configuration and produces out-of-plane bending. Alternatively, a single split is assumed at the section of highest tensile stress as determined by detailed stress analysis (e.g., finite element analysis).

(9) The dynamic force of the fluid jet discharge is based on a circular or elliptical (2D x 1/2D) break area equal to the effective cross-sectional flow area of the pipe at the break location and on a calculated fluid pressure modified by an analytically or experimentally determined thrust coefficient as determined for a circumferential break at the same location. Line restrictions, flow limiters, positive pump-controlled flow, and the absence of energy reservoirs may be taken into account as applicable in the reduction of jet discharge.

3.6.2.1.6.2 Pipe Cracks

The following criteria are used to postulate throughwall leakage cracks in high- or moderate-energy fluid systems or portions of systems.

(1) Cracks are postulated in moderate-energy fluid system piping and branch runs exceeding a nominal pipe size of one inch.

(2) At axial locations determined per Subsection 3.6.2.1.5, the postulated cracks are oriented circumferentially to result in the most severe environmental consequences.

(3) Crack openings are assumed as a circular orifice of area equal to that of a rectangle having dimensions one-half-pipe-diameter in length and one-half-pipe-wall thickness in width.

(4) The flow from the crack opening is assumed to result in an environment that wets all unprotected components within the compartment, with consequent flooding in the compartment and communicating compartments, based on a conservatively estimated time period to effect corrective actions.

3.6.2.2 Analytic Methods to Define Blowdown Forcing Functions and Response Models.

3.6.2.2.1 Analytic Methods to Define Blowdown Forcing Functions.

The rupture of a pressurized pipe causes the flow characteristics of the system to change creating reaction forces which can dynamically excite the piping system. The reaction forces are a function of time and space and depend upon fluid state within the pipe prior to rupture, break flow area, frictional losses, plant system characteristics, piping system, and other factors. The methods used to calculate the reaction forces for various piping systems are presented in the following subsections.

The criteria that are used for calculation of fluid blowdown forcing functions include:

(1) Circumferential breaks are assumed to result in pipe severance and separation amounting to at least a one-diameter lateral displacement of the ruptured piping sections unless physically limited by piping restraints, structural members, or piping stiffness as may be demonstrated by inelastic limit analysis (e.g., a plastic hinge in the piping is not developed under loading).

(2) The dynamic force of the jet discharge at the break location is based on the cross-sectional flow area of the pipe and on a calculated fluid pressure as modified by analytically- or experimentally-determined thrust coefficient. Line restrictions, flow limiters, positive pump-controlled flow, and the absence of energy reservoirs are taken into accounts, as applicable, in the reduction of jet discharge.

(3) All breaks are assumed to attain full size within one millisecond after break initiation.

The forcing functions due to th. stulated or pipe breaks near the reactor at branch connection are calculated by the solution of one-dimensional, compressible unsteady steam flow in the gas system. The numerical analysis is performed by the method of characteristics. The flow starts with steady flow from the RPV to the turbine. A pipe break causes the steam flow to reverse its direction and to flow from the turbine to the break location. The pipe segment force time histories are determined by calculating the momentum change in the pipe segments of a closed system. The broken pipe segment force time history is calculated in accordance with Appendix B of ANSI/ANS-58.2.-1988

A steady state blowdown force factor of 0.7 is used for ideal steam (see attached figure.)

3.6-7

(5) Piping within the broken loop is no longer considered part of the RCPB. Plastic deformation in the pipe is considered as a potential energy absorber. Limits of strain are imposed which are similar to strain levels allowed in restraint plastic members. Piping systems are designed so that plastic instability does not occur in the pipe at the design dynamic and static loads unless damage studies are performed which show the consequences do not result in direct damage to any essential system or component.

(6) Components such as vessel safe ends and valves which are attached to the broken piping system, do not serve a safety-related function, or failure of which would not further escalate the consequences of the accident are not designed to meet ASME Code-imposed limits for essential components under faulted loading. However, if these components are required for safe shutdown or serve to protect the structural integrity of an essential component, limits to meet the Code requirements for faulted conditions and limits to ensure required operability will be met.

(7) The piping stresses in the containment penetration areas due to loads resulting from a postulated piping failure can not exceed the limits specified in Subsection 3.6.2.1.4.2(1)(c).

3.6.2.2.2 Pipe Whip Dynamic Response Analyses

The prediction of time-dependent and steady-thrust reaction loads caused by blowdown of subcooled, saturated, and two-phase fluid from ruptured pipe is used in design and evaluation of dynamic effects of pipe breaks. A discussion of the analytical methods employed to compute these blowdown loads is given in Subsection 3.6.2.2.1. Following is a discussion of analytical methods used to account for this loading.

The criteria used for performing the pipe whip dynamic response analyses include:

(1) A pipe whip analysis is performed for each postulated pipe break. However, a given analysis can be used for more than one postulated break location if the blowdown forcing function, piping and restraint system geometry, and piping and restraint system properties are conservative for other break locations.

(2) The analysis includes the dynamic response of the pipe in question and the pipe whip restraints which transmit loading to the support structures.

(3) The analytical model adequately represents the mass/inertia and stiffness properties of the system.

(4) Pipe whipping is assumed to occur in the plane defined by the piping geometry and configuration and to cause pipe movement in the direction of the jet reaction.

An analysis for pipewhip restraint selection PDA computer program; ~~and a pipe break modeling~~ program ~~ANSYS are performed as~~ described in Appendix 3D, which predicts the response of a pipe subjected to the thrust force occurring after a pipe break. The program treats the situation in terms of generic pipe break configuration which involves a straight, uniform pipe fixed at one end and subjected to a time-dependent thrust force at the other end. A typical restraint used to reduce the resulting deformation is also included at a location between the two ends. Nonlinear and time-independent stress-strain relationships are used to model the pipe and the restraint. Using a plastic-hinge concept, bending of the pipe is assumed to occur only at

the fixed end and at the location supported by the restraint.

Effects of pipe shear deflection are considered negligible. The pipe-bending moment-deflection (or rotation) relation used for these locations is obtained from a static nonlinear cantilever-beam analysis. Using the moment-rotation relation, nonlinear equations of motion of the pipe are formulated using energy considerations and the equations are numerically integrated in small time steps to yield time-history of the pipe motion.

The piping stresses in the containment penetration areas are calculated by the ANSYS computer program, a program as described in Appendix 3D. The program is used to perform the non-linear analysis of a piping system for time varying displacements and forces due to postulated pipe breaks.

3.6.2.3 Dynamic Analysis Methods to Verify Integrity and Operability

3.6.2.3.1 Jet Impingement Analyses and Effects on Safety-Related Components

The methods used to evaluate the jet effects resulting from the postulated breaks of high-energy piping are described in Appendices C and D of ANSI/ANS 58.2 and presented in this subsection.

The criteria used for evaluating the effects of fluid jets on essential structures, systems, and components are as follows:

(1) Essential structures, systems, and components are not impaired so as to preclude essential functions. For any given postulated pipe break and consequent jet, those essential structures, systems, and components need to safely shut down the plant are identified.

(2) Essential structures, systems, and components which are not necessary to safely shut down the plant for a given break are not protected from the consequences of the fluid jet.

(3) Safe shutdown of the plant due to postulated pipe ruptures within the RCPB is not aggravated by sequential failures of safety-related piping and the required emergency cooling system performance is maintained.

(4) Offsite dose limits specified in 10CFR100 are complied with.

(5) Postulated breaks resulting in jet impingement loads are assumed to occur in high-energy lines at full (102%) power operation of the plant.

(6) Throughwall leakage cracks are postulated in moderate energy lines and are assumed to

result in wetting and spraying of essential structures, systems and components.

(7) Reflected jets are considered only when there is an obvious reflecting surface (such as a flat plate) which directs the jet onto an essential equipment. Only the first reflection is considered in evaluating potential targets.

(8) Potential targets in the jet path are considered at the calculated final position of the broken end of the ruptured pipe. This selection of potential targets is considered adequate due to the large number of breaks analyzed and the protection provided from the effects of these postulated breaks.

The analytical methods used to determine which targets will be impinged upon by a fluid jet and the corresponding jet impingement load include:

(1) The direction of the fluid jet is based on the arrested position of the pipe during steady-state blowdown.

(2) The impinging jet proceeds along a straight path.

(3) The total impingement force acting on any cross-sectional area of the jet is time and distance invariant with a total magnitude equivalent to the steady-state fluid blowdown force given in Subsection 3.6.2.2.1 and with jet characteristics shown in Figure 3.6-3.

(4) The jet impingement force is uniformly distributed across the cross-sectional area of the jet and only the portion intercepted by the target is considered.

(5) The break opening is assumed to be a circular orifice of cross-sectional flow area equal to the effective flow area of the break.

(6) The jet impingement force is equal to the steady-state value of the fluid blowdown force calculated by the methods described in Subsection 3.6.2.2.1.

(7) The distance of jet travel is divided into two or three regions. Region 1 (Figure 3.6-3) extends from the break to the asymptotic area. Within this region the discharging fluid flashes and undergoes expansion from the break area pressure to the atmospheric pressure. In Region 2 the jet expands further. For partial-separation circumferential breaks, the area increases as the jet expands. In Region 3, the jet expands at a half angle of 10°. (Figures 3.6-3a and c.)

(8) The analytical model for estimating the asymptotic jet area for subcooled water and saturated water assumes a constant jet area. For fluids discharging from a break which are below the saturation temperature at the corresponding room pressure or have a pressure at the break area equal to the room pressure, the free expansion does not occur.

(9) The distance downstream from the break where the asymptotic area is reached (Region 2) is calculted for circumferential and longitudinal breaks.

(10) Both longitudinal and fully separated circumferential breaks are treated similarly. The value of fL/D used in the blowdown calculation is used for jet impingement also.

(11) Circumferential breaks with partial (i.e., h < D/2) separation between the two ends of the broken pipe not significantly offset (i.e., no more than one pipe wall thickness lateral displacement) are more difficult to

... For these cases, the following assumptions are made.

(a) The jet is uniformly distributed around the periphery.

(b) The jet cross section at any cut through the pipe axis has the configuration depicted in Figure 3.6-3b and the jet regions are as therein delineated.

(c) The jet force F_j = total blowdown F.

(d) The pressure at any point intersected by the jet is:

$$P_j = \frac{F_s}{A_R}$$

where

A_R = the total 360° area of the jet at a radius equal to the distance from the pipe centerline to the target.

(e) The pressure of the jet is then multiplied by the area of the target submerged within the jet.

(12) Target loads are determined using the following procedures.

(a) For both the fully separated circumferential break and the longitudinal break, the jet is studied by determining target locations vs. ~~asumptomatic~~ distance and applying ANSI/ANS-58.2, Appendices C and D.

(b) For circumferential break limited separation, the jet is analyzed by using ~~different~~ equations of ANSI/ANS 58.2, Appendices C and D and determing respective target and ~~asymptomatic~~ locations

c) After determination of the total area of the jet at the target, the jet pressure is calculated by:

$$P_1 = \frac{F_j}{A_x}$$

where

P_1 = incident pressure

A_x = area of the expanded jet at the target intersection.

If the effective target area (A_{te}) is less than expanded jet area ($A_te \leq A_x$), the target is fully submerged in the jet and the impingement load is equal to (P_1) (A_{te}). If the effective target area is greater than expanded jet area ($A_{te} > A_x$), the target intercepts the entire jet and the impingement load is equal to (P_1) (A_x) = F_j. The effective target area (A_{te}) for various geometries follows:

(1) Flat surface - For a case where a target with physical area A_t is oriented at angle d with respect to the jet axis and with no flow reversal, the effective target area A_{te} is:

$$A_{te} = (A_t)(\sin\phi)$$

(2) Pipe Surface - As the jet hits the convex surface of the pipe, its forward momentum is decreased rather than stopped; therefore, the jet impingement load on the impacted area is expected to be reduced. For conservatism, no credit is taken for this reduction and the pipe is assumed to be impacted with the full impingement load. However, where shape factors are justifiable, they may be used. The effective target area A_{te} is:

$$A_{te} = (D_A)(D)$$

where

D_A = diameter of the jet at the target interface, and

D = pipe OD of target pipe for a fully submerged pipe.

When the target (pipe) is larger than the area of the jet, the effective target area equals the expanded jet area

$$A_{te} = A_x$$

(3) For all cases, the jet area (A_x) is assumed to be uniform and the load is uniformly distributed on the impinged target area A_{te}.

3.6.2.3.2 Pipe Whip Effects on Essential Components

This subsection provides the criteria and methods used to evaluate the effects of pipe displacements on essential structures, systems, and components following a postulated pipe rupture.

Pipe whip (displacement) effects on essential structures, systems, and components can be placed in two categories: (1) pipe displacement effects on components (nozzles, valves, tees, etc.) which are in the same piping run that the break occurs in; and (2) pipe whip or controlled displacements onto external components such as building structure, other piping systems, cable trays, and conduits, etc.

3.6.2.3.2.1 Pipe Displacement Effects on Components in the Same Piping Run

The criteria for determining the effects of pipe displacements on inline components are as follows:

(1) Components such as vessel safe ends and valves which are attached to the broken piping system and do not serve a safety function or failure of which would not further escalate the consequences of the accident need not be designed to meet ASME

Code Section III-imposed limits for essential components under faulted loading.

(2) If these components are required for safe shutdown or serve to protect the structural integrity of an essential component, limits to meet the ASME Code requirements for faulted conditions and limits to ensure required operability are met.

The methods used to calculate the pipe whip loads on piping components in the same run as the postulated break are described in Section 3.6.2.2.2.

3.6.2.3.2.2 Pipe Displacement Effects on Essential Structures, Other Systems, and Components

The criteria and methods used to calculate the effects of pipe whip on external components consists of the following:

(1) The effects on essential structures and barriers are evaluated in accordance with the barrier design procedures given in Subsection 3.5.3

(2) If the whipping pipe impacts a pipe of equal or greater nominal pipe diameter and equal or greater wall thickness, the whipping pipe does not rupture the impacted pipe. Otherwise, the impacted pipe is assumed to be ruptured.

(3) If the whipping pipe impacts other components (valve actuators, cable trays, conduits, etc.), it is assumed that the impacted component is unavailable to mitigate the consequences of the pipe break event.

(4) Damage of unrestrained whipping pipe on essential structures, components, and systems other than the ruptured one is prevented by either separating high energy systems from the essential systems or providing pipe whip restraints.

3.6.2.3.3 Loading Combinations and Design Criteria for Pipe Whip Restraint

Pipe whip restraints, as differentiated from piping supports, are designed to function and carry load for an extremely low-probability gross failure in a piping system carrying high-energy fluid. In the ABWR plant, the piping integrity does not depend on the pipe whip restraints for any piping design loading combination including earthquake but shall remain functional following an earthquake up to and including the SSE (See Subsection 3.2.1). When the piping integrity is lost because of a postulated break, the pipe whip restraint acts to limit the movement of the broken pipe to an acceptable distance. The pipe whip restraints (i.e., those devices which serve only to control the movement of a ruptured pipe following gross failure) will be subjected to once-in-a-lifetime loading. For the purpose of the pipe whip restraint design, the pipe break is considered to be a faulted condition (See Subsection 3.9.3.1.1.4) and the structure to which the restraint is attached is also analyzed and designed accordingly. The pipe whip restraints are non-ASME Code components; however, the ASME Code requirements ~~may be~~ used in the design selectively to assure its safety-related function ~~if ever needed.~~ Other methods, i.e. testing, with reliable data base for design and sizing of pipe whip restraints can also be used.

The pipe whip restraints utilize energy absorbing U-rods to attenuate the kinetic energy of a ruptured pipe. A typical pipe whip restraint is shown in Figure 3.6-6. The principal feature of these restraints is that they are installed with several inches of annular clearance between them and the process pipe. This allows for installation of normal piping insulation and for unrestricted pipe thermal movements during plant operation. Select critical locations inside primary containment are also monitored during hot functional testing to provide verification of adequate clearances prior to plant operation. The specific design objectives for the restraints are:

(1) The restraints shall in no way increase the reactor coolant pressure boundary stresses by their presence during any normal mode of reactor operation or condition;

(2) The restraint system shall function to stop the movement of a pipe failure (gross loss of piping integrity) without allowing damage to critical components or missile development; and

(3) The restraints should provide minimum hindrance to inservice inspection of the process piping.

For the purpose of design, the pipe whip restraints are designed for the following dynamic loads:

(1) Blowdown thrust of the pipe section that impacts the restraint;

(2) Dynamic inertia loads of the moving pipe section which is accelerated by the blowdown thrust and subsequent impact on the restraint;

(3) Design characteristics of the pipe whip restraints are included and verified by the pipe whip dynamic analysis described in Subsection 3.6.2.2.2; and

(4) Since the pipe whip restraints are not contacted during normal plant operation, the postulated pipe rupture event is the only design loading condition.

Penetration Sleeve/

3.6.2.4 Guard Pipe Assembly Design

The ABWR primary containment does not require guard pipes.

3.6.2.5 Material to be Supplied for the Operating License Review

See Subsection 3.6.4.1

3.6.3 Leak-Before-Break Evaluation Procedures

Per Regulatory Guide 1.70, Revision 3, November 1978, the safety analysis Section 3.6 has traditionally addressed the protection measures against dynamic effects associated with the non- mechanistic or postulated ruptures of piping. The dynamic effects are defined in introduction to Section 3.6. Three forms of piping failure (full flow area circumferential and longitudinal breaks, and throughwall leakage crack) are postulated in accordance with Subsection 3.6.2 and Branch Technical Position MEB 3-1 of NUREG - 0800 (Standard Review Plan) for their dynamic as well as environmental effects.

However, in accordance with the modified General Electric Criterion 4 (GDC-4), effective November 27, 1987, (Reference 1), the mechanistic leak-before-break (LBB) approach, justified by appropriate fracture mechanics techniques, is recognized as an acceptable procedure under certain conditions to exclude design against the dynamic effects from postulation of breaks in high energy piping. The LBB approach is not used to exclude postulation of cracks and associated effects as required in Subsection 3.6.2.1.5 and 3.6.2.1.6.2. It is anticipated, as mentioned in Subsection 3.6.4.2, that a COL applicant will apply to the NRC for approval of LBB qualification of selected piping. These approved piping, referred to in this SSAR as the LBB-

Strain rate effects and other material property variations have been considered in the design of the pipe whip restraints. The material properties utilized in the design have included one or more of the following methods:

(1) Code minimum or specification yield and ultimate strength values for the affected components and structures are used for both the dynamic and steady-state events;

(2) Not more than a 10% increase in minimum code or specification strength values is used when designing components or structures for the dynamic event, and code minimum or specification yield and ultimate strength values are used for the steady-state loads:

(3) Representative or actual test data values are used in the design of components and structures including justifiably elevated strain rate-affected stress limits in excess of 10%; or

(4) Representative or actual test data are used for any affected component(s) and the minimum code or specification values are used for the structures for the dynamic and the steady-state events

qualified piping, will be excluded from pipe breaks, which are required to be postulated by Subsections 3.6.1 and 3.6.2, for design against their potential dynamic effects.

The following subsections describe (1) certain design bases where the LBB approach is not recognized by the NRC as applicable for exclusion of pipe breaks, and (2) certain conditions which limit the LBB applicability. Appendix 3E provides guidelines for LBB applications describing in detail the following necessary elements of an LBB report to be submitted by a COL applicant for NRC approval: fracture mechanics methods, leak rate prediction methods, leak detection capabilities and typical special considerations for LBB applicability. Also included in Appendix 3E is a list of candidate piping systems for LBB qualification. The LBB application approach described in this subsection and Appendix 3E is consistent with that documented in Draft SRP 3.6.3 (Reference 4) and NUREG-1061 (Reference 5).

The LBB approach is not used to exclude postulation of cracks and associated effects in

accordance with Subsections 3.6.2.1.5 and 3.6.2.1.6.2.

The LBB approach is not applicable to piping systems where operating experience has indicated particular susceptibility to failure from the effects of intergranular stress corrosion cracking (IGSCC), water hammer, thermal fatigues, or erosion.

The LBB approach is not a replacement for existing regulations or criteria pertaining to the design bases of emergency core cooling system (Subsection 6.3), containment system (Subsection 6.2) or equipment qualification (Subsection 3.11). However, benefits of the LBB procedures to these areas will be taken and the subsections will be revised as the regulations will be relaxed by the NRC. For clarity, it is noted that the LBB approach is not used to relax the design requirements of the primary containment system that includes the primary containment vessel (PCV), vent systems (vertical flow channels and horizontal vent discharges), drywell zones, suppression chamber (wetwell), vacuum breakers, PCV penetrations, and drywell head. However, in designing for loads per Table 3.9-2, which does not apply to these PCV subsys- tems, the seven types of design loads identified with LOCA-induced dynamics of suppression pool or shield wall annulus pressurization are excluded if they are a result of LOCA postulated in those piping that meet the LBB criteria.

Appendix 3E characterizes fracture mechanics properties of piping materials and analysis methods including leakage calculation methods, as required by the criteria of this subsection. Following NRC's review and approval, this appendix will become approved LBB methodology for application to ABWR Standard Plant piping. Appendix 3F applies these properties and methods to specific piping to demonstrate their eligibility for exclusion under the LBB approach. See Subsection 3.6.4.2 for interface requirements.

3.6.3.1 General Evaluation

The high-energy piping system (or analyzable portion thereof) is evaluated with the following considerations in addition to the deterministic LBB evaluation procedure of Subsection 3.6.3.2

(1) Degradation by erosion, erosion/corrosion and erosion/cavitation due to unfavorable flow conditions and water chemistry is examined. The evaluation is based on the industry experience and guidelines. Additionally, fabrication wall thinning of elbows and other fittings is considered in the purchase specification to assure that the code minimum wall requirements are met. These evaluations demonstrate that these mechanisms are not potential sources of pipe rupture.

(2) The ABWR plant design involves operation below 700°F in ferritic steel piping and below 800°F in austenitic steel piping. This assures that creep and creep-fatigue are not potential sources of pipe rupture.

(3) The design also assures that the piping material is not susceptible to brittle cleavage-type failure over the full range of system operating temperatures (that is, the material is on the upper shelf).

(4) The ABWR plant design specifies use of austenitic stainless steel piping made of material (e.g., nuclear grade or low carbon type) that is recognized as resistant to IGSCC. The material of piping in reactor coolant pressure boundary is ferritic steel.

(5) A systems evaluation of potential water hammer is made to assure that pipe rupture due to this mechanism is unlikely. Water hammer is a generic term including various unanticipated high frequency hydrodynamic events such as steam hammer and water slugging. To demonstrate that water hammer is not a significant contributor to pipe rupture, reliance on historical frequency of water hammer events in specific piping systems coupled with a review of operating procedures and conditions is used for this evaluation. The ABWR design includes features such as vacuum breakers and jockey pumps coupled with improved operational procedures to reduce or eliminate the potential for water hammer identified by past

experience. Certain anticipated water hammer events, such as a closure of a valve, are accounted for in the Code design and analysis of the piping.

(6) The systems evaluation also addresses a potential for fatigue cracking or failure from thermal and mechanical induced fatigue. Based on past experience, the piping design avoids potential for significant mixing of high- and low- temperature fluids or mechanical vibration. The startup and preoperational monitoring assures avoidance of detrimental mechanical vibration.

(7) Based on experience and studies by Lawrence Livermore Laboratory, potential indirect sources of indirect pipe rupture are remote causes of pipe rupture. Compliance with the snubber surveillance requirements of the technical specifications assures that snubber failure rates are acceptably low.

(8) Initial LBB evaluation is based on the design configuration and stress levels that are acceptably higher than those identified by the initial analysis. This evaluation is reconciled when the as-built configuration is documented and the Code stress evaluation is reconciled. It is assured that the as-built configuration does not deviate significantly from the design configuration to invalidate the initial LBB evaluation, or a new evaluation coupled with necessary configuration modifications is made to assure applicability of the LBB procedure.

(9) Sufficiently reliable, redundant, diverse and sensitive leak detection systems are provided for monitoring of leak. The system that is relied upon to predict the through-wall flaw used in the deterministic fracture mechanics evaluation is sufficiently reliable and sensitive to justify a margin of 2 on the leakage prediction.

3.6.3.2 Deterministic Evaluation Procedure

The following deterministic analysis and evaluation are performed as an NRC-approved method for the ABWR Standard Nuclear Island to justify applicability of the LBB concept.

(1) Use the fracture mechanics and the leak rate computational methods that are accepted by the NRC staff, or are demonstrated accurate with respect to other acceptable computational procedures or with experimental data.

(2) Identify the types of materials and materials specifications used for base metal, weldments and safe ends, and provide the materials properties including toughness and tensile data, long-term effects such as thermal aging, and other limitations.

(3) Specify the type and magnitude of the loads applied (forces, bending and torsional moments), their source(s) and method of combination. For each pipe size in the functional system, identify the location(s) which have the least favorable combination of stress and material properties for base metal, weldments and safe ends.

(4) Postulate a throughwall flaw at the location(s) specified in (3) above. The size of the flaw should be large enough so that the leakage is assured detection with sufficient margin using the installed leak detection capability when the pipes are subjected to normal operating loads. If auxiliary leak detection systems are relied on, they should be described. For the estimation of leakage, the normal operating loads (i.e., deadweight, thermal expansion, and pressure) are to be combined based on the algebraic sum of individual values.

Using fracture mechanics stability analysis or limit load analysis based on (11) below, and normal plus SSE loads, determine the critical crack size for the postulated throughwall crack. Determine crack size margin by comparing the selected leakage size crack to the critical crack size. Demonstrate that there is a margin of 2 between the leakage and critical crack sizes. The same load combination method selected in (5) below is used to determine the critical crack size.

(5) Determine margin in terms of applied loads by a crack stability analysis. Demonstrate

that the leakage size cracks will not experience unstable crack growth if 1.4 times the normal plus SSE loads are applied. Demonstrate that crack growth is stable and the final crack is limited such that a double-ended pipe break will not occur. The dead-weight, thermal expansion, pressure, SSE (inertial), and seismic anchor motion (SAM) loads are combined based on the same method used for the primary stress evaluation by the ASME Code. The SSE (inertial) and SAM loads are combined by square-root-of-the-sum-of-the- squares (SRSS) method.

(6) The piping material toughness (J-R curves) and tensile (stress-strain curves) properties are determined at temperatures near the upper range of normal plant operation.

(7) The specimen used to generate J-R curves is assured large enough to provide crack extensions up to an amount consistent with J/T condition determined by analysis for the application. Because practical specimen size limitations exist, the ability to obtain the desired amount of experimental crack extension may be restricted. In this case, extrapolation techniques is used as described in NUREG-1061, Volume 3, or in NUREG/CR-4575. Other techniques can be used if adequately justified.

(8) The stress-strain curves are obtained over the range from the proportional limit to maximum load.

(9) Preferably, the materials tests should be conducted using archival materials for the pipe being evaluated. If archival material is not available, plant specific or industry wide generic material data bases are assembled and used to define the required material tensile and toughness properties. Test material includes base and weld metals.

(10) To provide an acceptable level of reliability, generic data bases are reasonable lower bounds for compatible sets of material tensile and toughness properties associated with materials at the plant. To assure that the plant specific generic data base is adequate, a determination is made to demonstrate that the generic data base represents the range of plant materials to be evaluated. This determination is based on a comparison of the plant material properties identified in (2) above with those of the materials used to develop the generic data base. The number of material heats and weld procedures tested are adequate to cover the strength and toughness range of the actual plant materials. Reasonable lower bound tensile and toughness properties from the plant specific generic data base are to be used for the stability analysis of individual materials, unless otherwise justified.

Industry generic data bases are reviewed to provide a reasonable lower bound for the population of material tensile and toughness properties associated with any individual specification (e.g., A106, Grade B), material type (e.g., austenitic steel) or welding procedures.

The number of material heats and weld procedures tested should be adequate to cover the range of the strength and tensile properties expected for specific material specifications or types. Reasonable lower bound tensile and toughness properties from the industry generic data base are used for the stability analysis of individual materials.

If the data are being developed from an archival heat of material, three stress-strain curves and three J-resistance curves from that one heat of material is sufficient. The tests should be conducted at temperatures near the upper range of normal plant operation. Tests should also be conducted at a lower temperature, which may represent a plant condition (e.g., hot standby) where pipe break would present safety concerns similar to normal operation. These tests are intended only to determine if there is any significant dependence of toughness on temperature over the temperature range of interest. The lower toughness should be used in the fracture mechanics evaluation. One J-R curve and one stress-strain curve for one base metal and weld metal are considered adequate to determine temperature dependence.

(11) There are certain limitations that currently preclude generic use of limit load analyses to evaluate leak-before-break conditions deterministically. However, a modified limit-load analysis ⁻ n be used for austenitic steel piping to demonstrate acceptable margins as indicated below:

Construct a master Curve where a stress index, SI, given by

$$SI = S + M\,P_m \quad (1)$$

is plotted as a function of postulated total circumferential throughwall flaw length, L, defined by

$$L = 2\,\theta\,R \quad (2)$$

where

$$S = \frac{2\,\sigma_f}{\pi}\,[\,2\sin\beta - \sin\theta\,], \quad (3)$$

$$\beta = 0.5\,[(\pi - \theta) - \pi\,(P_m/\sigma_f)] \quad (4)$$

θ = half angle in radians of the postulated throughwall circumferential flaw.

R = pipe mean radius, that is, the average between the inner and outer radius,

P_m = the combined membrane stress, including pressure, deadweight, and seismic components,

M = 1.4, the margin associated with the load combination method selected for the analysis, per item (5).

σ_f = flow stress for austenitic steel pipe material categories.

If $\theta + \beta$ from Eqs. (2) and (4) is greater than π, then

$$S = \frac{2\,\sigma_f}{\pi}\,[\,\sin\beta\,] \quad (5)$$

where

$$\beta = \quad - \pi(P_m/\sigma_f). \quad (6)$$

When the master curve is constructed using Eqs. (1), (2), and (3) or (5), the allowable circumferential throughwall flaw length can be determined by entering the master curve at a stress index (SI) value determined from the loads and austenitic steel piping material of interest. The allowable flaw size determined from the master curve at the appropriate SI value can then be used to determine if the required margins are met. Allowable values of θ are those that result in S being greater than zero from Eqs. (3) and (5). The flow stress used to construct the master curve and the definition of SI used to enter the master curve are defined for each material category as follows:

<u>Base Metal and TIG Welds:</u>

The flow stress used to construct the master curve is

$$\sigma_f = 0.5\,(\sigma_y + \sigma_u)$$

when the yield strength, σ_y, and the ultimate strength, σ_u, at temperature are known.

If the yield and ultimate strengths at temperature are not known, then Code minimum values at temperature can be used, or alternatively if

$$\frac{(SI)}{17M} < 2.5, \text{ then}$$

$$\sigma_f = 51 \text{ ksi, or}$$

if

$$\frac{(SI)}{17M} \geq 2.5, \text{ then}$$

$$\sigma_f = 45 \text{ ksi.}$$

The value of SI used to enter the master curve for base metal and TIG welds is

$$SI = M\,(P_m + P_b) \quad (7)$$

where

P_b = the combined primary bending stress.

3.6.4 COL License Information

3.6.4.1 Details of Pipe Break Analysis Results and Protection Methods

The following shall be provided by the COL applicant (See Subsection 3.6.2.5):

(1) A summary of the dynamic analyses applicable to high-energy piping systems in accordance with Subsection 3.6.2.5 of Regulatory Guide 1.70. This shall include:

(a) Sketches of applicable piping systems showing the location, size and orientation of postulated pipe breaks and the location of pipe whip restraints and jet impingement barriers.

(b) A summary of the data developed to select postulated break locations including calculated stress intensities, cumulative usage factors and stress ranges as delineated in BTP MEB 3-1.

(2) For failure in the moderate-energy piping systems listed in Table 3.6-6, descriptions showing how safety-related systems are protected from the resulting jets, flooding and other adverse environmental effects. 410.21

(3) Identification of protective measures provided against the effects of postulated pipe failures for protection of each of the systems listed in Tables 3.6-1 and 3.6-2. 410.22

(4) The details of how the MSIV functional capability is protected against the effects of postulated pipe failures. 410.26

(5) Typical examples, if any, where protection for safety-related systems and components against the dynamic effects of pipe failures include their enclosure in suitably designed structures or compartments (including any additional drainage system or equipment environmental qualification needs). 410.28

(6) The details of how the feedwater line check and feedwater isolation valves functional capabilities are protected against the effects of postulated pipe failures.

3.6.4.2 Leak-Before-Break Analysis Report

As required by Reference 1, and LBB analysis report shall be prepared for the piping systems proposed for exclusion from analysis for the dynamic effects due to failure of piping failure. The report shall be prepared in accrodance with the guidelines presented in Appendix 3E and Submitted by the COL applicant to the NRC for approval

3.6.5 References

1. *Modification of General Design Criterion 4 Requirements for Protection Against Dynamic Effects of Postulated Pipe Rupture*, Federal Register, Volume 52, No. 207, Rules and Regulations, Pages 41288 to 41295, October 27, 1987

2. *RELAP 3, A Computer Program for Reactor Blowdown Analysis*, IN-1321, issued June 1970, Reactor Technology TID-4500.

3. ANSI/ANS-58.2, *Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture*.

4. *Standard Review Plan; Public Comments Solicited*, Federal Register, Volume 52, No. 167, Notices, Pages 32626 to 32633, August 28, 1987.

5. NUREG-1061, Volume3, *Evaluation of Potential for Pipe Breaks, Report of the U.S. NRC Piping Review Committee*, November 1984.

6. Mehta, H. S., Patel, N.T. and Ranganath, S., *Application of the Leak-Before-Break Approach to BWR Piping*, Report NP-4991, Electric Power Research Institute, Palo Alto, CA, December 1986.

Table 3.6-1

ESSENTIAL SYSTEMS, COMPONENTS, AND EQUIPMENT* FOR POSTULATED PIPE FAILURES INSIDE CONTAINMENT

1. Reactor Coolant Pressure Boundary (up to and including the outboard isolation valves)

2. Containment Isolation system and Containment Boundary (including liner plate)

3. Reactor Protection system (SCRAM SIGNALS)

4. Emergency Core Cooling Systems** (For LOCA events only)

   One of the following combinations is available (see Table 6.3-3):

   (a) HPCF (B and C) + RCIC + RHR-LPFL (B and C) + ADS
   (b) HPCF (B and C) + RHR-LPFL (A and B and C) + ADS
   (c) HPCF (B or C) + RCIC + RHR-LPFL (A and either of B or C) + ADS

5. Core Cooling Systems (other than LOCA events)

   (a) HPCF (B or C) or RCIC

   (b) RHR-LPFL (A or B or C) + ADS

   (c) RHR shutdown Cooling Mode (two loops)

   (d) RHR Suppression Pool Cooling Mode (two loops)

6. Control rod drive (scram/rod insertion)

7. Flow restrictors (passive)

8. Atmospheric control (for LOCA event only)

9. Standby gas treatment*** (for LOCA event only)

10. Control Room Environmental***

11. The following equipment/systems or portions thereof required to assure the proper operation of those essential items listed in items 1 through 10.

    (a) Class 1E electrical systems, ac and dc (including diesel generator system***, 6900, 480 and 120V ac, and 125V dc emergency buses***, motor control centers***, switchgear***, batteries*** and distribution systems)

Table 3.6-1

ESSENTIAL SYSTEMS, COMPONENTS, AND EQUIPMENT* FOR POSTULATED PIPE FAILURES INSIDE CONTAINMENT (Continued)

(b) Reactor Building Cooling Water*** to the following:

1. Room coolers
2. Pump coolers
3. Diesel generator jacket coolers
4. Electrical switchgear coolers

(c) Environmental Systems*** (HVAC)

(d) Instrumentation (including post-LOCA monitoring)

(e) Fire Protection System ***

410.22 (f) HVAC Emergency Cooling Water System ***

(g) Process Sampling System ***

NOTE

* The essential items listed in this table are protected in accordance with Subsection 3.6.1 consistent with the particular pipe break evaluated.

** Reference Section 6.3 for detailed discussion of emergency core cooling capabilities.

*** Located outside containment but listed for completeness of essential shutdown requirements.

Table 3.6-2

ESSENTIAL SYSTEMS, COMPONENTS, AND EQUIPMENT* FOR POSTULATED PIPE FAILURES OUTSIDE CONTAINMENT

1. Containment Isolation System and containment boundary.

2. Reactor Protection System (SCRAM signals)

3. Core Cooling systems

   (a) HPCF (B or C) or RCIC

   (b) RHR-LPFL (A or B or C) + ADS

   (c) RHR shutdown cooling mode (two loops)

   (d) RHR suppression pool cooling mode (two loops)

4. Flow restrictors

5. Control room habitability

6. Spent fuel pool cooling

7. Standby gas treatment

8. The following equipment/systems or portions thereof required to assure the proper operation of those essential items listed in items 1 through 7.

   (a) Class 1E electrical systems, ac and dc (including diesel generator system, 6900, 480 and 120V ac, and 125V dc emergency buses, motor control centers, switchgear, batteries, auxiliary shutdown control panel, and distribution systems).

   (b) Reactor Building Cooling water to the following:

      (1) Room coolers

      (2) Pump coolers (motors and seals)

      (3) Diesel generator auxiliary system coolers

      (4) Electrical switchgear coolers

      (5) RHR heat exchangers

* The essential items listed in this table are protected in accordance with Subsection 3.6.1 consistent with the particular pipe break evaluated.

Table 3.6-2

ESSENTIAL SYSTEMS, COMPONENTS, AND EQUIPMENT* FOR POSTULATED PIPE FAILURES OUTSIDE CONTAINMENT (Continued)

(6) FPC heat exchangers

(7) HECW refrigerators

(c) HVAC

(d) Instrumentation (including post accident monitoring)

(e) Fire Water System

(f) HVAC Emergency Cooling Water System

(g) Process Sampling System

Table 3.6-3

HIGH-ENERGY PIPING INSIDE CONTAINMENT

Piping System	
Main steam	
Main steam drains	
Steam supply to RCIC	
Feedwater	
Recirculation motor cooling	
HPCF	(RPV to first check valve)
RHR-LPFL	(RPV to first check valve)
RHR	(Suction from RPV to first normally closed gate valve)
Reactor Water Cleanup (from RHR and RPV drain)	
RPV head spray (RPV to first check valve)	
RPV vent (RPV to first closed valve)	
Standby Liquid Control (from HPCF to first check valve)	
CRD	(Scram/rod insertion)
RPV bottom head drain lines (RPV to first closed valves)	
Miscellaneous 3-inch and smaller piping	

Table 3.6-4

HIGH ENERGY PIPING OUTSIDE CONTAINMENT

Piping System*
Main Steam
Main Steam Drains
Steam supply to RCIC Turbine
CRD(to and from HCU)
RHR(injection to feedwater from nearest check valves in the RHR lines)
Reactor Water Cleanup (to Feedwater via RHR and to first inlet valve to RPV head spray)
Reactor Water Cleanup (pumps suction and discharge)

* *Fluid systems operating at high-energy levels less than 2 percent of the total time are not included. These systems are classified moderate-energy systems, (i.e., HPCF, RCIC, SAM and SLCS).*

Deleted

Table 3.6-6

MODERATE-ENERGY PIPING OUTSIDE CONTAINMENT

Residual Heat Removal System
(Piping beyond outermost isolation valve)

High Pressure Core Flooder System
(Piping beyond outermost isolation valve)

Reactor Core Isolation Cooling System
(Suction line from condensate storage pool beyond second shutoff valve, vacuum pump discharge line from vacuum pump to containment isolation valve)

Control Rod Drive System
(Piping up to pump suction)

Standby Liquid Control System
(Piping beyond injection valves)

Suppression Pool Cleanup System
(Beyond containment isolation valve) 410.21

Fuel Pool Cooling and Cleanup System

Radioactive Waste System
(Beyond isolation valve)

Instrument/Service Air System
(Beyond isolation valve)

HVAC Cooling Water System

Makeup Water System (Condensate)

Reactor Building Cooling Water System

Turbine Building Cooling Water System

Atmospheric Control System
(Beyond shutoff valve)

Table 3.6-7

ADDITIONAL CRITERIA FOR INTEGRATED LEAKAGE RATE TEST

(1) Those portions of fluids systems that are part of the reactor coolant pressure boundary, that are open directly to the primary reactor containment atmosphere under post-accident conditions and become an extension of the boundary of the primary reactor containment, shall be opened or vented to the containment atmosphere prior to or during the Type A test. Portions of closed systems inside containment that penetrate primary containment and are not relied upon for containment isolation purposes following a LOCA shall be vented to the containment atmosphere.

(2) All vented systems shall be drained of water to the extent necessary to ensure exposure of the system primary containment isolation valves to the containment air test pressure.

(3) Those portions of fluid systems that penetrate primary containment, that are external to containment and are not designed to provide a containment isolation barrier, shall be vented to the outside atmosphere as applicable, to assure that full post-accident differential pressure is maintained across the containment isolation barrier.

(4) Systems that are required to maintain the plant in a safe condition during the Type A test shall be operable in their normal mode and are not vented.

(5) Systems that are normally filled with water and operating under post-LOCA conditions need not be vented.

Deleted

Deleted

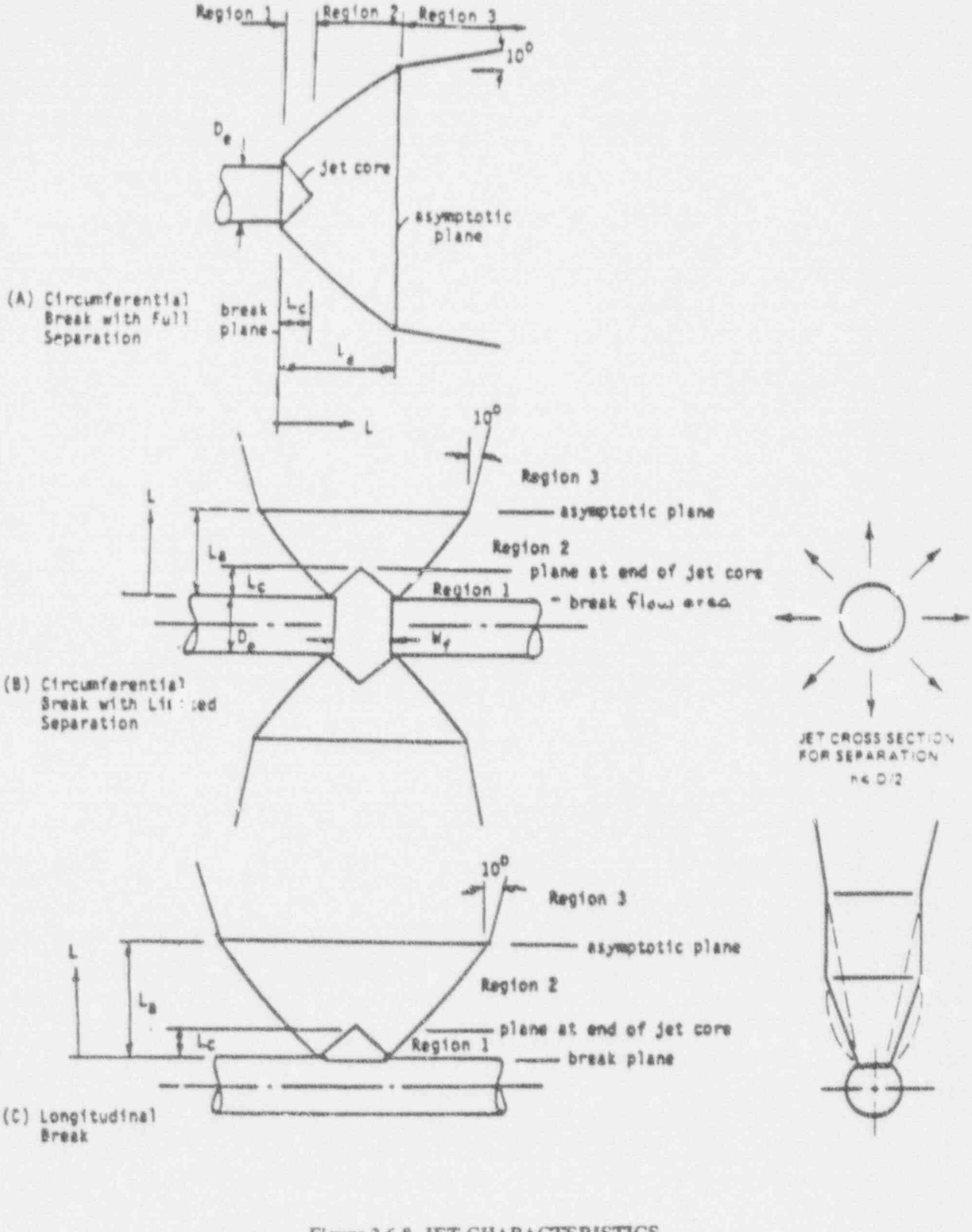


Figure 3.6-8 JET CHARACTERISTICS

Deleted

Deleted

Deleted

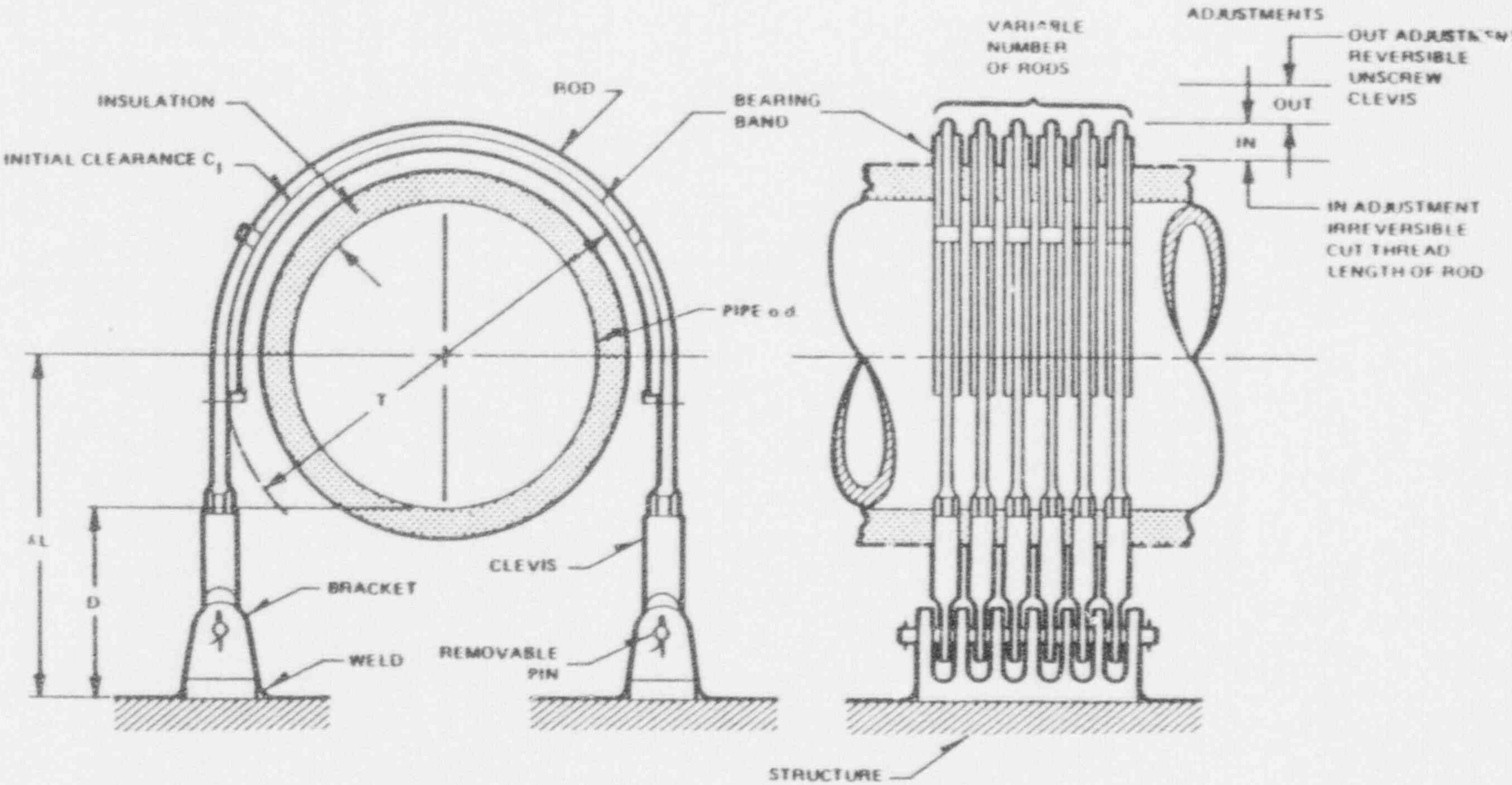
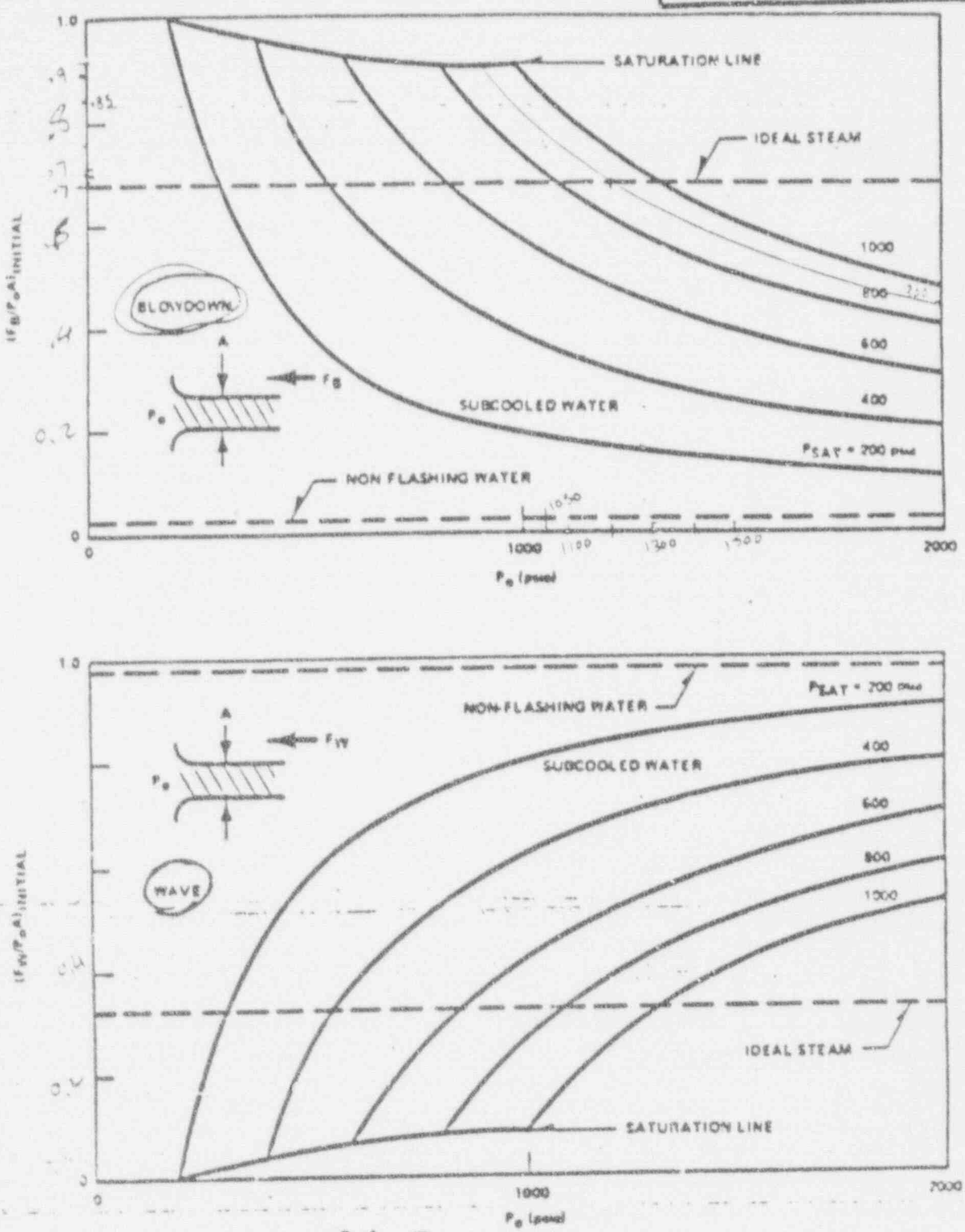


Figure 3.6-6 TYPICAL PIPE WHIP RESTRAINT CONFIGURATION



36-7

FIGURE 5. INITIAL BLOWDOWN AND WAVE FORCES

SECTION 3.7

CONTENTS

SECTION 3.7

CONTENTS (Continued)

SECTION 3.7

CONTENTS (Continued)

SECTION 3.7

CONTENTS (Continued)

SECTION 3.7

CONTENTS (Continued)

SECTION 3.7

TABLES

SECTION 3.7

ILLUSTRATIONS

SECTION 3.7

ILLUSTRATIONS (Continued)

SECTION 3.7

ILLUSTRATIONS (Continued)

3.7 SEISMIC DESIGN

All structures, systems, and equipment of the facility are defined as either Seismic Category I or non-Seismic Category I. The requirements for Seismic Category I identification are given in Section 3.2 along with a list of systems, components, and equipment which are so identified.

All structures, systems, components, and equipment that are safety-related, as defined in Section 3.2, are designed to withstand earthquakes as defined herein and other dynamic loads including those due to reactor building vibration (RBV) caused by suppression pool dynamics. Although this section addresses seismic aspects of design and analysis in accordance with Regulatory Guide 1.70, the methods of this section are also applicable to other dynamic loading aspects, except for the range of frequencies considered. The cutoff frequency for dynamic analysis is 33 Hz for seismic loads and 60 Hz for suppression pool dynamic loads. For piping systems with a fundamental frequency greater than 20 Hz, the cutoff frequency for dynamic analysis is 33 Hz for seismic loads and 100 Hz for suppression pool dynamic loads. The definition of rigid system used in this section is applicable to seismic design only.

The safe shutdown earthquake (SSE) is that earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology, seismology, and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which Seismic Category I systems and components are designed to remain functional. These systems and components are those necessary to ensure:

(1) the integrity of the reactor coolant pressure boundary;

(2) the capability to shut down the reactor and maintain it in a safe shutdown condition; and

(3) the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposures of 10CFR100.

The operating basis earthquake (OBE) is that earthquake which, considering the regional and local geology, seismology, and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant. It is that earthquake which produce vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional. During the OBE loading condition, the safety-related systems are designed to be capable of continued safe operation. Therefore, for this loading condition, safety-related structures, and equipment are required to operate within design limits.

The seismic design for the SSE is intended to provide a margin in design that assures capability to shut down and maintain the nuclear facility in a safe condition. In this case, it is only necessary to ensure that the required systems and components do not lose their capability to perform their safety-related function. This is referred to as the no-loss-of-function criterion and the loading condition as the SSE loading condition.

Not all safety-related components have the same functional requirements. For example, the reactor containment must retain capability to restrict leakage to an acceptable level. Therefore, based on present practice, elastic behavior of this structure under the SSE loading condition is ensured. On the other hand, there are certain structures, components, and systems that can suffer permanent deformation without loss of function. Piping and vessels are examples of the latter where the principal requirement is that they retain contents and allow fluid flow.

Table 3.2-1 identifies the equipment in various systems as Seismic Category I or non-Seismic Category I.

3.7.1 Seismic Input

3.7.1.1 Design Response Spectra

The design earthquake loading is specified in terms of a set of idealized, smooth curves called the design response spectra in accordance with Regulatory Guide 1.60.

Figure 3.7-1 shows the standard ABWR design values of the horizontal SSE spectra applied at the ground surface in the free field for damping ratios of 2.0, 5.0, 7.0 and 10.0% of critical damping where the maximum horizontal ground acceleration is 0.3g @ 33Hz.

values of the vertical SSE spectra applied at the ground surface in the free field for damping ratios of 2.0, 5.0, 7.0, and 10.0% of critical damping where the maximum vertical ground acceleration is 0.30 g at 33Hz, same as the maximum horizontal ground acceleration.

The design values of the OBE response spectra are one-half* of the spectra shown in Figures 3.7-1 and 3.7-2. These spectra are shown in Figures 3.7-3 through 3.7-20.

The design spectra are constructed in accordance with Regulatory Guide 1.60. The normalization factors for the maximum values in two horizontal directions are 1.0 and 1.0 as applied to Figure 3.7-1. For vertical direction, the normalization factor is 1.0 as applied to Figure 3.7-2.

3.7.1.2 Design Time History

The design time histories are synthetic acceleration time histories generated to match the design response spectra defined in Subsection 3.7.1.1.

The design time histories considered in GESSAR (Reference 1) are used. They are developed based on the method proposed by Vanmarcke and Cornell (Reference 2) because of its intrinsic capability of imposing statistical independence among the synthesized acceleration time history components. The earthquake acceleration time history components are identified as H1, H2, and V. The H1 and H2 are the two horizontal components mutually perpendicular to each other. Both H1 and H2 are based on the design horizontal ground spectra shown in Figure 3.7-1. The V is the vertical component and it is based on the design vertical ground spectra shown in Figure 3.7-2.

The magnitude of the SSE design time history is equal to twice the magnitude of the design OBE time history. The OBE time histories and response spectra are used for dynamic analysis and evaluation of the structural Seismic System; the OBE results are doubled for evaluating the structural adequacy for SSE. For development of floor response spectra for Seismic Subsystem analysis and evaluation, see Subsection 3.7.2.5.

The response spectra produced from the OBE design time histories are shown in Figures 3.7-3 through 3.7-20 along with the design OBE response spectra. The closeness of the two spectra in all cases indicates that the synthetic time histories are acceptable.

The response spectra from the synthetic time histories for the damping values of 1, 2, 3 and 4 percent conform to the requirement for an enveloping procedure provided in Item II.1.b of Section 3.7.1 of NUREG-0800 (Standard Review Plan, SRP). However, the response spectra for the higher damping values of 7 and 10 percent show that there are some deviations from the SRP requirement. This deviation is considered inconsequential, because (1) generating an artificial time history whose response spectra would envelop design spectra for five different damping values would result in very conservative time histories for use as design basis input, and (2) the response spectra from the synthetic time histories do envelop the design spectra for the lower damping values. This is very important because the loads due to SSE on structures should use 7 percent damping for concrete components, but are obtained by ratioing up the response from the OBE analysis involving the lower damping. The OBE analysis uses only the lower damping values (up to 4%), which are consistent with the SRP requirements (See Subsection 3.7.1.3).

* *The OBE given in Chapter 2 is one-third of the SSE, i.e., 0.10 g, for the ABWR Standard Nuclear Island design. However, as discussed in Chapter 2, a more conservative value of one-half of the SSE, i.e., 0.15 g, was employed to evaluate the structural and component response.*

The frequency range used in generating the response spectra from synthetic histories is 0.2 to 33 Hz. The frequency range intervals used in generating those spectra is the same as given in Table 3.7.1-1 of SRP Section 3.7.1.

The coherence function for the three earthquake acceleration time history components H1, H2, and V are generated to check the statistical independence among them. The coherence function for H1 and H2 is given in Figure 3.7-21; for H1 and V in Figure 3.7-22; and for H2 and V in Figure 3.7-23. All values within the frequency range between 0 to 50 Hz are calculated at a frequency increment of 0.1 Hz. The small values of these coherence functions indicate that the three components are sufficiently statistically independent.

To assess the energy content of the synthetic time history, the power spectral density functions (PSDFs) are generated from the two horizontal components H1 and H2. The PSDFs are computed at a frequency increment of 0.024 Hz, and are smoothed using the average method as recommended in Revision 2 of Reference 3.

The stationary duration used in the calculation is taken to be 22 seconds which is the total duration of the synthetic time history. The calculated PSDFs for the H1 and H2 time histories normalized to 0.15g peak ground acceleration are shown in Figures 3.7-24 and 3.7-25, respectively, for frequencies ranging from 0.3 to 24 Hz.

The target PSDFs and 80% of target PSDFs specified on revision 2 of Reference 3 are also plotted on these figures for comparison. As shown, PSDF of H1 and H2 time histories envelope the target PSDF with a wide margin in the specified frequency range of 0.3 to 24 Hz. This demonstrates that the two synthetic time kectonies have sufficient energy content.

3.7.1.3 Critical Damping Values

The damping values for OBE and SSE analyses are presented in Table 3.7-1 for various structures and components. They are in compliance with Regulatory Guides 1.61 and 1.84

For seismic system evaluation of the SSE, the larger SSE damping values shown in Table 3.7-1 are not used. The SSE loads are obtained by doubling the OBE loads that result from the OBE Seismic System analysis based on the lower OBE damping values (see Subsection 3.7.1.2).

For analysis and evaluation of seismic subsystems (piping, components and equipment), the floor response spectra are obtained from the OBE time-history response of the seismic system, that supports the subsystems. The floor response spectra are computed (see Subsection 3.7.2.5) for damping values that are applicable to the subsystems under OBE as well as SSE; and further the OBE spectra are doubled to obtain the SSE floor response spectra for input to the SSE analysis in design of the subsystems.

3.7.1.4 Supporting Media for Seismic Category I Structures

The following ABWR Standard Plant Seismic Category I structures have concrete mat foundations supported on soil, rock or compacted backfill. The maximum value of the embedment depth below plant grade to the bottom of the base mat is given below for each structure.

(1) Reactor Building (including the enclosed primary containment vessel and reactor pedestal) - 25.7 m (84 ft, 4 in.).

(2) Control Building - 12.2 m (40 ft).

(3) Service Building - Surface founded.

All of the above buildings have independent foundations. In all cases the maximum value of embedment is used for the dynamic analysis to determine seismic soil-structure interaction effects. The foundation support materials withstand the pressures imposed by appropriate loading combinations without failure. The total structural height of each building is described in Subsection 3.8.2 through 3.8.4. For details of the structural foundations refer to Subsection 3.8.5. The ABWR Standard Plant is designed for a range of soil conditions given in Appendix 3A.

3.7.1.4.1 Soil-Structure Interaction

When a structure is supported on a flexible foundation, the soil-structure interaction is taken into account by coupling the structural model with the soil medium. The finite-element representation is used for a broad range of supporting medium conditions. A different representation based on the continuum impedance approach is also used for selected site conditions. Detailed methodology and results of the soil-structure interaction analysis are provided in Appendices 3A and 3G, respectively.

3.7.2 Seismic System Analysis

This subsection applies to the design of Seismic Category I structures and the reactor pressure vessel (RPV). Subsection 3.7.3 applies to all Seismic Category I piping systems and equipment.

3.7.2.1 Seismic Analysis Methods

Analysis of Seismic Category I structures and the RPV is accomplished using the response spectrum or time-history approach. The time-history approach is made either in the time domain or in the frequency domain.

Either approach utilizes the natural period, mode shapes, and appropriate damping factors of the particular system toward the solution of the equations of dynamic equilibrium. The time-history approach may alternately utilize the direct integration method of solution. When the structural response is computed directly from the coupled structure-soil system, the time-history approach solved in the frequency domain is used. The frequency domain analysis method is described in Appendix 3A.

3.7.2.1.1 The Equations of Dynamic Equilibrium for Base Support Excitation

Assuming velocity proportional damping, the dynamic equilibrium equations for a lumped-mass, distributed-stiffness system are expressed in a matrix form as:

$$[M]\{\ddot{u}(t)\} + [c]\{\dot{u}(t)\} + [K]\{u(t)\} = \{P(t)\} \quad (3.7\text{-}2)$$

where

$\{u(t)\}$ = time-dependent displacement vector of non-support points relative to the supports ($u_t(t) = u(t) + u_s(t)$)

$\{\dot{u}(t)\}$ = time-dependent velocity vector of non-support points relative to the supports

$\{\ddot{u}(t)\}$ = time-dependent acceleration vector of non-support points relative to the supports

$[M]$ = mass matrix

$[C]$ = damping matrix

$[K]$ = stiffness matrix

$\{P(t)\}$ = time-dependent inertia force vector $(-[M]\{u_s(t)\})$ acting at non-support points

The manner in which a distributed-mass, distributed-stiffness system is idealized into a lumped-mass, distributed-stiffness system of Seismic Category I structures and the RPV is

shown in Figure 3.7-28 along with a schematic representation of relative acceleration; $\ddot{u}(t)$, support acceleration; $\ddot{u}_s(t)$ and total acceleration; $\ddot{u}_t(t)$.

3.7.2.1.2 Solution of the Equations of Motion by Modal Superposition

The technique used for the solution of the equations of motion is the method of modal superposition.

The set of homogeneous equations represented by the undamped free vibration of the system is:

$$[M]\{\ddot{u}(t)\} + [K]\{u(t)\} = \{0\}. \qquad (3.7\text{-}3)$$

Since the free oscillations are assumed to be harmonic, the displacements can be written as:

$$\{u(t)\} = \{\phi\}\, e^{i\omega t} \qquad (3.7\text{-}4)$$

where

$\{\phi\}$ = column matrix of the amplitude of displacements $\{u\}$

ω = circular frequency of oscillation

t = time.

Substituting Equation 3.7-4 and its derivatives in Equation 3.7-3 and noting that $e^{i\omega t}$ is not necessarily zero for all values of ωt yields:

$$[-\omega^2 [M] + [K]]\,\{\phi\} = \{0\}. \qquad (3.7\text{-}5)$$

Equation 3.7-5 is the classic dynamic characteristic equation, with solution involving the eigenvalues of the frequencies of vibrations ω_i and the eigenvalues mode shapes, $\{\phi\}_i$, $(i = 1, 2, ..., n)$.

For each frequency ω_i, there is a corresponding solution vector $\{\phi\}_i$ determined to within arbitrary scalar factor Y_i known as the normal coordinate. It can be shown that the mode shape vectors are orthogonal with respect to the weighting matrix [K] in the n-dimensional vector space.

The mode shape vectors are also orthogonal with respect to the mass matrix [M].

The orthogonality of the mode shapes can be used to effect a coordinate transformation of the displacements, velocities and accelerations such that the response in each mode is independent of the response of the system in any other mode. Thus, the problem becomes one of solving n independent differential equations rather than n simultaneous differential equations; and, since the system is linear, the principle of superposition holds and the total response of the system oscillating simultaneously in n modes may be determined by direct addition of the responses in the individual modes.

3.7.2.1.3 Analysis by Response Spectrum Method

The response spectrum method is based on the fact that the modal response can be expressed as a set of convolution integrals which satisfy the governing differential equations. The advantage of this form of solution is that, for a given ground motion, the only variables under the integral are the damping factor and the frequency. Thus, for a specified damping factor it is possible to construct a curve which gives a maximum value of the integral as a function of frequency.

Using the calculated natural frequencies of vibration of the system, the maximum values of the modal responses are determined directly from the appropriate response spectrum. The modal maxima are then combined as discussed in Subsection 3.7.2.7.

When the equipment is supported at more than two points located at different elevations in the building, the response spectrum analysis is performed using the envelope response spectrum of all attachment points. Alternatively, the multiple support excitation analysis methods may be used where acceleration time histories or response spectra are applied to all the equipment attachment points. In some cases, the worst single floor response spectrum selected from a set of floor response spectra obtained at various floors may be applied identically to all floors provided there is no significant shift in frequencies of the spectra peaks.

3.7.2.1.4 Support Displacements in Multi-Supported Structures

In the preceding sections, analysis procedures for forces and displacements induced by time-dependent support displacement were discussed. In a multi-supported structure there are, in addition, time-dependent support displacements which produce additional displacements at nonsupport points and pseudo-static forces at both support and nonsupport points.

The governing equation of motion of a structural system which is supported at more than one point and has different excitations applied at each may be expressed in the following concise matrix form:

$$\begin{bmatrix} M_a & O \\ O & M_s \end{bmatrix} \begin{Bmatrix} \ddot{U}_a \\ \ddot{\bar{U}}_s \end{Bmatrix} + \begin{bmatrix} C_{aa} & C_{as} \\ C_{as} & C_{ss} \end{bmatrix} \begin{Bmatrix} \dot{U}_a \\ \dot{\bar{U}}_s \end{Bmatrix} + \begin{bmatrix} K_{aa} & K_{as} \\ K_{as} & K_{ss} \end{bmatrix} \begin{Bmatrix} U_a \\ \bar{U}_s \end{Bmatrix} = \begin{Bmatrix} \bar{F}_a \\ F_s \end{Bmatrix} \quad (3.7\text{-}6)$$

where

U_a = displacement of the active (unsupported) degrees of freedom;

$\bar{U}_s$ = Specified displacements of support points;

M_a and M_s = lumped diagonal mass matrices associated with the active degrees of freedom and the support points;

C_{aa} and K_{aa} = damping matrix and elastic stiffness matrix, respectively, expressing the forces developed in the active degrees of freedom due to the motion of the active degrees of freedom;

C_{ss} and K_{ss} = support forces due to unit velocities and displacement of the supports;

C_{as} and K_{as} = damping and stiffness matrices denoting the coupling forces developed in the active degrees of freedom by the motion of the supports and vice versa;

$\bar{F}_a$ = prescribed external time-dependent forces applied on the active degrees of freedom; and

F_s = reaction forces at the system support points.

Total differentiation with respect to time is denoted by $(\cdot)$ in Equation 3.7-6. Also, the contributions of the fixed degrees of freedom have been removed in the equation. The procedure utilized to construct the damping matrix is discussed in Subsection 3.7.2.15. The mass and elastic stiffness matrices are formulated by using standard procedures.

Equation 3.7-6 can be separated into two sets of equations. The first set of equations can be written as:

$$[M_s]\{\ddot{\bar{U}}_s\} + [C_{ss}]\{\dot{\bar{U}}_s\} + [K_{ss}]\{\bar{U}_s\} + [C_{as}]\{\dot{U}_a\} + [K_{as}]\{U_a\} = \{F_s\}; \quad (3.7\text{-}7a)$$

and the second set as:

$$[M_a]\{\ddot{U}_a\} + [C_{aa}]\{\dot{U}_a\} + [K_{aa}]\{U_a\} + [C_{as}]\{\dot{\bar{U}}_s\} + [K_{as}]\{\bar{U}_s\} = \{\bar{F}_a\}; \quad (3.7\text{-}7b)$$

The timewise solution of Equation 3.7-7b can be obtained easily by using the standard normal mode solution technique. After obtaining the displacement response of the active degrees of freedom (U_a), Equation 3.7-7a can then be used to solve the support point reaction forces (F_s). Analysis can be performed using either the time history method or response spectrum method.

Modal superposition is used to determine the solutions of the uncoupled form of Equation 3.7-7a. The procedure is identical to that described in Subsection 3.7.2.1.2. Additional requirements associated with the independent support motion response spectrum method of analysis are given in Subsection 3.7.3.8.1.10.

3.7.2.1.5 Dynamic Analysis of Buildings

The time-history method either in the time domain or in the frequency domain is used in the dynamic analysis of buildings. As for the modeling, both finite-element and lumped-mass methods are used.

3.7.2.1.5.1 Description of Mathematical Models

A mathematical model reflects the stiffness, mass, and damping characteristics of the actual structural systems. One important consideration is the information required from the analysis. Consideration of maximum relative displacements among supports of Seismic Category I structures, systems, and components require that enough points on the structure be used. Locations of Seismic Category I equipment are taken into consideration. Buildings are mathematically modeled as a system of lumped masses located at elevations of mass concentrations such as floors.

In general three-dimensional models are used for seismic analysis. In all structures, six degrees of freedom exist for all mass points (i.e., three translational and three rotational). However, in most structures, some of the dynamic degrees of freedom can be neglected or can be uncoupled form each other so that separate analyses can be performed for different types of motions.

Coupling between the two horizontal motions occurs when the center of mass, the centroid, and the center of rigidity do not coincide. The degree of coupling depends on the amount of eccentricity and the ratio of the uncoupled torsional frequency to the uncoupled lateral frequency. Since lateral/torsional coupling and torsional response can significantly influence floor accelerations, structures are in general designed to keep minimum eccentricities. However, for analysis of structures that possess unusual eccentricities, a model of the support building is developed to include the effect of lateral/torsional coupling.

3.7.2.1.5.1.1 Reactor Building and Reactor Pressure Vessel

The reactor building (RB) complex includes: (a) the reinforced concrete containment vessel (RCCV) that includes the reactor shield wall (RSW), the reactor pedestal, and the reactor pressure vessel (RPV) and its internal components (b) the secondary containment zone having many equipment compartments, and (c) the clean zone. The building basemat is assumed to be rigid. Building elevations along the 0°-180° and 90°-270° sections are shown in Figures 3.7-29 and 3.7-30, respectively. The mathematical model is shown in Figure 3.7-31. Model elevations are with respect to the RPV bottom head. The model X and Y axes correspond to the RB 0°-180° and 90°-270° directions, respectively. The Z axis is along the vertical direction. The combined RB model as shown in Figure 3.7-31 basically consists of two uncoupled 2-D models in the X-Z and Y-Z planes since the building is essentially of a symmetric design with respect to its two principal directions in the horizontal plane. The coupling effects of the lateral and torsional motions on the building natural frequencies in the horizontal directions are found to be negligible. Therefore, the uncoupled 2-D models which omit the torsional degrees of freedom are used for seismic dynamic analysis. The methods used to account for torsional effects to define design loads are given in Subsection 3.7.2.11.

The model shown in Figure 3.7-31 corresponds to the X-Z plane. The only differences in terms of schematic representation between the X-Z and Y-Z plane models are that (1) the two building walls represented above EL. 18.5 m (60.7ft) in the X-Z plane by two sticks combine into one stick in the Y-Z plane, and (2) the rotational spring between the RCCV top slab (node 90) and the basemat top (node 88) is presented only in the X-Z plane.

Each structure in the reactor building complex is idealized by a center-lined stick model of a series of massless beam elements. Axial, flexural, and shear deformation effects are included in formulating beam stiffness terms. Coupling between individual structures is modeled by linear spring elements. Masses including dead weights of structural elements, equipment weights and piping weights are lumped to nodal points. The weights of water in the

spent fuel storage pool and the suppression pool are also considered and lumped to appropriate locations.

The portions of the reactor building outside the RCCV are box-type shear wall systems of reinforced concrete construction. The major walls between floor slabs are represented by beam elements of a box cross section. The shear rigidity in the direction of excitation is provided by the parallel walls. The bending rigidity includes the cross walls contribution. The reactor building is fully integrated with the RCCV through floor slabs at various elevations. Spring elements are used to represent the slab in-plane shear stiffness in the horizontal direction. The outer and inner walls between EL. 44.7 m (146.6ft) and 18.5 m (60.7ft) along the X direction are also coupled rigidly in rotation about the Y axis at the connecting slab locations. In the vertical direction a single mass point is used for each slab and it is connected to the walls and RCCV by spring elements. The spring stiffness is determined so that the fundamental frequency of the slab in the vertical direction is maintained.

The RCCV is a cylindrical structure with a flat top slab with the drywell opening, which, along with upper pool girders and reactor building walls, form the upper pool. Mass points are selected at the RB floor slab locations. Stiffnesses are represented by a series of beam elements. In the X-Z plane, a rotational spring element connecting the top slab and the basemat is used to account for the additional rotational rigidity provided by the integrated RCCV-pool girder-building walls system. The RCCV is also coupled to the RPV through the refueling bellows, to the RSW through the RSW stabilizers, and to the reactor pedestal through the diaphragm floor. Spring elements are used to account for these interactions. The lower drywell access tunnels spanning between the RCCV and the reactor pedestal are not modeled since flexible rings are provided which are designed to reduce the coupling effects.

The RSW consists of two steel ring plates with concrete fill in between for shielding purposes. Concrete in the RSW does not contribute to stiffness, but its weight is included. The reactor pedestal is a cylindrical structure of a composite steel-concrete design. The total stiffness of the pedestal includes the full strength of the concrete core. Mass points are selected at equipment interface locations and geometrical discontinuities. In addition, intermediate mass points are chosen to result in more uniform mass distribution. The pedestal supports the reactor pressure vessel and it also provides lateral restraint to the reactor control rod drive housings below the vessel. The top of the RSW is connected to the RPV by the RPV stabilizers which are modeled as spring elements.

The model of the RPV and its internal components is described in Subsection 3.7.2.3.2. This model as shown in Figure 3.7-32 is coupled with the above-described RB model for the seismic analysis.

3.7.2.1.5.1.2 Control Building

The control building dynamic model is shown in Figure 3.7-33. The control building is box type shear wall system reinforced concrete. The major walls between floor slabs are represented by beam elements of a box cross section. The shear rigidity in the direction of excitation is provied by the parallel walls. The bending rigidity includes the cross walls contribution. In the vertical direction a single mass point is used for each slab and it is connected to the walls by spring elements. The spring element stiffness is determined so that the fundamental frequency of the slab in the vertical direction is maintained.

3.7.2.1.5.1.3 Radwaste Building

The radwaste building dynamic model is shown in Figure 3.7-34. The radwaste building is box type shear wall system of reinforced concrete. The major walls between floor slabs are represented by beam elements of a box cross section. The shear rigidity in the direction of excitation is provided by the parallel walls. The bending rigidity includes the cross walls contribution. In the vertical direction a single mass point is used for each slab and it is connected to the walls by spring elements. The spring element stiffness is determined so

that the fundamental frequency of the slab in the vertical direction is maintained.

3.7.2.1.5.2 Rocking and Torsional Effects

Rocking effects due to horizontal ground movement are considered in the soil-structure interaction analysis as described in Appendix 3A. Whenever building response is calculated from a second step structural analysis, rocking effects are included as input simultaneously applied with the horizontal translational motion at the basemat. The torsional effect considered is described in Subsection 3.7.2.11.

3.7.2.1.5.3 Hydrodynamic Effects

For a dynamic system in which a liquid such as water is involved, the hydrodynamic effects on adjacent structures due to horizontal excitation are taken into consideration by including hydrodynamic mass coupling terms in the mass matrix. The basic formulas used for computing these terms are in Reference 4. In the vertical excitation, the hydrodynamic coupling effects

are assumed to be negligible and the water mass is lumped to appropriate structural locations.

3.7.2.2 Natural Frequencies and Response Loads

The natural frequencies up to 33 Hz for the reactor-control buildings and radwaste are presented in Tables 3.7-2 through 3.7-5 and 3.7-10 for the fixed base condition.

Enveloped response loads at key locations in the reactor building complex due to OBE for the range of site conditions considered in Appendix 3A are presented in Appendix 3G. Response spectra at the major equipment elevations and support points are also given in Appendix 3G.

The SSE loads are two times the OBE loads as explained in Subsection 3.7.1.2.

3.7.2.3 Procedure Used for Modeling

3.7.2.3.1 Modeling Techniques for Systems Other Than Reactor Pressure Vessel

An important step in the seismic analysis of systems other than the reactor pressure vessel is the procedure used for modeling. The techniques center around two methods. The first method, the system is represented by lumped masses and a set of spring dashpots idealizing both the inertial and stiffness properties of the system. The details of the mathematical models are determined by the complexity of the actual structures and the information required for the analysis. For the decoupling of the subsystem and the supporting system, the following criteria equivalent to the SRP requirements are used:

(1) If $R_m \leq 0.01$, decoupling can be done for any R_f.

(2) If $0.01 \leq R_m \leq 0.1$, decoupling can be done if $R_f \leq 0.8$ or $R_f \geq 1.25$.

(3) If $R_m > 0.1$, an approximate model of the subsystem should be included in the primary system model.

Where R_m and R_f are defined as:

R_m = Total mass of the supported system/ Mass that supports the subsystem

R_f = Fundamental frequency of the supported subsystem/frequency of the dominant support motion

If the subsystem is comparatively rigid in relation to the supporting system, and also is rigidly connected to the supporting system, it is sufficient to include only the mass of the subsystem at the support point in the primary system model. On the other hand, in case of a subsystem supported by very flexible connections, e.g., pipe supported by hangers, the subsystem need not be included in the primary model. In most cases the equipment and components, which come under the definition of subsystems, are analyzed (or tested) as a decoupled system from the primary structure and the seismic input for the former is obtained by the analysis of the latter. One important exception to this procedure is the reactor coolant system, which is considered a subsystem but is usually analyzed using a coupled model of the reactor coolant system and primary structure.

In the second method of modeling, the structure of the system is represented as a two- or three-dimensional finite-element model using combinations of beam, plate, shell, and solid elements. The details of the mathematical models are determined by the complexity of the actual structures and the information required for the analysis.

3.7.2.3.2 Modeling of Reactor Pressure Vessel and Internals

The seismic loads on the RPV and reactor internals are based on coupled dynamic analysis with the reactor building. The mathematical model of the RPV and internals is shown in Figure 3.7-32. This model is coupled with the reactor building model for this analysis.

The RPV and internals mathematical model consists of lumped masses connected by elastic beam element members. Using the elastic properties of the structural components, the stiffness properties of the model are determined and the effects of axial bending and shear are included.

Mass points are located at all points of critical interest such as anchors, supports,

points of discontinuity, etc. In addition, mass points are chosen so that the mass distribution in various zones is uniform as practicable and the full range of frequency of response of interest is adequately represented. Further, in order to facilitate hydrodynamic mass calculations, several mass points (fuel, shroud, vessel) are selected at the same elevation. The RPV and internals are quite stiff in the vertical direction. Vertical modes in the frequency range of interest are adequately obtained with few dynamic degrees of freedom. Therefore, vertical masses are distributed to a few key nodal points. The various length of control rod drive housing are grouped in to the two representative lengths shown in Figure 3.7-32. These lengths represent the longest and shortest housing in order to adequately represent the full range of frequency response of the housings.

Not included in the mathematical model are the stiffness properties of light components, such as in-core guide tubes and housings, sparger, and their supply headers. This is done to reduce the complexity of the dynamic model. For the seismic responses of these components, floor response spectra generated from system analysis is used.

The presence of a fluid and other structural components (e.g., fuel within the RPV) introduces a dynamic coupling effect. Dynamic effects of water enclosed by the RPV are accounted for by introduction of a hydrodynamic mass matrix which will serve to link the acceleration terms of the equations of motion of points at the same elevation in concentric cylinders with a fluid entrapped in the annulus. The details of the hydrodynamic mass derivation are given in Reference 4.

3.7.2.4 Soil-Structure Interaction

The soil model and soil-structure interaction analysis are described in Appendix 3A.

3.7.2.5 Development of Floor Response Spectra

In order to predict the seismic effects on equipment located at various elevations within a structure, floor response spectra are developed using a time-history analysis technique.

The procedure entails first developing the mathematical model assuming a linear system and then obtaining its natural frequencies and mode shapes. The dynamic response at the mass points is subsequently obtained by using a time-history approach.

Using the acceleration time-history response of a particular mass point, a spectrum response curve is developed and incorporated into a design acceleration spectrum to be utilized for the seismic analysis of equipment located at the mass point. Horizontal and vertical response spectra are computed for various damping values applicable for OBE and SSE evaluation of equipment. Two orthogonal horizontal and one vertical earthquake component are input separately. Response spectra at selected locations are then generated for each earthquake component separately. They are combined using the square-root-of-the-sum-of-the-squares (SRSS) method to predict the total co-directional floor response spectrum for that particular frequency. This procedure is carried out for each site-soil case used in the soil-structure interaction analysis. Response spectra for all site-soil cases are finally combined to arrive at one set of final response spectra.

An alternate approach to obtain co-directional floor response spectra is to perform dynamic analysis with simultaneous input of various earthquake components if those components are statistically independent to each other.

The SSE floor response spectra are obtained by doubling the OBE response spectra as explained in Subsection 3.7.1.3.

The response spectra values are computed as a minimum either at frequency intervals as specified in Table 3.7.1-1 of SRP 3.7.1 or at a set of frequencies in which each frequency is within 10% of the previous one.

3.7.2.6 Three Components of Earthquake Motion

The three components of earthquake motion are considered in the building seismic analyses. To properly account for the responses of systems subjected to the three-directional excitation, a statistical combination is used to obtain the net response according to the SRSS criterion of Regulatory Guide 1.92. The SRSS method accounts for the randomness of magnitude and direction of

earthquake motion. The SRSS criterion, applied to the responses associated with the three components of ground earthquake motion, is used for seismic stress computation for steel structural design as well as for resultant seismic member force computations for reinforced concrete structural design.

3.7.2.7 Combination of Modal Response

Since only the time-history method is used for seismic system analysis, the response spectrum combination of modal responses is not applied.

3.7.2.8 Interaction of Non-Category I Structures with Seismic Category I Structures

The interfaces between Seismic Category I and non-Seismic Category I structures and plant equipment are designed for the dynamic loads and displacements produced by both the Category I and non-Category I structures and plant equipment. All non-Category I structures will meet any one of the following requirements:

(1) The collapse of any non-Category I structure will not cause the non-Category I structure to strike a Seismic Category I structure component.

(2) The collapse of any non-Category I structure will not impair the integrity of Seismic Category I structures or components

(3) The non-Category I structures will be analyzed and designed to prevent their failure under SSE conditions in manner such that the margin of safety of these structures is equivalent to that of Seismic Category I structures.

3.7.2.9 Effects of Parameter Variations on Floor Response Spectra

The following conservative assumptions are included in the calculation of the floor response spectra:

(1) The expected actual earthquake time histories are enveloped by a smooth ground response spectrum for design use. The smooth curve leads to conservative effects on modal analysis because it treats all the modes in the maximum acceleration range having the same amplification factor as the most strongly amplified.

(2) The time history used to calculate the floor response spectra produces a ground response which envelopes the design ground response spectra. In order to do this, it has spectral peaks which are substantially higher than the design spectra.

(3) The building and soil damping values used in the analysis are near the lower bound of the available damping data. The actual values of damping are expected to be much higher than the values used in the analysis.

(4) The yield strengths used in the analysis are based on the minimum values and are considerably lower than expected values.

(5) The additional strength and damping that is available when materials are stressed beyond yield are neglected when using linear elastic analytical methods.

(6) The working stresses for most equipment are usually considerably below the yield stresses.

(7) The calculated natural frequencies of equipment are usually lower than actual because of conservative modeling assumptions.

These elements of conservatism are in series (i.e., they are compounded), which results in an extremely conservative design. The only reason for broadening the spectra at all is to account for the unlikely possibility that a particular piece of equipment might have a natural frequency which is not on the calculated spectral peak but is on the real peak.

Since the peaks characteristic of the low damping response are narrow, such an occurrence is extremely improbable. Even if this eventuality does occur, the extreme conservatism described above ensures seismic adequacy of equipment design. Further, the floor response spectra obtained from the time-history analysis of the building are b[illegible]ed plus and minus 10% in frequency. Al[illegible]vely, peak shifting

method of ASME Code Case N-397, as permitted by Regulatory Guide 1.84, Revision 24, is used.

The broadening method of accounting for variations causes modes having frequencies near the spectral peaks to be calculated as though they experience the peak acceleration. This is quite conservative because the spectra for the actual structure have only one narrow peak somewhere in the 20% broadened range.

3.7.2.10 Use of Constant Vertical Static Factors

Since all Seismic Category I structures and the RPV are subjected to a vertical dynamic analysis with a time-history defining the input, no constant vertical static factors are utilized.

3.7.2.11 Methods Used to Account for Torsional Effects

Torsional effects for two-dimensional analytical models are accounted for in the following manner. The locations of the center of mass are calculated for each floor. The centers of rigidity and rotational stiffness are determined for each story. Torsion effects are introduced in each story by applying a rotational moment about its center of rigidity. The rotational moment is calculated as the sum of the products of the inertial force applied at the center of mass of each floor above and a moment arm equal to the distance from the center of mass of the floor to the center of rigidity of the story plus five percent of the maximum building dimension at the level under consideration. To be conservative, the absolute values of the moments are used in the sum. The torsional moment and story shear are distributed to the resisting structural elements in proportion to each individual stiffness.

The RPV model is axisymmetric with no built-in eccentricity. Hence, the torsional effects for the RPV are only those associated with the reactor building model.

3.7.2.12 Comparison of Responses

Since only the time-history method is used for structural analysis, the responses obtained from response spectrum and time-history methods are not compared.

3.7.2.13 Methods for Seismic Analysis of Category I Dams

The analysis of all Category I dams, if applicable for the site, taking into consideration the dynamic nature of forces (due to both horizontal and vertical earthquake loadings), the behavior of the dam material under earthquake loadings, soil structure interaction effects, and nonlinear stress-strain relations for the soil, will be used. Analysis of earth-filled dams, if applicable, includes an evaluation of deformations.

3.7.2.14 Determination of Seismic Category I Structure Overturning Moments

Seismic loads are dynamic in nature. The method of calculating seismic loads with dynamic analysis and then treating them as static loads to evaluate the overturning of structures and foundation failures while treating the foundation materials as linear elastic is conservative. Overturning of the structure, assuming no soil slip failure occurs, can be caused only by the center of gravity of the structure moving far enough horizontally to cause instability.

Furthermore, when the combined effect of earthquake ground motion and structural response is strong enough, the structure undergoes a rocking motion pivoting about either edge of the base. When the amplitude of rocking motion becomes so large that the center of structure mass reaches a position right above either edge of the base, the structure becomes unstable and may tip over. The mechanism of the rocking motion is like an inverted pendulum and its natural period is long compared with the linear, elastic struc- tural response. Thus with regard to overturning, the structure is treated as a rigid body.

The maximum kinetic energy can be conservatively estimated to be:

$$E_s = \frac{1}{2} \sum_i m_i \left[(v_H)_i^2 + (v_V)_i^2 \right] \qquad (3.7\text{-}8)$$

where (v_H) and (v_V) are the maximum values of the total lateral velocity and total vertical velocity, respectively, of mass m_i.

Values for $(v_H)_i$ and $(v_V)_i$ are computed as follows:

$$(v_H)_i^2 = (v_x)_i^2 + (v_H)_g^2 \quad (3.7\text{-}9)$$

$$(v_V)_i^2 = (v_z)_i^2 + (v_V)_g^2 \quad (3.7\text{-}10)$$

where $(v_H)_g$ and $(v_V)_g$ are the peak horizontal and vertical ground velocity, respectively, and $(v_x)_i$ and $(v_z)_i$ are the maximum values of the relative lateral and vertical velocity of mass m_i.

Letting m_o be total mass of the structure and base mat, the energy required to overturn the structure is equal to

$$E_o = m_o g h \quad (3.7\text{-}11)$$

where h is the height to which the center of mass of the structure must be lifted to reach the overturning position. Because the structure may not be a symmetrical one, the value of h is computed with respect to the edge that is nearer to the center of mass. The structure is defined as stable against overturning when the ratio E_o to E_s exceeds 1.5.

These calculations assume the structure rests on the ground surface, hence, are conservative because the structure is actually embedded to a considerable depth. The embedded effect is considered only when the ratio E_o to E_s is less than 1.5.

3.7.2.15 Analysis Procedure for Damping

In a linear dynamic analysis using a modal superposition approach, the procedure to be used to properly account for damping in different elements of a coupled system model is as follows:

(1) The structural percent critical damping of the various structural elements of the model is first specified. Each value is referred to as the damping ratio (C_j) of a particular component which contributes to the complete stiffness of the system.

(2) An eigenvalue analysis of the linear system model is performed. This results in the eigenvector matrices (ϕ_i) which are normalized and satisfy the orthogonality conditions:

$$\phi_i^T K \phi_i = \omega_i^2, \text{ and } \phi_i^T K \phi_j = 0 \text{ for } i \neq j \quad (3.7\text{-}12)$$

where

K = stiffness matrix;

ω_i = circular natural frequency associated with mode i; and

ϕ_i^T = transpose of i^{th} mode eigenvector ϕ_i

Matrix ϕ contains all translational and rotational coordinates.

(3) Using the strain energy of the individual components as a weighting function, the following equation is derived to obtain a suitable damping ratio (β_i) for mode i

$$\beta_i = \frac{1}{\omega_i^2} \sum_{j=1}^{N} \left[C_j \left(\phi_i^T K \phi_i \right)_j \right] \quad (3.7\text{-}13)$$

where

β_i = modal damping coefficient for i^{th} mode;

N = total number of structural elements;

ϕ_i = component of i^{th} mode eigenvector corresponding to j^{th} element;

ϕ_i^T = Transpose of ϕ_i defined above;

C_j = percent critical damping associated with element j.

K = stiffness matrix of element j; and

ω_i = circular natural frequency of mode i.

3.7.3 Seismic Subsystem Analysis

3.7.3.1 Seismic Analysis Methods

This subsection discusses the methods by which Seismic Category I subsystems and components are qualified to ensure the functional integrity of the specific operating requirements which characterize their Seismic Category I designation.

In general, one of the following five methods of seismically qualifying the equipment is chosen based upon the characteristics and complexities of the subsystem:

(1) dynamic analysis;

(2) testing procedures;

(3) equivalent static load method of analysis;

(4) a combination of (1) and (2); or

(5) a combination of (2) and (3).

replace w/ Att. A

Equivalent static load method of subsystem analysis is described in Subsection 3.7.3.5.

Appropriate design response spectra (OBE and SSE) are furnished to the manufacturer of the equipment for seismic qualification purposes. Additional information such as input time history is also supplied only when necessary.

When analysis is used to qualify Seismic Category I subsystems and components, the analytical techniques must conservatively account for the dynamic nature of the subsystems or components. Both the SSE and OBE, with their difference in damping values, are considered in the dynamic analysis as explained in Subsection 3.7.1.3.

~~The general approach employed in the dynamic analysis of Seismic Category I equipment and component design is based on the response spectrum technique.~~ The time-history technique described in Subsection 3.7.2.1.1 generates timehistories at various support elevations for use in the analysis of subsystems and equipment. The structural response spectra curves are subsequently generated from the time history accelerations.

The dynamic analysis of Seismic Category I subsystems and components is accomplished using the response spectrum or time-history approach. Time History analysis is performed using either the direct integration method or the modal superposition method.

At each level of the structure where vital components are located, three orthogonal components of floor response spectra, two horizontal and one vertical, are developed. The floor response spectrum is smoothed and envelopes all calculated response spectra from different site soil conditions. The response spectra are peak broadened plus or minus 10%. When components are supported at two or more elevations, the response spectra of each elevation are superimposed and the resulting spectrum is the upper bound envelope of all the individual spectrum curves considered.

~~For vibrating systems and their supports, multi-degree-of-freedom models are used in accordance with the lumped-parameter modeling techniques and normal mode theory described in Subsection 3.7.2.1.1. Piping analysis is described in Subsection 3.7.3.3.1.~~

When testing is used to qualify Seismic Category I subsystems and components, all the loads normally acting on the equipment are simulated during the test. The actual mounting of the equipment is also simulated or duplicated. Tests are performed by supplying input accelerations to the shake table to such an extent that generated test response spectra (TRS) envelope the required response spectra.

For certain Seismic Category I equipment and components where dynamic testing is necessary to ensure functional integrity, test performance data and results reflect the following:

(1) performance data of equipment which has been subjected to dynamic loads equal to or greater than those experienced under the specified seismic conditions;

(2) test data from previously tested comparable equipment which has been subjected under similar conditions to dynamic loads equal to or greater than those specified; and

ATTACHMENT A for page 3.7-14

For vibrating systems and their supports, two general methods are used to obtain the solution of the equations of dynamic equilibrium of a multi-degree-of-freedom model. The first is the Method of Modal Superposition described in subsection 3.7.2.1.2. The second method of dynamic analysis is the Direct Integration Method. The solution of the equations of motion is obtained by direct step-by-step numerical integration. The numerical integration time step, Δt, must be sufficiently small to accurately define the dynamic excitation and to render stability and convergency of the solution up to the highest frequency of significance. The integration time step is considered acceptable when smaller time steps introduce no more than a 10% error in the total dynamic response. For most of the commonly used numerical integration methods (such as Newmark β -method and Wilson θ - method), the maximum time step is limited to one-tenth of the smallest period of interest. The smallest period of interest is generally the reciprocal of the analysis cutoff frequency.

When the time-history method of analysis is used, the time-history data is broadened plus and minus 15% of Δt in order to account for modeling uncertainties. For loads such as Safety-Relief Valve blowdown, tests have been performed which confirm the conservatism of the analytical results. Therefore, for these loads the calculated force time-histories are not broadened plus and minus 15% of Δt.

Piping modeling and dynamic analysis are described in subsection 3.7.3.3.1.

(3) actual testing of equipment in accordance with one of the methods described in Subsection 3.9.2.2 and Section 3.10.

3.7.3.2 Determination of Number of Earthquake Cycles

3.7.3.2.1 Piping

Fifty (50) peak OBE cycles are postulated for fatigue evaluation.

3.7.3.2.2 Other Equipment and Components

Criterion II.2.b of SRP Section 3.7.3 recommends that at least one safe shutdown earthquake (SSE) and five operating basis earthquakes (OBEs) should be assumed during the plant life. It also recommends that a minimum of 10 maximum stress cycles per earthquake should be assumed (i.e., 10 cycles for SSE and 50 cycles for OBE). For equipment and components other than piping, 10 peak OBE stress cycles are postulated for fatigue evaluation based on the following justification.

To evaluate the number of cycles engendered by a given earthquake, a typical Boiling Water Reactor Building reactor dynamic model was excited by three different recorded time histories: May 18, 1940, El Centro NS component, 29.4 sec; 1952, Taft N69° W component, 30 sec; and March 1957, Golden Gates 89°E component, 13.2 sec. The modal response was truncated so that the response of three different frequency bandwidths could be studied, 0+-to-10 Hz, 10-to-20 Hz, and 20-to-50 Hz. This was done to give a good approximation to the cyclic behavior expected from structures with different frequency content.

Enveloping the results from the three earthquakes and averaging the results from several different points of the dynamic model, the cyclic behavior given in Table 3.7-6 was formed.

Independent of earthquake or component frequency, 99.5% of the stress reversals occur below 75% of the maximum stress level, and 95% of the reversals lie below 50% of the maximum stress level.

In summary, the cyclic behavior number of fatigue cycles of a component during a earthquake is found in the following manner:

(1) the fundamental frequency and peak seismic loads are found by a standard seismic analysis (i.e., from eigen extraction and forced response analysis);

(2) the number of cycles which the component experiences are found from Table 3.7-6 according to the frequency range within which the fundamental frequency lies; and

(3) for fatigue evaluation, one-half percent (0.005) of these cycles is conservatively assumed to be at the peak load, and 4.5% (0.045) at the three-quarter peak. The remainder of the cycles have negligible contribution to fatigue usage.

The SSE has the highest level of response. Howeve , the encounter probability of the SSE is so small that it is not necessary to postulate the possibility of more than one SSE during the 60-year life of a plant. Fatigue evaluation due to the SSE is not necessary since it is a faulted condition and thus not required by ASME Code Section III.

The OBE is an upset condition and is included in fatigue evaluations according to ASME Code Section III. Investigation of seismic histories for many plants show that during a 60-year life it is probable that five earthquakes with intensities one-tenth of the SSE intensity, and one earthquake approximately 20% of the proposed SSE intensity, will occur. The 60-year life corresponds to 40 years of actual plant operation divided by a 67% usage factor. To cover the combined effects of these earthquakes and the cumulative effects of even lesser earthquakes, 10 peak OBE stress cycles are postulated for fatigue evaluation.

3.7.3.3 Procedure Used for Modeling

3.7.3.3.1 Modeling of Piping Systems

3.7.3.3.1.1 Summary

To predict the dynamic response of a piping system to the specified forcing function, the dynamic model must adequately account for all significant modes. Careful selection must be made of the proper response spectrum curves and

proper location of anchors in order to separate Seismic Category I from non-Category I piping systems.

3.7.3.3.1.2 Selection of Mass Points

When performing a dynamic analysis, a piping system is idealized either as a mathematical model consisting of lumped masses connected by weightless elastic members or as a consistent mass model. The elastic members are given the properties of the piping system being analyzed. The mass points are carefully located to adequately represent the dynamic properties of the piping system. A mass point is located at the beginning and end of every elbow or valve, at the extended valve operator, and at the intersection of every tee. On straight runs, mass points are located at spacings no greater than the span length corresponding to 33 Hz. A mass point is located at every extended mass to account for torsional effects on the piping system. In addition, the increased stiffness and mass of valves are considered in the modeling of a piping system.

Replace with Att. B

3.7.3.3.1.3 Selection of Spectrum Curves

In selecting the spectrum curve to be used for dynamic analysis of a particular piping system, a curve is chosen which most closely describes the accelerations existing at the end points and restraints of the system. The procedure for decoupling small branch lines from the main run of Seismic Category I piping systems when establishing the analytical models to perform seismic analysis are as follows:

(1) *The small branch lines are decoupled from the main runs if the ratio of run to branch pipe moment of inertia is 25 to 1, or more.*

(2) The stiffness of all the anchors and its supporting steel is large enough to effectively decouple the piping on either side of the anchor for analytic and code jurisdictional boundary purposes. The RPV is very stiff compared to the piping system and therefore, it is modeled as an anchor. Penetration assemblies (head fittings and penetration sleeve pipe) are very stiff compared to the piping system and are modeled as anchors.

The stiffness matrix at the attachment location of the process pipe (i.e., main steam, RHR supply and return, RCIC, etc.) head fitting is sufficiently high to decouple the penetration assembly from the process pipe. Previous analysis indicates that a satisfactory minimum stiffness for this attachment point is equal to the stiffness in bending and torsion of a cantilevered pipe section of the same size as the process pipe and equal in length to three times the process pipe outer diameter.

For a piping system supported at more than two points located at different elevations in the building, the response spectrum analysis is performed using the envelope response spectrum of all attachment points. Alternatively, the multiple support excitation analysis methods may be used where ~~acceleration time histories or~~ response spectra are applied at all the piping attachment points. Finally, the worst single floor response spectrum selected from a set of floor response spectra obtained at various floors may be applied identically to all floors provided it envelops the other floor response spectra in the set.

INSERT ATT. C

3.7.3.3.2 Modeling of Equipment

For dynamic analysis, Seismic Category I equipment is represented by lumped-mass systems which consist of discrete masses connected by weightless springs. The criteria used to lump masses are:

(1) The number of modes of a dynamic system is controlled by the number of masses used; therefore, the number of masses is chosen so that all significant modes are included. The modes are considered as significant if the corresponding natural frequencies are less than 33 Hz and the stresses calculated from these modes are greater than 10% of the total stresses obtained from lower modes. This approach is acceptable provided at least 90% of the loading/inertia is contained in the modes used. Alternately,

ATTACHMENT B for page 3.7-16

3.7.3.3.1.2 Selection of Mass Points

Mathematical models for Seismic Category I piping systems are constructed to reflect the dynamic characteristics of the system. The continuous system is modelled as an assemblage of pipe elements supported by hangers, guides, anchors, struts and snubbers. Pipe and hydrodynamic masses are lumped at the nodes and are connected by weightless elastic beam elements which reflect the physical properties of the corresponding piping segment. The node points are selected to coincide with the locations of large masses, such as valves, pumps and motors, and with locations of significant geometry change. All pipe mounted equipment, such as valves, pumps and motors, are modelled with lumped masses connected by elastic beam elements which reflect the physical properties of the pipe mounted equipment. The torsional effects of valve operators and other pipe mounted equipment with offset centers of gravity with respect to the piping center line are included in the mathematical model. On straight runs, mass points are located at spacings no greater than the span which would have a fundamental frequency equal to the cutoff frequency stipulated in Subsection 3.7 when calculated as a simply supported beam with uniformly distributed mass.

ATTACHMENT C to page 3.7-16

3.7.3.3.1.7 Modelling of Special Engineered Pipe Supports

Modifications to the normal linear-elastic piping analysis methodology used with conventional pipe supports are required to calculate the loads acting on the supports and on the piping components when the special engineered supports, described in Subsection 3.9.3.4.1(6), are used. These modifications are needed to account for greater damping of the energy absorbers and the non-linear behavior of the limit stops. If these special devices are used, the modeling and analytical methodology will be in accordance with methodology accepted by the regulatory agency at the time of certification or at the time of application, per the discretion of the applicant.

3.7.3.3.1.5 Selection of Input Time-Histories

"In selecting the acceleration time-history to be used for dynamic analysis of a piping system, the time-history chosen is one which most closely describes the accelerations existing at the piping support attachment points. For a piping system supported at more than two points located at different elevations in the building, the time-history analysis is performed using the independent support motion method where acceleration time histories are input at all of the piping structural attachment points."

3.7.3.3.1.6 Modeling of Piping Supports

Snubbers are modeled with an equivalent stiffness which is based on dynamic tests performed on prototype snubber assemblies or on data provided by the vendor. Struts are modeled with a stiffness calculated based on their length and cross-sectional properties. The stiffness of the supporting structure for snubbers and struts is included in the piping analysis model, unless the supporting structure can be considered rigid relative to the piping. The supporting structure can be considered as rigid relative to the piping as long as the criteria specified in Subsection 3.7.3.3.4 are met.

Anchors at equipment such as tanks, pumps and heat exchangers are modeled with calculated stiffness properties. Frame type pipe supports are modeled as described in Subsection 3.7.3.3.4.

Attachment C. to pg. 3.7-16 (continued)

GE-NE
ABWR PROGRAMS
MECHANICAL SYSTEMS DESIGN
FILE: MH-A13

DISTRIBUTION:
JBK; JNF;

DATE: AUGUST 27, 1992

TO: MARYANN HERZOG

FROM: E.O. SWAIN

SUBJECT: AUDIT ITEM A-13 - RESPONSE SPECTRA AT DECOUPLED PIPE CONNECTION

3.7.3.3.1.~~6~~ 4 Dynamic Analysis of seismic Category 1, Decoupled Branch Pipe

The dynamic analysis of seismic Category 1, decoupled branch pipe is performed by either the equivalent static method or by one of the dynamic analysis methods described in the SSAR. In addition small bore branch pipe may be designed and analyzed in accordance with a small bore pipe manual in accordance with the requirements of Paragraph 3.7.3.8.1.9.

The response spectra used for the dynamic analysis or for determining the static input load when the equivalent static method is used will be selected as follows:

(1) The response spectra will be based on the building or structure elevation of the branch line connection to the run pipe and the elevation of the branch line anchors and restraints

(2) The response spectra will not be less than the envelope of the response spectra used in the dynamic analysis of run pipe. Amplification by the run pipe must be accounted for. However,

(3) If the location of branch connection to the run pipe is more than three run pipe diameters from the nearest run pipe seismic restraint, amplification by the run pipe will be accounted for.

When the equivalent static analysis method is used, the horizontal and vertical load coefficients, C_h and C_v, applied to the response spectra accelerations will conform with Paragraph 3.7.3.8.1.5.

The relative anchor motions to be used in either static or dynamic analysis of the decoupled branch pipe shall be as follows:

(1) The inertial displacements only, as determined from analysis of the run pipe, may be applied to the branch pipe if the relative differential building movements of the large pipe supports and the branch pipe supports are less than 1/16".

(2) If the relative differential building movements of the large pipe supports and the branch pipe supports are more than 1/16", motion of the restraints and anchors of the branch pipe must be considered in addition to the inertial displaceme[illegible] of the run pipe.

the number of degrees of freedom are taken more than twice the number of modes with frequencies less than 33 Hz.

(2) Mass is lumped at any point where a significant concentrated weight is located (e.g., the motor in the analysis of pump motor stand, the impeller in the analysis of pump shaft, etc).

(3) If the equipment has free-end overhang span with flexibility significant compared to the center span, a mass is lumped at the overhang span.

(4) When a mass is lumped between two supports, it is located at a point where the maximum displacement is expected to occur. This tends to lower the natural frequencies of the equipment because the equipment frequencies are in the higher spectral range of the response spectra. Similarly, in the case of live loads (mobile) and a variable support stiffness, the location of the load and the magnitude of support stiffness are chosen to yield the lowest frequency content for the system. This ensures conservative dynamic loads since the equipment frequencies are such that the floor spectra peak is in the lower frequency range. If not, the model is adjusted to give more conservative results.

3.7.3.3 Field Location of Supports and Restraints

Service Level D

The field location of seismic supports and restraints for Seismic Category I piping and piping systems components is selected to satisfy the following two conditions:

(1) the location selected must furnish the required response to control strain within allowable limits; and

(2) adequate building strength and stiffness for attachment of the component supports must be available.

The final location of seismic supports and restraints for Seismic Category I piping, piping system components, and equipment, including the placement of snubbers, is checked against the drawings and instructions issued by the engineer. An additional examination of these supports and restraining devices is made to assure that their location and characteristics are consistent with the dynamic and static analyses of the system.

3.7.3.3.4 Analysis of Frame Type Pipe Supports

The design loads on frame type pipe supports include (a) loads transmitted to the support by the piping response to thermal expansion, dead weight, and the inertia and anchor motion effects, and (b) support internal loads caused by the weight, thermal and inertia effects of loads of the structure itself, and (c) friction loads caused by the pipe sliding on the support. To calculate the frictional force acting on the support, dynamic loads that are cyclic in nature need not be considered. The coefficient of friction used will be static coefficients and will be substantiated by actual test data covering the range of materials, geometry and loading condition. To determine the response of the support structure to applied dynamic loads, the equivalent static load method of analysis described in Paragraph 3.7.3.8.1.5 may be used. The loads transmitted to the support by the piping will be applied as static loads acting on the support.

As in the case of other supports, the forces the piping places on the frame-type support are obtained from an analysis of the piping. In the analysis of the piping the stiffness of the frame-type supports shall be included in the piping analysis model, unless the support can be shown to be rigid. The frame type supports may be modeled as rigid restraints providing they are designed so the maximum deflection in the direction of the applied load is less than 1/16 inch and providing the total gap or diametrical clearance between the pipe and frame support is between 1/16" and 3/16" when the pipe is in either the hot or cold condition. ← Add insert AA

3.7.3.4 Basis of Selection of Frequencies

Where practical, in order to avoid adverse resonance effects, equipment and components are designed/selected such that their fundamental frequencies are outside the range of 1/2 to twice the dominant frequency of the associated support structures. Moreover, in any case, the equipment is analyzed and/or tested to demonstrate that it is adequately designed for the applicable loads considering both its fundamental frequency and the forcing frequency of the applicable support structure. 210.27

Insert AA to pg. 3.7-17

For a frame type support to be considered rigid, it should be at least 50 times as stiff as the piping. The piping stiffness is calculated using the following equation:

$$K_p = \frac{EI}{L^3}$$

E = modulus of Elasticity of pipe

I = moment of inertia of pipe

L = one-half the suggested pipe support spacing in Table NF-3611-1 of ASME Code Section III

the number of degrees of freedom are taken more than twice the number of modes with frequencies less than 33 Hz.

(2) Mass is lumped at any point where a significant concentrated weight is located (e.g., the motor in the analysis of pump motor stand, the impeller in the analysis of pump shaft, etc).

(3) If the equipment has free-end overhang span with flexibility significant compared to the center span, a mass is lumped at the overhang span.

(4) When a mass is lumped between two supports, it is located at a point where the maximum displacement is expected to occur. This tends to lower the natural frequencies of the equipment because the equipment frequencies are in the higher spectral range of the response spectra. Similarly, in the case of live loads (mobile) and a variable support stiffness, the location of the load and the magnitude of support stiffness are chosen to yield the lowest frequency content for the system. This ensures conservative dynamic loads since the equipment frequencies are such that the floor spectra peak is in the lower frequency range. If not, the model is adjusted to give more conservative results.

3.7.3.3.3 Field Location of Supports and Restraints

The field location of seismic supports and restraints for Seismic Category I piping and piping systems components is selected to satisfy the following two conditions:

(1) the location selected must furnish the required response to control strain within allowable limits; and

(2) adequate building strength and stiffness for attachment of the component supports must be available.

The final location of seismic supports and restraints for Seismic Category I piping, piping system components, and equipment, including the placement of snubbers, is checked against the drawings and instructions issued by the engineer. An additional examination of these supports and restraining devices is made to assure that their location and characteristics are consistent with the dynamic and static analyses of the system.

3.7.3.4 Basis of Selection of Frequencies

Where practical, in order to avoid adverse resonance effects, equipment and components are designed/selected such that their fundamental frequencies are outside the range of 1/2 to twice the dominant frequency of the associated support structures. Moreover, in any case, the equipment is analyzed and/or tested to demonstrate that it is adequately designed for the applicable loads considering both its fundamental frequency and the forcing frequency of the applicable support structure. 2.10.27

All frequencies in the range of 0.25 to 33 Hz are considered in the analysis and testing of structures, systems, and components. These frequencies are excited under the seismic excitation.

If the fundamental frequency of a component is greater than or equal to 33 Hz, it is treated as seismically rigid and analyzed accordingly. Frequencies less than 0.25 Hz are not considered as they represent very flexible structures and are not encountered in this plant.

The frequency range between 0.25 Hz and 33 Hz covers the range of the broad band response spectrum used in the design.

3.7.3.5 Use of Equivalent Static Load Methods of Analysis

3.7.3.5.1 Subsystems Other Than NSSS

See Subsection 3.7.3.8.1.5 for equivalent static load analysis method.

3.7.3.5.2 NSSS Subsystems

When the natural frequency of a structure or component is unknown, it may be analyzed by applying a static force at the center of mass. In order to conservatively account for the possibility of more than one significant dynamic mode, the static force is calculated as 1.5

times the mass times the maximum spectral acceleration from the floor response spectra of the point of attachments of multispan structures. The factor of 1.5 is adequate for simple beam type structures. For other more complicated structures, the factor used is justified.

3.7.3.6 Three Components of Earthquake Motion

The total seismic response is predicted by combining the response calculated from the two

horizontal and the vertical analysis.

or static coefficient method

When the response spectrum method or static coefficient method is used, the method for combining the responses due to the three orthogonal components of seismic excitation is given as follows:

$$R_i = \left[\sum_{j=1}^{3} R_{ij}^2 \right]^{1/2} \quad (3.7\text{-}14)$$

where

R_{ij} = maximum, coaxial seismic response of interest (e.g., displacement, moment, shear, stress, strain) in directions i due to earthquake excitation in direction j, (j = 1, 2, 3).

R_i = seismic response of interest in i direction for design (e.g., displacement, moment, shear, stress, strain) obtained by the SRSS rule to account for the nonsimultaneous occurrence of the R_{ij}'s.

insert Attachment DD

3.7.3.7 Combination of Modal Response

3.7.3.7.1 Subsystems Other Than NSSS

When the response spectrum method of modal analysis is used, contributions from all modes, except the closely spaced modes (i.e., the difference between any two natural frequencies is equal to or less than 10%) are combined by the square-root-of-the-sum-of-the-squares (SRSS) combination of modal responses. This is defined mathematically as:

$$R = \sqrt{\sum_{i=1}^{N} (R_i)^2} \quad (3.7\text{-}15)$$

where

R = combined response;

R_i = response to the i^{th} mode; and

N = number of modes considered in the analysis.

Closely spaced modes are combined by taking the absolute sum of the such modes.

An alternate to the absolute sum method presented in Regulatory Guide 1.92 is the following:

$$R = \left[\sum_{i=1}^{N} R_i^2 + 2\Sigma \left| R_\ell R_m \right| \right]^{1/2} \quad (3.7\text{-}16)$$

where the second summation is to be done on all ℓ and m modes whose frequencies are closely spaced to each other.

3.7.3.7.2 NSSS Subsystems

In a response spectrum modal dynamic analysis, if the modes are not closely spaced (i.e., if the frequencies differ from each other by more than 10% of the lower frequency), the modal responses are combined by the square-root-of-the-sum-of- the-squares (SRSS) method as described in Subsection 3.7.3.7.1 and Regulatory Guide 1.92.

If some or all of the modes are closely spaced, a double sum method, as described in Subsection 3.7.3.7.2.2, is used to evaluate the combined response. In a time-history method of dynamic analysis, the vector sum of every step is used to calculate the combined response. The use of the time-history analysis method precludes the need to consider closely spaced modes.

3.7.3.7.2.1 Square-Root-of-the-Sum-of-the-Squares Method

Mathematically, this SRSS method is expressed as follows:

$$R = \left(\sum_{i=i}^{N} (R_i)^2 \right)^{1/2} \quad (3.7\text{-}17)$$

ATTACHMENT DD to pg. 3.7-18

When the time history method of analysis is used and separate analyses are performed for each earthquake component, the total combined response for all three components shall be obtained using the SRSS method described above to combine the maximum codirectional responses from each earthquake component. The total response may alternatively be obtained, if the three component motions are mutually statistically independent, by algebraically adding the codirectional responses calculated separately for each component at each time step.

When the time history analysis is performed by applying the three component motions simultaneously, the combined response is obtained directly by solution of the equations of motion. This method of combination is applicable only if the three component motions are mutually statistically independent.

INSERT ATT. E

where

- R = combined response;
- R_i = response to the i^{th} mode; and
- N = number of modes considered in the analysis

3.7.3.7.2.2 Double Sum Method

This method, as defined in Regulatory Guide 1.92, is mathematically:

$$R = \left(\sum_{k=1}^{N} \sum_{s=1}^{N} | R_k R_s | \epsilon_{ks} \right)^{1/2} \quad (3.7\text{-}18)$$

where

- R = representative maximum value of a particular response of a given element to a given component of excitation;
- R_k = peak value of the response of the element due to the k^{th} mode;
- N = number of significant modes considered in the modal response combination; and
- R_s = peak value of the response of the element attributed to s^{th} mode

where

$$\epsilon_{ks} = \left[1 + \left\{ \frac{(\omega'_k - \omega'_s)}{(\beta'_k \omega_k + \beta'_s \omega_s)} \right\}^2 \right]^{-1} \quad (3.7\text{-}19)$$

in which

$$\omega'_k = \omega_k \left[1 - \beta_k^2 \right]^{1/2}$$

$$\beta'_k = \beta_k + \frac{2}{t_d \omega_k}$$

where ω_k and β_k are the modal frequency and the damping ratio in the kth mode, respectively, and t_d is the duration of the earthquake.

3.7.3.8 Analytical Procedure for Piping

3.7.3.8.1 Piping Subsystems Other Than NSSS

3.7.3.8.1.1 Qualification by Analysis

The methods used in seismic analysis vary according to the type of subsystems and supporting structure involved. The following possible cases are defined along with the associated analytical methods used.

3.7.3.8.1.2 Rigid Subsystems with Rigid Supports

If all natural frequencies of the subsystem are greater than 33 Hz, the subsystem is considered rigid and analyzed statically as such. In the static analysis, the seismic forces on each component of the subsystem are obtained by concentrating the mass at the center of gravity and multiplying the mass by the appropriate maximum floor acceleration.

3.7.3.8.1.3 Rigid Subsystems with Flexible Supports

If it can be shown that the subsystem itself is a rigid body (e.g., piping supported at only two points) while its supports are flexible, the overall subsystem is modeled as a single-degree-of-freedom subsystem consisting of an effective mass and spring.

The natural frequency of the subsystem is computed and the acceleration determined from the floor response spectrum curve using the appropriate damping value. A static analysis is performed using 1.5 times the acceleration value. In lieu of calculating the natural frequency, the peak acceleration from the spectrum curve may be used.

If the subsystem has no definite orientation, the excitation along each of three mutually perpendicular axes is aligned with respect to the system to produce maximum loading. The

Attachment E pg 3.7-19

3.7.3.7.3 Methodologies Used to Account for High-Frequency Modes

Sufficient modes are to be included in the dynamic analysis to ensure that the inclusion of additional modes does not result in more than a 10% increase in responses. To satisfy this requirement, the responses associated with high-frequency modes are combined with the low-frequency modal responses. High-frequency modes are those modes with frequencie greater than the dynamic analysis cutoff frequency specified in Subsection 3.7.

For modal combination involving high-frequency modes, the following procedure applies:

Step 1 — Determine the modal responses only for those modes that have natural frequencies less than that at which the spectral acceleration approximately returns to the ZPA of the input response spectrum (33 Hz for seismic). Combine such modes in accordance with the methods described ~~above~~ in Subsections 3.7.3.7.1 and 2

Step 2 — For each degree of freedom (DOF) included in the dynamic analysis, determine the fraction of DOF mass included in the summation of all of the modes included in Step 1. This fraction d_i for each DOF i is given by:

$$d_i = \sum_{n=1}^{N} \Gamma_n \times \phi_{n,i} \qquad (3.7\text{-}11)\ 20$$

where:

n	=	order of the mode under consideration
N	=	number of modes included in Step 1
$\phi_{n,i}$	=	mass-normalized mode shape for mode n and DOF i
Γ_n	=	participation factor for mode n (see Eq. 3.7-3 for expression)

Next, determine the fraction of DOF mass not included in the summation of these modes:

$$e_i = |d_i - \delta_{ij}| \qquad (3.7\text{-}12)\ 21$$

where δ_{ij} is the Kronecker delta, which is one if DOF i is in the direction of the input motion and zero if DOF i is a rotation or not in the direction of the input motion. If, for any DOF i, the absolute value of this fraction e_i exceeds 0.1, one should include the response from higher modes with those included in Step 1.

Step 3 — Higher modes can be assumed to respond in phase with the ZPA and, thus, with each other; hence, these modes are combined algebraically, which is equivalent to pseudo-static response to the inertial forces from these higher modes excited at the ZPA. The pseudo-static inertial forces associated with the summation of all higher modes for each DOF i are given by:

$$P_i = ZPA \times M_i \times e_i \qquad (3.7\text{-}13)\ 22$$

where P_i is the force or moment to be applied at DOF i, and M_i is the mass or mass moment of inertia associated with DOF i. The system is then statically analyzed for this set of pseudo-static inertial forces applied to all of the degrees of freedom to determine the maximum responses associated with high-frequency modes not included in Step. 1

Step 4 — The total combined response to high-frequency modes (Step 3) are combined by the SRSS method with the total combined response from lower-frequency modes (Step 1) to determine the overall peak responses.

This procedure requires the computation of individual modal responses only for lower-frequency modes (below the ZPA). Thus, the more difficult higher-frequency modes

need not be determined. The procedure ensures inclusion of all modes of the structural model and proper representation of DOF masses.

In lieu of the above procedure, an alternative method is as follows. Modal responses are computed for enough modes to ensure that the inclusion of additional modes does not increase the total response by more than 10 percent. Modes that have natural frequencies less than that at which the spectral acceleration approximately returns to the ZPA are combined in accordance with RG 1.92. Higher-mode responses are combined algebraically (i.e., retain sign) with each other. The absolute value of the combined higher modes is then added directly to the total response from the combined lower modes.

3.7.2.8 Interaction of Non-Category I Structures with Seismic Category I Structures

The interfaces between Seismic Category I and non-Category I structures and plant equipment are designed for the dynamic loads and displacements produced by both the Seismic Category I and non-Category I structures and plant equipment. All non-Category I structures meet any one of the following requirements:

- The collapse of any non-Category I structure will not cause the non-Category I structure to strike a Seismic Category I structure or component.
- The collapse of any non-Category I structure will not impair the integrity of Seismic Category I structures or components.
- The non-Category I structures will be analyzed and designed to prevent their failure under SSE conditions in a manner such that the margin of safety of these structures is equivalent to that of Seismic Category I structures.

3.7.2.9 Effects of Parameter Variations on Floor Response Spectra

Floor response spectra calculated according to the procedures described in Subsection 3.7.2.5 are peak broadened to account for uncertainties in the structural frequencies owing to uncertainties in the material properties of the structure and soil and to approximations in the modeling techniques used in the analysis. If no parametric variation studies are performed, the spectral peaks associated with each of the structural frequencies are broadened by ±15. If a detailed parametric variation study is made, the minimum peak broadening ratio is ±10. When the seismic analysis is performed for a wide range of site conditions with sufficient variation in soil properties for the purpose of standardized design, the site-envelope floor response spectra are peak broadened by ±10. In lieu of peak broadening, the peak shifting method of Appendix N of ASME Section III, as permitted by RG 1.84, can be used.

excitation in each of the three axes is considered to act simultaneously. The excitations are combined by the SRSS method.

3.7.3.8.1.4 Flexible Subsystems

If the piping subsystem has more than two supports, it cannot be considered a rigid body and must be modeled as a multi-degree-of-freedom subsystem.

The subsystem is modeled as discussed in Subsection 3.7.3.3.1 in sufficient detail (i.e., number of mass points) to ensure that the lowest natural frequency between mass points is greater than 33 Hz. The mathematical model is analyzed using a time-history analysis technique or a response spectrum analysis approach. After the natural frequencies of the subsystem are obtained, a stress analysis is performed using the inertia forces and equivalent static loads obtained from the dynamic analysis for each mode.

For a response spectrum analysis based on a modal superposition method, the modal response accelerations are taken directly from the spectrum. The total seismic stress is normally obtained by combining the modal stress using the SRSS method. The seismic stress of closely spaced modes (i.e., within 10% of the adjacent mode) are combined by absolute summation. The resulting total is treated as a pseudomode and is then combined with the remaining modal stresses by the SRSS method.

The approach is simple and straightforward in all cases where the group of modes with closely spaced frequencies is tightly bundled (i.e., the lowest and the highest modes of the group are within 10% of each other). However, when the group of closely spaced modes is spaced widely over the frequency range of interest while the frequencies of the adjacent modes are closely spaced, the absolute sum method of combining response tends to yield over-conservative results. To prevent this problem, a general approach applicable to all modes is considered appropriate. The following equation is merely a mathematical representation of this approach.

The most probable system response, R, is given by:

$$R = \left(\sum_{i=1}^{N} R_i^2 + 2\Sigma \left| R_\ell R_m \right| \right)^{1/2} \quad (3.7-20)$$

where the second summation is to be done on all ℓ and m modes whose frequencies are closely spaced to each other,

and where

R_i = response to the i^{th} mode

N = number of significant modes considered in the modal response combinations.

The excitation in each of the three major orthogonal directions is considered to act simultaneously with their effect combined by the SRSS method.

3.7.3.8.1.5 Static Analysis

A static analysis is performed in lieu of a dynamic analysis by applying the following forces at the concentrated mass locations (nodes) of the analytical model of the piping system:

(1) horizontal static load, $F_h = C_h W$, in one of the horizontal principal directions;

(2) equal static load, F_h, in the other horizontal principal direction; and

(3) vertical static load, $F_v = C_v W$;

where

C_h, C_v = multipliers of the gravity acceleration, g, determined from the horizontal and vertical floor response spectrum curves, respectively. (They are functions of the period and the appropriate damping of the piping system); and

W = weight at node points of the analytical model.

In a response spectrum dynamic analysis, modal responses are combined as described in Subsection 3.7.3.7.
In a response spectrum or time-history dynamic analysis, responses due to the three orthogonal components of seismic excitation are combined as described in Subsection 3.7.3.6.

For special case analyses, C_h and C_v may be taken as:

(1) 1.0 times the zero-period acceleration of the response spectrum of subsystems described in Subsection 3.7.3.8.1.2;

(2) 1.5 times the value of the response spectrum at the determined frequency for subsystems described in Subsection 3.7.3.8.1.3 and 3.7.3.8.1.4; and

(3) 1.5 times the peak of the response spectrum for subsystems described in Subsections 3.7.3.8.1.3 and 3.7.3.8.1.4.

An alternate method of static analysis which allows for simpler technique with added conservatism is acceptable. No determination of natural frequencies is made, but rather the response of the subsystem is assumed to be the peak of the appropriate response spectrum at a conservative and justifiable value of damping. The response is then multiplied by a static coefficient of 1.5 to take into account the effects of both multifrequency excitation and multimodal response.

3.7.3.8.1.6 Dynamic Analysis

The dynamic analysis procedure using the response spectrum method is provided as follows:

(1) The number of node points and members is indicated. If a computer program is utilized, use the same order of number in the computer program input. The mass at each node point, the length of each member, elastic constants, and geometric properties are determined.

(2) The dynamic degrees of freedom according to the boundary conditions are determined.

(3) The dynamic properties of the subsystem (i.e., natural frequencies and mode shapes) are computed.

(4) Using a given direction of earthquake motion, the modal participation factors, s_j, for each mode are calculated:

$$s_j = \frac{\sum_{i=1}^{N} M_i \Phi_{ij}}{\sum_{i=1}^{N} M_i \phi_{ij}^2} \qquad (3.7\text{-}21)$$

where

M_i = i^{th} mass

Φ_{ij} = component of ϕ_{ij} in the earthquake direction

ϕ_{ij} = i^{th} characteristic displacement in the j^{th} mode

s_j = modal participation factor for the j^{th} mode

N = number of masses.

(5) Using the appropriate response spectrum curve, the spectral acceleration, r_{aj}, for the j^{th} mode as a function of the j^{th} mode natural frequency and the damping of the system is determined.

(6) The maximum modal acceleration at each mass point, i, in the model is computed as follows:

$$a_{ij} = s_j\, r_{aj} \Phi_{ij} \qquad (3.7\text{-}22)$$

where

a_{ij} = acceleration of the i^{th} mass point in the j^{th} mode.

(7) The maximum modal inertia force at the i^{th} mass point for the j^{th} mode is calculated from the equation:

$$F_{ij} = M_i\, a_{ij} \qquad (3.7\text{-}23)$$

(8) For each mode, the maximum inertia forces

are applied to the subsystem model, and the modal forces, shears, moments, stresses, and deflections are determined.

(9) The modal forces, shears, moments, stresses, and deflections for a given direction are combined in accordance with Subsection 3.7.3.8.1.4.

(10) Steps (5) through (9) are performed for each of the three earthquake directions.

(11) The seismic force, shear, moment, and stress resulting from the simultaneous application of the three components of earthquake loading are obtained in the following manner:

$$R = \sqrt{R_x^2 + R_y^2 + R_z^2} \quad (3.7\text{-}24)$$

R = equivalent seismic response quantity (force, shear, moment, stress, etc.)

R_x R_y R_z = colinear response quantities due to earthquake motion in the x, y, and z directions, respectively.

3.7.3.8.1.7 Damping Ratio

The damping ratio percentage of critical damping of piping subsystems corresponds to Regulatory Guide 1.61 or 1.84 (ASME Code Case N-411-1). The damping ratio is specified in Table 3.7-1.

→ ADD INSERT G

3.7.3.8.1.8 Effect of Differential Building Movements

In most cases piping subsystems are anchored and restrained to floors and walls of buildings that may have differential movements during a seismic event. The movements may range from insignificant differential displacements between rigid walls of a common building at low elevations to relatively large displacements between separate buildings at a high seismicity site.

Differential endpoint or restraint deflections cause forces and moments to be induced into the piping system. The stress thus produced is a secondary stress. It is justifiable to place this stress, which results from restraint of free-end displacement of the piping system, in the secondary stress category because the stresses are self-limiting and, when the stresses exceed yield strength, minor distortions or deformations within the piping system satisfy the condition which caused the stress to occur.

The earthquake thus produces a stress-exhibiting property much like a thermal expansion stress and a static analysis can be used to obtain actual stresses. The differential displacements are obtained from the dynamic analysis of the building. The displacements are applied to the piping anchors and restraints corresponding to the maximum differential displacements which could occur. The static analysis is made three times: once for one of the horizontal differential displacements, once for the other horizontal differential displacement, and once for the vertical.

→ ADD INSERT F

3.7.3.8.1.9 Design of Small Branch and Small Bore Piping

(1) Small branch lines are defined at those lines that can be decoupled from analytical model used for the analysis of the main run piping to which the branch lines attach. As allowed by Paragraph 3.7.3.3.1.3 branch lines can be decoupled when the ratio of run to branch pipe moment of inertia is 25 to 1, or greater. In addition to the moment of inertia criterion for acceptable decoupling, these small branch lines shall be designed with no concentrated masses, such as valves, in the first one-half span length from the main run pipe; and with sufficient flexibility to prevent restrain of movement of the main run pipe. The small branch line is considered to have adequate flexibility if its first anchor or restraint to movement is at least one-half pipe span in a direction perpendicular to the direction of relative movement between the pipe run and the first anchor or restraint of the branch piping. A pipe span is defined as the length tabulated in Table NF-3611-1, Suggested Piping Support Spacing, ASME B&PV Code, Section III, Subsection NF. For branches where the preceding criteria for sufficient flexibility cannot be met, the applicant will demonstrate acceptability by using an alternative criteria for sufficient flexibility, or by accounting for the effects of the branch piping in the analysis of the main run piping.

INSERT F page 3.7-22

The inertia (primary) and displacement (secondary) loads are dynamic in nature and their peak values are not expected to occur at the same time. Hence combination of the peak values of inertia load and anchor displacement load is quite conservative. In addition, anchor movement effects are computed from static analyses in which the displacements are applied to produce the most conservative loads on the components. Therefore, the primary and secondary loads are combined by the SRSS method.

INSERT G page 3.7-22

Strain energy weighted modal damping can also be used in the dynamic analysis. Strain energy weighting is used to obtain the modal damping coefficient due to the contributions of damping in the different elements of the piping system. The element damping values are specified in Table 3.7-1. Strain energy weighted modal damping is calculated as specified in Subsection 3.7.2.15.

In direct integration analysis, damping is input in the form of α & β damping constants, which give the percentage of critical damping, λ as a function of the circular frequency, ω .

$$\lambda = \frac{\alpha}{2\omega} + \frac{\beta\omega}{2}$$

(2) For small bore piping, defined as piping 2 inches and less nominal pipe size, and small branch lines 2 inches and less nominal pipe size, as defined in (1) above, it is acceptable to use small bore piping handbooks in lieu of performing a system flexibility analysis, using static and dynamic mathematical models, to obtain loads on the piping elements and using these loads to calculate stresses per the equations in NB, NC, and ND3600 in Section III of ASME Code, whenever the following are met:

(1) The small bore piping handbook at the time of application is currently accepted by the regulatory agency for use on equivalent piping at other nuclear power plants.

(2) When the small bore piping handbook is serving the purpose of the Design Report it meets all of the ASME requirements for a piping design report. This includes the piping and its supports.

(3) Formal documentation exists showing piping designed and installed to the small bore piping handbook (a) is conservative in comparison to results from a detail stress analysis for all applied loads and load combinations defined in the design specification, (b) does not result in piping that is less reliable because of loss of flexibility or because of excessive number of supports, (c) satisfies required clearances around sensitive components.

The small bore piping handbook methodology will not be applied when specific information is needed on (a) magnitude of pipe and fitting stresses, (b) pipe and fitting cumulative usage factors, (c) accelerations of pipe mounted equipment, or locations of postulated breaks and leaks.

The small bore piping handbook methodology will not be applied to piping systems that are fully engineered and installed in accordance with the engineering drawings.

ADD NEW 3.7.3.8.1.10

3.7.3.8.2 NSSS Piping Subsystems

3.7.3.8.2.1 Dynamic Analysis

As described in Subsection 3.7.3.3.1, pipe line is idealized as a mathematical model consisting of lumped masses connected by elastic members. The stiffness matrix for the piping subsystem is determined using the elastic properties of the pipe. This includes the effects of torsional, bending, shear, and axial deformations as well as changes in stiffness due to curved members.

Next, the mode shapes and the undamped natural frequencies are obtained. The dynamic response of the subsystem is usually calculated by using the response spectrum method of analysis. When the connected equipment is supported at more than two points located at different elevations in the building, the response spectrum analysis is performed using the envelope response spectrum of all attachment points. Alternatively, the multiple excitation analysis methods may be used where acceleration time histories or response spectra are applied at all the equipment and piping attachment points.

→ ADD INSERT I

5.5 Analysis Procedure for Damping. Damping values for equipment and piping are shown in Table 3-1 and they are consistent with RG 1.61. For piping systems damping values of ASME Code Case N-411-1 (alternative damping values for response spectra analysis of Class 1, 2, and 3 piping, Section III, Division 1), may be used as permitted by RG 1.84. For systems made of subsystems with different damping properties, the analysis procedures described in Section 4.13 are applicable.

5.6 Three Components of Earthquake Motion. The applicable methods of spatial combination of responses due to each of the three input motion components are described in Section 4.6.

5.7 Combination of Modal Responses. The applicable methods of modal response combination are described in Section 4.7.

5.8 Interaction of Other Systems with Category I Systems. Each non-Category I system should be designed to be isolated from any Category I system by either a constraint or barrier, or should be remotely located with regard to the Category I system. If it is not feasible or practical to isolate the Category I system, adjacent non-Category I systems should be analyzed according to the same seismic criteria as applicable to the Category I systems. For non-Category I systems attached to Category I systems, the dynamic effects of the non-Category I systems should be simulated in the modeling of the Category I system. The attached non-Category I systems, up to the first anchor beyond the interface, should also be designed in such a manner that during an earthquake of SSE intensity it will not cause a failure of the Category I system.

3.7.3.8.1.10 ~~5.9~~ Multiply-Supported Equipment and Components with Distinct Inputs

~~5.9.1~~ For multi-supported systems (equipment and piping) analyzed by the response spectrum method for the determination of inertial responses, either of the following two input motions are acceptable:

a. envelope response spectrum of all support points for each orthogonal direction of excitation, or

b. independent support motion (ISM) response spectrum at each support for each orthogonal direction of excitation.

When the ISM response spectrum method of analysis is used, the following conditions should be met:

a. ASME Code Case N-411-1 damping is not used.

b. A support group is defined by supports which have the same time-history input. This usually means all supports located on the same floor, or portions of a floor, of a structure.

c. The responses due to motions of supports in two or more different groups are combined by the SRSS procedure

In lieu of the response spectrum analysis, the time history method of analysis subjected to distinct support motions may be used for multi-supported systems.

IN I page 3.7-22.1

In a response spectrum dynamic analysis, modal responses are combined as described in Subsection 3.7.3.7. In a independent support motion response spectrum analysis, group responses are combined as described in Subsection 3.7.3.8.1.10. In a response spectrum or time-history dynamic analysis, responses du to the three orthogonal components of seismic excitation re combined as described in Subsection 3.7.3.6.

INSERT BB page 3.7-23

3.7.3.12 Buried Seismic Category I Piping and Tunnels

All underground Category I piping systems are installed in tunnels. The following items are considered in the analysis:

(1) The inertial effects due to an earthquake upon underground piping systems and tunnels will be

INSERT CC page 3.7-23

(2) The design response spectra for the underground piping are the horizontal and vertical design spectra at the ground surface given in Figures 3.7-1 and 3.7-2. These design spectra are constructed in accordance with Regulatory Guide 1.60. The piping analysis is performed using one of the methods described in Subsection 3.7.3.

3.7.3.8.2.2 Effect of Differential Building Movements

The relative displacement between anchors is determined from the dynamic analysis of the structures. The results of the relative anchor-point displacement are used in a static analysis to determine the additional stresses due to relative anchor-point displacements. Further details are given in Subsection 3.7.3.8.1.8.

3.7.3.9 Multiple Supported Equipment Components With Distinct Inputs

The procedure and criteria for analysis are described in Subsections 3.7.2.1.3 and 3.7.3.3.1.3.

3.7.3.10 Use of Constant Vertical Static Factors

All Seismic Category I subsystems and components are subjected to a vertical dynamic analysis with the vertical floor spectra or time histories defining the input. A static analysis is performed in lieu of dynamic analysis if the peak value of the applicable floor spectra times a factor of 1.5 is used in the analysis. A factor of 1.0 instead of 1.5 can be used if the equipment is simple enough such that it behaves essentially as a single degree of freedom system. If the fundamental frequency of a component in the vertical direction is greater than or equal to 33 Hz, it is treated as seismically rigid and analyzed statically using the zero-pe-sponse spectrum.

210.28

3.7.3.11 Torsional Effects of Eccentric Masses

Torsional effects of eccentric masses are included for Seismic Category I subsystems similar to that for the piping systems discussed in Subsection 3.7.3.3.1.2.

3.7.3.12 Buried Seismic Category I Piping and Tunnels

For buried Category I buried piping systems and tunnels the following items are considered in the analysis:

(1) The inertial effects due to an earthquake upon buried systems and tunnels will be adequately accounted for in the analysis. In case of buried systems sufficiently flexible relative to the surrounding or underlying soil, it is assumed that the systems will follow essentially the displacements and deformations that the soil would have if the systems were absent. When applicable, procedures, which take into account the phenomena of wave travel and wave reflection in compacting soil displacements from the ground displacements, are employed.

Replace with INSERT BB

(2) The effects of static resistance of the surrounding soil on piping deformations or displacements, differential movements of piping anchors, bent geometry and curvature changes, etc., are considered. When applicable, procedures utilizing the principles of the theory of structures on elastic foundations are used.

Replace with INSERT C

(3) When applicable, the effects due to local soil settlements, soil arching, etc., are also considered in the analysis.

3.7.3.13 Interaction of Other Piping with Seismic Category I Piping

In certain instances, non-Seismic Category I piping may be connected to Seismic Category I piping at locations other than a piece of equipment which, for purposes of analysis, could be represented as an anchor. The transition points typically occur at Seismic Category I valves which may or may not be physically anchored. Since a dynamic analysis must be modeled from pipe anchor point to anchor point, two options exist:

(1) specify and design a structural anchor at the Seismic Category I valve and analyze the Seismic Category I subsystem; or, if impractical to design an anchor,

(2) analyze the subsystem from the anchor point in the Seismic Category I subsystem through the valve to either the first anchor point in the non-Seismic Category I subsystem; or ~~to sufficient distance in the non-Seismic Category I Subsystem so as not to significantly degrade the accuracy of analysis of the Seismic Category I piping.~~ for a distance such that there are at least two seismic restraints in each of the three orthogonal directions.

it can be decoupled from the

Where small, non-Seismic Category piping is directly attached to Seismic Category I piping, ~~its effect on the~~ Seismic Category I piping ~~is accounted for by lumping a portion of its mass with the Seismic Category I piping at the point of attachment~~ per subsection 3.7.3.3.1.3.

Furthermore, non-Seismic Category I piping (particularly high energy piping as defined in Section 3.6) is designed to withstand the SSE to avoid jeopardizing adjacent Seismic Category I piping if it is not feasible or practical to isolate these two piping systems.

3.7.3.14 Seismic Analysis for Reactor Internals

The modeling of RPV internals is discussed in Subsection 3.7.2.3.2. The damping values are given in Table 3.7-1. The seismic model of the RPV and internal in shown in Figure 3.7-32.

3.7.3.15 Analysis Procedures for Damping

The modeling of RPV internals is discussed in Subsection 3.7.2.3.2. The damping values are given in Table 3.7-1. The seismic model of the RPV and internals is shown in Figure 3.7-32.

3.7.3.16 Analysis Procedure for NonSeismic Structures in Lieu of Dynamic Analysis

The method described here can be used for non-seismic structures in lieu of a dynamic analysis.

Structures designed to this method should be able to do the following:

(1) Resist minor levels of earthquake ground motion without damage.

(2) Resist moderate levels of earthquake ground motion without structural damage, but possibly experience some nonstructural damage.

(3) Resist major levels of earthquake ground motion having an intensity equal to the strongest either experienced or forecast at the building site, without collapse, but possibly with some structural as well as nonstructural damage.

3.7.3.16.1 Lateral Forces

Seismic loads are characterized as a force profile that varies with the height of the structure. These forces are applied at each floor of the structure and the resulting forces and moments are calculated from static equilibrium.

The buildings total base shear is characterized by the following equation:

$V = Z*I*C*W/R_w$; where,

V	=	Total lateral force or shear at the base.
$F_i F_i F_n$	=	Lateral force applied to level i, n, or x respectively.
F_t	=	That portion of V considered to be concentrated at the top of the structure in addition to F_n
Z	=	Seismic zone factor
I	=	Importance factor
C	=	Numerical Coefficient
R_w	=	Numerical Coefficient
S	=	Coefficient for site soil characteristics
T	=	Fundamental period of vibration of the structure in the direction under consideration, as determined by using the properties and deformation characteristics of the resisting elements in a properly substantiated analysis.
W	=	Total dead load of building including the partition load where applicable.
$w_i w_x$	=	That portion of W which is located at or is assigned to level i or x, respectively
$h_i h_x$	=	Height in feet above the base to level i or x, respectively

[illegible] functional capability of the essential piping are the ASME Code Section III Service Level D stress limits. GE/EPRI Pipe Tests confirmed that functional capability is assured when the stresses are less than the Service Level D allowables.

analyzed for the faulted loading conditions. The ECCS and SLC pumps are active ASME Class 2 components. The allowable stresses for active pumps are provided in a footnote to Table 3.9-2.

The reactor coolant pressure boundary components of the reactor recirculation system (RRS) pump motor assembly, and recirculation motor cooling (RMC) subsystem heat exchanger are ASME Class 1 and Class 3, respectively, and are analyzed for the faulted loading conditions. All equipment stresses are within the elastic limits.

3.9.1.4.7 Fuel Storage and Refueling Equipment

Storage, refueling, and servicing equipment which is important to safety is classified as essential components per the requirements of 10CFR50 Appendix A. This equipment and other equipment which in case of a failure would degrade an essential component is defined in Section 9.1 and is classified as Seismic Category I. These components are subjected to an elastic dynamic finite-element analysis to generate loadings. This analysis utilizes appropriate floor response spectra and combines loads at frequencies up to 33 Hz for seismic loads and up to 60 Hz for other dynamic loads in three directions. Imposed stresses are generated and combined for normal, upset, and faulted conditions. Stresses are compared, depending on the specific safety class of the equipment, to Industrial Codes, ASME, ANSI or Industrial Standards, AISC, allowables.

3.9.1.4.8 Fuel Assembly (Including Channel)

GE BWR fuel assembly (including channel) design bases, and analytical and evaluation methods including those applicable to the faulted conditions are the same as those contained in References 1 and 2.

3.9.1.4.9 ASME Class 2 and 3 Vessels

Elastic analysis methods are used for evaluating faulted loading conditions for Class 2 and 3 vessels. The equivalent allowable stresses using elastic techniques are obtained from NC/ND-3300 and NC-3200 of the ASME Code Section III. These allowables are above elastic limits.

3.9.1.4.10 ASME Class 2 and 3 Pumps

Elastic analysis methods are used for evaluating faulted loading conditions for Class 2 and 3 pumps. The equivalent allowable stresses for nonactive pumps using elastic techniques are obtained from NC/ND-3400 of the ASME Code Section III. These allowables are above elastic limits. The allowables for active pumps are provided in a footnote to Table 3.9-2.

3.9.1.4.11 ASME Class 2 and 3 Valves

Elastic analysis methods and standard design rules are used for evaluating faulted loading conditions for Class 2, and 3 valves. The equivalent allowable stresses for nonactive valves using elastic techniques are obtained from NC/ND-3500 of ASME Code, Section III. These allowables are above elastic limits. ~~The allowables for active valves are provided in a footnote to Table 3.9-2.~~

3.9.1.4.12 ASME Class 1, 2 and 3 Piping

Elastic analysis methods are used for evaluating faulted loading conditions for Class 1, 2, and 3 piping. The equivalent allowable stresses using elastic techniques are obtained from ~~Appendix F (for Class 1) and~~ NC/ND-3600 (for Class 2 and 3 piping) of the ASME Code Section III. ~~These allowables are above elastic limits. The allowables for functional capability of the essential piping are provided in a footnote to Table 3.9-2.~~ NB/ 2

3.9.1.5 Inelastic Analysis Methods

Inelastic analysis is only applied to ABWR components to demonstrate the acceptability of three types of postulated events. Each event is an extermly low-probability occurence and the equipment affected by these events would not be reused. These three events are:

(1) Postulated gross piping failure.

(2) Postulated blowout of a reactor internal recirculation (RIP) motor casing due to a weld failure.

(3) Postulated blowout of a control rod drive (CRD) housing due to a weld failure.

The results of the data analyses, vibration amplitudes, natural frequencies, and mode shapes are then compared to those obtained from the theoretical analysis.

Such comparisons provide the analysts with added insight into the dynamic behavior of the reactor internals. The additional knowledge gained from previous vibration tests has been utilized in the generation of the dynamic models for seismic and loss of coolant accident (LOCA) analyses for this plant. The models used for this plant are similar to those used for the vibration analysis of earlier prototype BWR plants.

3.9.3 ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures

3.9.3.1 Loading Combinations, Design Transients, and Stress Limits

This section delineates the criteria for selection and definition of design limits and loading combination associated with normal operation, postulated accidents, and specifi[illegible] seism[illegible] and other reactor building vibrati[illegible] (RB[illegible]) for the design of safety-relat[illegible] AS[illegible] components (except containme[illegible] co[illegible] which are discussed in Section 3.8

Th[illegible] discusses the ASME Class 1, and [illegible]nt and associated pressure retaini[illegible] parts and identifies the applicable loading calculation methods, calculated stresses, a[illegible] allowable stresses. A discussion of maj[illegible] equipment is included on a component-by-compone[illegible] basis to provide examples. Design transients a[illegible] dynamic loading for ASME Class 1, 2, and [illegible] equipment are covered in Subsection 3.9.1. Seismic-related loads and dynamic analyses a[illegible] discussed in Section 3.7. The suppressio[illegible] pool-related RBV loads are described in Append[illegible] 3B. Table 3.9-2 presents the combinations of dynamic events to be considered for the design and analysis of all ABWR ASME Code Class 1, 2, and 3 components, component supports, core support structures and equipment. Specific loading combinations considered for evaluation of each specific equipment are derived from Table 3.9-2 and are contained in the design specifications and/or design reports of the respective equipment. (See Subsection 3.9.7.4 for COL license information)

Table 3.9-2 also presents the evaluation models and criteria. The predicted loads or stresses and the design or allowable values for the most critical areas of each component are compared in accordance with the applicable code criteria or other limiting criteria. The calculated results meet the limits.

The design life for the ABWR Standard Plant is 60 years. A 60 year design life is a requirement for all major plant components with reasonable expection of meeting this design life. However, all plant operational components and equipment except the reactor vessel are designed to be replaceable, design life not withstanding. The design life requirement allows for refurbishment and repair, as appropriate, to assure the design life of the overall plant is achieved. **In effect, essentially all piping systems, components and equipment are designed for a 60 year design life. Many of these components are classified as ASME Class 2 or 3 or Quality Group D.** *In the event any non-Class 1 components are subjected to cyclic loadings, including operating vibration loads and thermal transients effects, of a magnitude and/or duration so severe that the 60 year design life can not be assured by required Code calculations, applicants referencing the ABWR design will identify these components and either provide an appropriate analysis to demonstrate the required design life or provide designs to mitigate the magnitude or duration of the cyclic loads. Components excluded from this requirement are (1) tees where mixing of hot and cold fluids occurs and thermal sleeves have been provided in accordance with the P&ID's, (2) components, such as the quencher, for which a fatigue analysis has already been performed, providing the component is designed so as to not cause excessive localized stresses, or harmful thermal gradients in the pipe wall, (3) Feedwater piping outside containment that is designed to cyclic loadings and stresses are no more severe than experienced by Class 1 piping inside containment.*

3.9.3.1.1 Plant Conditions

All events that the plant will or might credibly experience during a reactor year are evaluated to establish design basis for plant equipment. These events are divided into four plant conditions. The plant conditions described in the following paragraphs are based on event probability (i.e., frequency of occurrence as discussed in Subsection 3.9.3.1.1.5) and correlated to service levels for design limits defined in the ASME Boiler and Pressure Vessel Code Section III as shown in Tables 3.9-1 and 3.9-2.

to accomplish its safety functions as required by any subsequent design condition event.

~~Specific stress criteria to meet the functional requirements are identified in a footnote to Table 3.9-2.~~

3.9.3.1.2 Reactor Pressure Vessel Assembly

The reactor vessel assembly consists of the reactor pressure vessel, vessel support skirt, and shroud support.

The reactor pressure vessel, vessel support skirt, and shroud support are constructed in accordance with the ASME Boiler and Pressure Vessel Code Section III. The shroud support consists of the shroud support plate and the shroud support cylinder and its legs. The reactor pressure vessel assembly components are classified as an ASME Class 1. Complete stress reports on these components are prepared in accordance with ASME Code requirements. NUREG-0619 (Reference 5) is also considered for feedwater nozzle and other such RPV inlet nozzle design.

The stress analysis is performed on the reactor pressure vessel, vessel support skirt, and shroud support for various plant operating conditions (including faulted conditions) by using the elastic methods except as noted in Subsection 3.9.1.4.2. Loading conditions, design stress limits, and methods of stress analysis for the core support structures and other reactor internals are discussed in Subsection 3.9.5.

3.9.3.1.3 **Main Steam (MS) System Piping**

The piping systems extending from the reactor pressure vessel to and including the outboard main steam isolation valve are constructed in accordance with the ASME Boiler and Pressure Vessel Code Section III, Class 1 criteria. ~~The rules contained in Appendix F of ASME Code Section III are used in evaluating faulted loading conditions independently of other design and operating conditions. Stresses calculated on an elastic basis are evaluated in accordance with F-1360.~~

The MS system piping extending from the outboard main steam isolation valve to the turbine stop valve is constructed in accordance with the ASME Boiler and Pressure Vessel Code Section III, Class 2 Criteria. ← INSERT ATT. K

3.9.3.1.4 **Recirculation Motor Cooling (RMC) Subsystem**

The RMC system piping loop between the recirculation motor casing and the heat exchanger is constructed in accordance with the ASME Boiler and Pressure Vessel Code Section III, Subsection NB-3600. ~~The rules contained in Appendix F of ASME Code Section III are used in evaluating faulted loading conditions independently of all other design and operating conditions. Stresses calculated on an elastic basis are evaluated in accordance with F-1360.~~

3.9.3.1.5 **Recirculation Pump Motor Pressure Boundary**

The motor casing of the recirculation internal pump is a part of and welded into an RPV nozzle and is constructed in accordance with the requirements of an ASME Boiler and Pressure Vessel Code Section III, Class 1 component. The motor cover is a part of the pump/motor assembly and is constructed as an ASME Class 1 component. These pumps are not required to operate during the safe shutdown earthquake or after an accident.

3.9.3.1.6 **Standby Liquid Control (SLC) Tank**

The standby liquid control tank is constructed in accordance with the requirements of an ASME Boiler and Pressure Vessel Code Section III, Class 2 component.

3.9.3.1.7 **RRS and RHR Heat Exchangers**

The primary and secondary sides of the RRS (reactor recirculation system) are constructed in accordance with the requirements of an ASME Boiler and Pressure Vessel Code Section III, Class 1 and Class 2 component, respectively. The primary and secondary side of the RHR system heat exchanger is constructed as an ASME Class 2 and Class 3 component respectively.

Stresses are calculated on an elastic basis and evaluated in accordance with NB-3600 of the ASME Code Section III.

ATTACHMENT K to page 3.9-20

Turbine stop valve (TSV) closure in the main steam (MS) piping system results in a transient that produces momentary unbalanced forces acting on the MS piping system. Upon closure of the TSV, a pressure wave is created and it travels at sonic velocity toward the reactor vessel through each MS line. Flow of steam into each MS line from the reactor vessel continues until the steam compression wave reaches the reactor vessel. Repeated reflection of the pressure wave at the reactor vessel and the TSV produce time varying pressures and velocities, throughout the MS lines.

The analysis of the MS piping TSV closure transient consists of a stepwise time-history solution of the steam flow equation to generate a time-history of the steam properties at numerous locations along the pipe. Reaction loads on the pipe are determined at each elbow. These loads are composed of pressure-times-area, momentum change and fluid-friction terms.

The time-history direct integration method of analysis is used to determine the response of the MS piping system to TSV closure. The forces are applied at locations on the piping system where steam flow changes direction thus causing momentary reactions. The resulting loads on the MS piping are combined with loads due to other effects as specified in Subsection 3.9.3.1.

3.9.3.1.8 RCIC Turbine

Although not under the jurisdiction of the ASME Code, the RCIC turbine is designed and evaluated and fabricated following the basic guidelines of ASME Code Section III for Class 2 components.

3.9.3.1.9 ECCS Pumps

The RHR, RCIC, and HPCF pumps are constructed in accordance with the requirements of an ASME Code Section III, Class 2 component.

3.9.3.1.10 Standby Liquid Control (SLC) Pump

The SLC system pump is constructed in accordance with the requirements for ASME Code Section III, Class 2 component.

3.9.3.1.11 Standby Liquid Control (SLC) Valve (Injection Valve)

The SLC system injection valve is constructed in accordance with the requirements for ASME Code Section III, Class 1 component.

3.9.3.1.12 Main Steam Isolation and Safety/Relief Valves

The main steam isolation valves and SRVs are constructed in accordance with ASME Boiler and Pressure Vessel Code Section III, Subsection NB-3500, requirements for Class 1 component.

3.9.3.1.13 Safety/Relief Valve Piping and Quencher

The safety/relief valve discharge piping in the drywell extending from the relief valve discharge flange to the diaphragm floor penetration and the safety/relief valve discharge piping in the wetwell extending from the diaphragm floor penetration to and including the quencher is constructed in accordance with the ASME Boiler and Pressure Vessel Code, Section III, requirements for Class 3 components. In addition, all welds in the SRVDL piping in the wetwell above the surface of the suppression pool shall be non-destructively examined to the requirements of ASME Boiler and Pressure Vessel Code, Section III, Class 2.

3.9.3.1.14 Reactor Water Cleanup (RWCU) System Pump and Heat Exchangers

The RWCU pump and heat exchangers (regenerative and nonregenerative) are not part of a safety system and are non-Seismic Category I equipment. ASME Boiler and Pressure Vessel Code Section III for Class 3 components is used as a guide in constructing the RWCU System pump and heat exchanger components.

3.9.3.1.15 Fuel Pool Cooling and Cleanup System Pumps and Heat Exchangers

The pumps and heat exchangers are constructed in accordance with the requirements for ASME Boiler and Pressure Vessel Code Section III, Class 3 component.

3.9.3.1.16 ASME Class 2 and 3 Vessels

The Class 2 and 3 vessels (all vessels not previously discussed) are constructed in accordance with the ASME Boiler and Pressure Vessel Code Section III. The stress analysis of these vessels is performed using elastic methods.

3.9.3.1.17 ASME Class 2 and 3 Pumps

The Class 2 and 3 pumps (all pumps not previously discussed) are designed and evaluated in accordance with the ASME Boiler and Pressure Vessel Code Section III. The stress analysis of these pumps is performed using elastic methods. See Subsection 3.9.3.2 for additional information on pump operability.

3.9.3.1.18 ASME Class 1, 2 and 3 Valves

The Class 1, 2, and 3 valves (all valves not previously discussed) are constructed in accordance with the ASME Boiler and Pressure Vessel Code Section III.

All valves and their extended structures are designed to withstand the accelerations due to seismic and other RBV loads. The attached piping is supported so that these accelerations are not exceeded. The stress analysis of these valves is performed using elastic methods. See Subsection 3.9.3.2 for additional information on valve operability.

3.9.3.1.19 ASME Class 1, 2 and 3 Piping

The Class 1, 2 and 3 piping (all piping not previously discussed) is constructed in accord-

ance with the ASME Boiler and Pressure Vessel Code Section III. ~~For Class 1 piping, for the faulted plant condition, stresses are calculated on an elastic basis and evaluated in accordance with Appendix F of the Code.~~ For Class 2 and 3 piping, stresses are calculated on an elastic basis and evaluated in accordance with NC/ND-3600 of the Code.

3.9.3.2 Pump and Valve Operability Assurance

Active mechanical (with or without electrical operation) equipment are Seismic Category I and each is designed to perform a mechanical motion for its safety-related function during the life of the plant under postulated plant conditions. Equipment with faulted condition functional requirements include active pumps and valves in fluid systems such as the residual heat removal system, emergency core cooling system, and main steam system.

This Subsection discusses operability assurance of active ASME Code Section III pumps and valves, including motor, turbine or operator that is a part of the pump or valve (See Subsection 3.9.2.2).

Safety-related valves and pumps are qualified by testing and analysis and by satisfying the stress and deformation criteria at the critical locations within the pumps and valves. Operability is assured by meeting the requirements of the programs defined in Subsection 3.9.2.2, Section 3.10, Section 3.11 and the following subsections.

Section 4.4 of GE's Environmental Qualification Program (Reference 6) applies to this subsection, and the seismic qualification methodology presented therein is applicable to mechanical as well as electrical equipment.

3.9.3.2.1 ECCS Pumps, Motors and Turbine

Dynamic qualification of the ECCS (RHR, RCIC and HPCF) pumps with motor or turbine assembly is also described in Subsections 3.9.2.2.2.6 and 3.9.2.2.2.7.

3.9.3.2.1.1 Consideration of Loading, Stress, and Acceleration Conditions in the Analysis

In order to avoid damage to the ECCS pumps during the faulted plant condition, the stresses caused by the combination of normal operating loads, SSE, other RBV loads, and dynamic system loads are limited to the material elastic limit. A three dimensional finite-element model of the pump and associated motor (see Subsections 3.9.3.2.2 and 3.9.3.2.1.5 for RCIC pump and turbine, respectively) and its support is developed and analyzed using the response spectrum and the dynamic analysis method. The same is analyzed due to static nozzle loads, pump thrust loads, and dead weight. Critical location stresses are compared with the allowable stresses and the critical location deflections with the allowables; and accelerations are checked to evaluate operability. The average membrane stress σm for the faulted condition loads is limited to 1.2S or approximately 0.75 σ_y (σ_y = yield stress), and the maximum stress in local fibers (σm + bending stress σb) is limited to 1.8S or approximately 1.1 σ_y. The max- imum faulted event nozzle loads are also con- sidered in an analysis of the pump supports to assure that a system misalignment cannot occur.

Performing these analyses with the conservative loads stated and with the restrictive stress limits as allowables assures that critical parts of the pump and associated motor or turbine will not be damaged during the faulted condition and that the operability of the pump for post-faulted condition operation will not be impaired.

3.9.3.2.1.2 Pump/Motor Operation During and Following Dynamic Loading

Active ECCS pump/motor rotor combinations are designed to rotate at a constant speed under all conditions. Motors are designed to withstand short periods of severe overload. The high rotary inertia in the operating pump

quirements and perform their mechanical motion in conjunction with a dynamic (SSE and other RBV) load event. These valves are supported entirely by the piping, i. e., the valve operators are not used as attachment points for piping supports (See Subsection 3.9.3.4.1). The dynamic qualification for operability is unique for each valve type; therefore, each method of qualification is detailed individually below.

3.9.3.2.4.1 Main Steam Isolation Valve

The typical Y-pattern MSIVs described in Subsection 5.4.5.2 are evaluated by analysis and test for capability to operate under the design loads that envelop the predicted loads during a design basis accident and safe shutdown earthquake.

The valve body is designed, analyzed and tested in accordance with the ASME Code Section III, Class 1 requirements. The MSIVs are modeled mathematically in the main steam line system analysis. The loads, amplified accelerations and resonance frequencies of the valves are determined from the overall steamline analysis. The piping supports (snubbers, rigid restraints, etc.) are located and designed to limit amplified accelerations of and piping loads in the valves to the design limits.

As described in Subsection 5.4.5.3, the MSIV and associated electrical equipment (wiring, solenoid valves, and position switches) are dynamically qualified to operate during an accident condition.

3.9.3.2.4.2 Main Steam Safety/Relief Valve

The typical SRV design described in Subsection 5.2.2.4.1 is qualified by type test to IEEE 344 for operability during a dynamic event. Structural integrity of the configuration during a dynamic event is demonstrated by both Code (ASME Class 1) analysis and test.

(1) Valve is designed for maximum moments on inlet and outlet which may be imposed when installed in service. These moments are resultants due to dead weight plus dynamic loading of both valve and connecting pipe, thermal expansion of the connecting pipe, and reaction forces from valve discharge.

(2) A production SRV is demonstrated for operability during a dynamic qualification (shake table) type test with moment and "g" loads applied greater than the required equipment's design limit loads and conditions.

A mathematical model of this valve is included in the main steam line system analysis, as with the MSIVs. This analysis assures the equipment design limits are not exceeded.

3.9.3.2.4.3 Standby Liquid Control Valve (Injection Valve)

The typical SLC Injection Valve design is qualified by type test to IEEE 344. The valve body is designed, analyzed and tested per the ASME Code, Section III, Class 1. The qualification test demonstrates the ability to remain operable after the application of the horizontal and vertical dynamic loading exceeding the predicted dynamic loading.

3.9.3.2.4.4 High Pressure Core Flooder Valve (Motor-Operated)

The typical HPCF valve body design, analysis and testing is in accordance with the requirements of the ASME Code, Section III, Class 1 or 2 components. The Class 1E electrical motor actuator is qualified by type test in accordance with IEEE 382, as discussed in Subsection 3.11.2. A mathematical model of this valve is included in the HPCF piping system analysis. The analysis results are assured not to exceed the horizontal and vertical dynamic acceleration limits acting simultaneously for a dynamic (SSE and other RBV) event, which is treated as an emergency condition.

3.9.3.2.5 Other Active Valves

Other safety-related active valves are ASME Class 1, 2 or 3 and are designed to perform their mechanical motion during dynamic loading

conditions. The operability assurance program ensures that these valves will operate during a dynamic seismic and other RBV event.

3.9.3.2.5.1 Procedures

Qualification tests accompanied by analyses are conducted for all active valves. Procedures for qualifying electrical and instrumentation components which are depended upon to cause the valve to accomplish its intended function are described in Subsection 3.9.3.2.5.1.3.

3.9.3.2.5.1.1 Tests

Prior to installation of the safety-related valves, the following tests are performed: (1) shell hydrostatic test to ASME Code Section III requirements; (2) back seat and main seat leakage tests; (3) disc hydrostatic test; (4) functional tests to verify that the valve will open and close within the specified time limits when subject to the design differential pressure; and (5) operability qualification of valve actuators for the environmental conditions over the installed life. Environmental qualification procedures for operation follow those specified in Section 3.11. The results of all required tests are properly documented and included as a part of the operability acceptance documentation package.

3.9.3.2.5.1.2 Dynamic Load Qualification

The functionality of an active valve during and after a seismic and other RBV event may be demonstrated by an analysis or by a combination of analysis and test. The qualification of electrical and instrumentation components controlling valve actuation is discussed in Subsection 3.9.3.2.5.1.3. The valves are designed using either stress analyses or the pressure temperature rating requirements based upon design conditions. An analysis of the extended structure is performed for static equivalent dynamic loads applied at the center of gravity of the extended structure. See Subsection 3.9.2.2 for further details.

The maximum stress limits allowed in these analyses confirm structural integrity and are the limits developed and accepted by the ASME for the particular ASME Class of valve analyzed. ~~Additional detail on stress limits for operability is provided in a footnote to Table 3.9-2.~~

Dynamic load qualification is accomplished in the following way:

(1) All the active valves are designed to have a fundamental frequency which is greater than the high frequency asymptote (ZPA) of the dynamic event. This is shown by suitable test or analysis.

(2) The actuator and yoke of the valve system is statically loaded to an amount greater than that due to a dynamic event. The load is applied at the center to gravity of the actuator alone in the direction of the weakest axis of the yoke. The simulated operational differential pressure is simultaneously applied to the valve during the static deflection tests.

(3) The valve is then operated while in the deflected position (i.e., from the normal operating position to the safe position). The valve is verified to perform its safety-related function within the specified operating time limits.

(4) Motor operators and other electrical appurtenances necessary for operation are qualified as operable during a dynamic event by appropriate qualification tests prior to installation on the valve. These motor operators then have individual Seismic Category I supports attached to decouple the dynamic loads between the operators and valves themselves.

The piping, stress analysis, and pipe support design maintain the motor operator accelerations below the qualification levels with adequate margin of safety.

If the fundamental frequency of the valve, by test or analysis, is less than that for the ZPA, a dynamic analysis of the valve performed to determine the equivalent acceleration to be applied during the static test. The analysis provides the amplification of the input

3.9.3.4 Component Supports

The design of bolts for component supports is specified in the ASME Code Section III, Subsection NF. Stress limits for bolts are given in NF-3225. The rules and stress limits which must be satisfied are those given in NF-3324.6 multiplied by the appropriate stress limit factor for the particular service loading level and stress category specified in Table NF-3225.2-1.

Moreover, on equipment which is to be, or may be, mounted on a concrete support, sufficient holes for anchor bolts are provided to limit the anchor bolt stress to less than 10,000 psi on the nominal bolt area in shear or tension.

Concrete anchor bolts (including under-cut type anchor bolts) which are used for pipe support base plates will be designed to the applicable factors of safety which are defined in I&E Bulletin 79-02, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," Revision ~~1~~ 2 dated ~~June 21, 1979~~ November 8, 1979.

3.9.3.4.1 Piping

Supports and their attachments for essential ASME Code Section III, Class 1,2, and 3 piping are designed in accordance with Subsection NF* up to the interface of the building structure, with jurisdictional boundaries as defined by Subsection NF. ~~The building structure component supports are designed in accordance with ANSI/AISC N690, Nuclear Facilities Steel Safety-Related Structures for Design, Fabrication and Erection or AISC Specification for the Design, Fabrication, and Erection of Structural Steel for buildings.~~ The loading combinations for the various operating conditions correspond to those used for design of the supported pipe. The component loading combinations are discussed in Subsection 3.9.3.1. The stress limits are per ASME III, Subsection NF and Appendix F. Supports are generally designed either by load rating method per paragraph NF-3260 or by the stress limits for linear supports per paragraph NF-3231. The critical buckling loads for the Class 1 piping supports subjected to faulted loads that are more severe than normal, upset and emergency loads, are determined by using the methods discussed in Appendices F and XVII of the Code. To avoid buckling in the piping supports, the allowable loads are limited to two thirds of the determined critical buckling loads.

INSERT NEW PARA 3.9-31A & 3.9-31B

The design of all supports for non-nuclear piping satisfies the requirements of ASME/ANSI B31.1 Power Piping Code, Paragraphs 120 and 121.

For the major active valves identified in Subsection 3.9.3.2.4, the valve operators are not used as attachment points for piping supports.

The design criteria and dynamic testing requirements for the ASME III piping supports are as follows:

(1) Piping Supports - All piping supports are designed, fabricated, and assembled so that they cannot become disengaged by the movement of the supported pipe ~~or~~ or equipment after they have been installed. All piping supports are designed in accordance with the rules of Subsection NF of the ASME Code up to the building structure interface as defined ~~in the project design specifications.~~ by jurisdictional boundaries in Subsection NF.

(2) Spring Hangers - The operating load on spring hangers is the load caused by dead weight. The hangers are calibrated to ensure that they support the operating load at both their hot and cold load settings. Spring hangers provide a specified down travel and up travel in excess of the specified thermal movement. Deflections due to dynamic loads are checked to confirm that they do not fall outside the working range of the support and the variation in the support load does not induce unacceptable loads on other supports.

*Augmented by the following: (1) application of Code Case N-476, Supplement 89.1 which governs the design of single angle members of ASME Class 1,2,3 and MC linear component supports; and (2) when eccentric loads or other torsional loads are not accommodated by designing the load to act through the shear center or meet "Standard for Steel Support Design", analyses will be performed in accordance with torsional analysis methods such as: "Torsional Analysis of Steel Members, USS Steel Manual", Publication T114-2/83.

NEW PARA 3.9-31A

Maximum calculated static and dynamic piping deflections at support locations are checked to confirm that the support has not rotated beyond the Vendor's recommended cone of action or the recommended arc of loading.

NEW PARA. 3.9-31B

Supports for ASME Code Section III instrumentation lines are designed and analyzed in accordance with ASME Code Section III.

(3) Snubbers - The operating loads on snubbers are the loads caused by dynamic events (e.g., seismic, RBV due to LOCA and SRV discharge, discharge through a relief valve line or valve closure) during various operating conditions. Snubbers restrain piping against response to the vibratory excitation and to the associated differential movement of the piping system support anchor points. The criteria for locating snubbers and ensuring adequate load capacity, the structural and mechanical performance parameters used for snubbers and the installation and inspection considerations for the snubbers are as follows:

(a) Required Load Capacity and Snubber Location

~~The entire piping system including valves and support system between anchor points is mathematically modeled for complete piping structural analysis. In the dynamic analysis, the snubbers are modeled as a spring~~ with a given spring stiffness depending on the snubber size. The analysis determines the forces and moments acting on each piping components and the forces acting on the snubbers due to all dynamic loading and operating conditions defined in the piping design specification. The forces on snubbers are operating loads for various operating conditions. The calculated loads cannot exceed the snubber design load capacity for various operating conditions, i.e., design, normal, upset, ~~emergency and faulted.~~

The loads calculated in the piping dynamic analysis, described in Subsection 3.7.3.8, cannot exceed the snubber load capacity for design,normal,upset,emergency and faulted conditions.

Snubbers are generally used in situations where dynamic support is required because thermal growth of the piping prohibits the use of rigid supports. The snubber locations and support directions are first decided by estimation so that the stresses in the piping system will have acceptable values. The snubber locations and support directions are refined by performing the dynamic analysis of the piping and support system as described above in order that the piping stresses and support loads meet the Code requirements.

The pipe support design specification requires that snubbers be provided with position indicators to identify the rod position. This indicator facilitates the checking of hot and cold settings of the snubber, as specified in the installation manual, during plant preoperational and startup testing.

(b) Inspection, Testing, Repair and/or Replacement of Snubbers

The pipe support design specification requires that the snubber supplier prepare an installation instruction manual. This manual is required to contain complete instructions for the testing, maintenance, and repair of the snubber. It also contains inspection points and the period of inspection.

The pipe support design specification requires that hydraulic snubbers be equipped with a fluid level indicator so that the level of fluid in the snubber can be ascertained easily.

The spring constant achieved by the snubber supplier for a given load capacity snubber is compared against the spring constant used in the piping system model. If the spring constants are the same, then the snubber location and support direction become confirmed. If the spring constants are not in agreement, they are brought in agreement, and the system analysis is redone to confirm the snubber loads. This iteration is continued until all snubber load capacities and spring constants are reconciled.

(c) Snubber Design and Testing

To assure that the required structural and mechanical performance characteristics and product quality are achieved, the following requirements for design and testing are imposed by the design specification:

(i) The snubbers are required by the pipe support design specification to be designed in accordance with all of the rules and regulations of the ASME Code Section III, Subsection NF. This design requirement includes analysis for the normal, upset, emergency, and faulted loads. These calculated loads are then compared against the allowable loads to make sure that the stresses are below the code allowable limit.

(ii) The snubbers are tested to insure that they can perform as required during the seismic and other RBV events, and under anticipated operational transient loads or other mechanical loads associated with the design requirements for the plant. The following test requirements are included:

o Snubbers are subjected to force or displacement versus time loading at frequencies within the range of

o Dynamic cyclic load tests are conducted for hydraulic snubbers to determine the operational characteristics of the snubber control valve.

significant modes of the piping system;

- Displacements are measured to determine the performance characteristics specified;

- Tests are conducted at various temperatures to ensure operability over the specified range;

- Peak test loads in both tension and compression are required to be equal to or higher than the rated load requirement, and

- The snubbers are tested for various abnormal environmental conditions. Upon completion of the abnormal environmental transient test, the snubber is tested dynamically at a frequency within a specified frequency range. The snubber must operate normally during the dynamic test.

(d) Snubber Installation Requirements

An installation instruction manual is required by the pipe support design specification. This manual is required to contain instructions for storage, handling, erection, and adjustments (if necessary) of snubbers. Each snubber has an installation location drawing which contains the installation location of the snubber on the pipe and structure, the hot and cold settings, and additional information needed to install the particular snubber.

(e) Snubber Pre-service Examination

The pre-service examination plan of all snubbers covered by the Chapter 16 technical specifications will be prepared. This examination will be made after snubber installation but not more than 6 months prior to initial system pre-operational testing. The pre-service examination will verify the following:

(i) There are no visible signs of damage or impaired operability as a result of storage, handling, or installation.

(ii) The snubber location, orientation, position setting, and configuration (attachments, extensions, etc.) are according to design drawings and specifications.

(iii) Snubbers are not seized, frozen or jammed.

(iv) Adequate swing clearance is provided to allow snubber movements.

(v) If applicable, fluid is to be recommended level and not be leaking from the snubber system.

(vi) Structural connections such as pins, fasteners and other connecting hardware such as lock nuts, tabs, wire, cotter pins are installed correctly.

If the period between the initial pre-service examination and initial system pre-operational tests exceeds 6 months because of unexpected situations, reexamination of Items 1, 4, and 5 will be performed. Snubbers which are installed incorrectly or otherwise fail to meet the above requirements will be repaired or replaced and re-examined in accordance with the above criteria.

(4) Struts - ~~The design load on struts includes those loads caused by dead weight, thermal expansion, seismic forces (i.e., OBE and SSE), other RBV loads.~~

Replace w/ Att. M

Att. M for page 3.9-33

Struts - Struts are defined as ASME Section III, Subsection NF, Component Standard Supports. They consist of rigid rods pinned to a pipe clamp or lug at the pipe and pinned to a clevis attached to the building structure or supplemental steel at the other end. Struts, including the rod, clamps, clevises, and pins are designed in accordance with ASME Code Section III, Subsection NF-3000.

Struts are passive supports, requiring little maintenance and in-service inspection, and will normally be used instead of snubbers where dynamic supports are required and the movement of the pipe due to thermal expansion and/or anchor motions is small. Struts will not be used at locations where restraint of pipe movement to thermal expansion will significantly increase the secondary piping stress ranges or equipment nozzle loads. Increases of thermal expansion loads in the pipe and nozzles will normally be restricted to less than 20%.

Because of the pinned connections at the pipe and structure, struts carry axial loads only. The design loads on struts may include those loads caused by thermal expansion, dead weight, and the inertia and anchor motion effects of all dynamic loads. As in the case of other supports, the forces on struts are obtained from an analysis, which are assured not to exceed the design loads for various operating conditions.

system anchor displacements, and reaction forces caused by relief valve discharge or valve closure, etc.

Struts are designed in accordance with ASME Code Section III, Subsection NF-3000 to be capable of carrying the design loads for various operating conditions. As in case of snubbers, the forces on struts are obtained from an analysis, which are assured not to exceed the design loads for various operating conditions.

INSERT Att. A

3.9.3.4.2 Reactor Pressure Vessel Support Skirt

The ABWR RPV support skirt is designed as an ASME Code Class 1 component per the requirements of ASME Code Section III, Subsection NF*. The loading conditions and stress criteria are given in Tables 3.9-1 and 3.9-2, and the calculated stresses meet the Code allowable stresses in the critical support areas for various plant operating conditions. The stress level margins assure the adequacy of the RPV support skirt. An analysis for buckling shows that the support skirt complies with Subparagraph F-1332.5 of ASME III, Appendix F, and the loads do not exceed two thirds of the critical buckling strength of the skirt. The permissible skirt loads at any elevation, when simultaneously applied, are limited by the following interaction equation:

$$(P/P_{crit}) + (q/q_{crit}) + (\tau/\tau_{crit}) < (1/S.F.)$$

where:

- q = longitudinal load
- P = external pressure
- τ = transverse shear stress
- S.F. = safety factor
  - = 3.0 for design, testing, service levels A & B
  - = 2.0 for Service Level C
  - = 1.5 for Service Level D.

3.9.3.4.3 Reactor Pressure Vessel Stabilizer

The RPV stabilizer is designed as a Safety Class 1 linear type component support in accordance with the requirements of ASME Boiler and Pressure Vessel Code Section III, Subsection NF. The stabilizer provides a reaction point near the upper end of the RPV to resist horizontal loads due to effects such as earthquake, pipe rupture and RBV. The design loading conditions, and stress criteria are given in Tables 3.9-1 and 3.9-2, and the calculated stresses meet the Code allowable stresses in the critical support areas for various plant operating conditions.

3.9.3.4.4 Floor-Mounted Major Equipment (Pumps, Heat Exchangers, and RCIC Turbine)

Since the major active valves are supported by piping and not tied to building structures, valve "supports" do not exist (See Subsection 3.9.3.4.1).

The HPCF, RHR, RCIC, SLC, FPCCU, SPCU, and CUW pumps; RMC, RHR, RWCU, and FPCCU heat exchangers; and RCIC turbine are all analyzed to verify the adequacy of their support structure under various plant operating conditions. In all cases, the load stresses in the critical support areas are within ASME Code allowables.

Seismic Category I active pump supports are qualified for dynamic (seismic and other RBV) loads by testing when the pump supports

*Augmented by the following: (1) application of Code Case N-476, Supplement 89.1 which governs the design of single angle members of ASME Class 1,2,3 and MC linear component supports; and (2) when eccentric loads or other torsional loads are not accommodated by designing the load to act through the shear center or meet "Standard for Steel Support Design", analyses will be performed in accordance with torsional analysis methods such as: "Torsional Analysis of Steel Members, USS Steel Manual", Publication T114-2/83.

Att N. for page 3.9-34

Add new Paragraph 3.9.3.4.1 (5)

"Frame Type (Linear) Pipe Supports - Frame type pipe supports are linear supports as defined as ASME Section III, Subsection NF, Component Standard Supports. They consist of frames constructed of structural steel elements that are not attached to the pipe. They act as guides to allow axial and rotational movement of the pipe but act as rigid ~~restraints~~ to lateral movement in either one or two directions. Frame type pipe supports are designed in accordance with ASME Code Section III, Subsection NF-3000.

restraints

"Frame type pipe supports are passive supports, requiring little maintenance and in-service inspection, and will normally be used instead of struts when they are more economical or where environmental conditions are not suitable for the ball bushings at the pinned connections of struts. Similar to struts, frame type supports will not be used at locations where restraint of pipe movement to thermal expansion will significantly increase the secondary piping stress ranges or equipment nozzle loads. Increases of thermal expansion loads in the pipe and nozzles will normally be restricted to less than 20%.

Frame type supports

"The design loads on frame type pipe supports include those loads caused by thermal expansion, dead weight, and the inertia and anchor motion effects of all dynamic loads. As in the case of other supports, the forces on ~~struts~~ are obtained from an analysis, which are assured not to exceed the design loads for various operating conditions."

Add new Paragraph 3.9.3.4.1 (6):

Special Engineered Pipe Supports - In an effort to minimize the use and application of snubbers there may be ~~isolated~~ instances where special engineered pipe supports can be used where either struts or frame-type supports cannot be applied. Examples of special engineered supports are Energy Absorbers, and Limit Stops.

Energy Absorbers - are linear energy absorbing support parts designed to dissipate energy associated with dynamic pipe movements by yielding. When energy absorbers are used they will be designed to meet the requirements of ASME Section III Code Case N-420, Linear Energy Absorbing Supports for Subsection NF, Classes 1, 2, and 3 Construction, Section III, Division 1. The restrictions on location and application of struts and frame-type supports, discussed in (4) and (5) above, are also applicable to energy absorbers since energy absorbers allow thermal movement of the pipe only in its design directions.

Limit Stops - are passive seismic pipe support devices consisting of limit stops with gaps sized to allow for thermal expansion while preventing large seismic displacements. Limit stops are linear supports as defined as ASME Section III, Subsection NF, and are designed in accordance with ASME Code Section III, Subsection NF-3000. They consist of box frames constructed of structural steel elements that are not attached to the pipe. The box frames allow free movement in the axial direction but limit large displacements in the lateral direction.

3.9.7 COL License Information

3.9.7.1 Reactor Internals Vibration Analysis, Measurement and Inspection Program

The first COL applicant will provide, at the time of application, the results of the vibration assessment program for the ABWR prototype internals. These results will include the following information specified in Regulatory Guide 1.20.

R.G. 1.20	Subject
C.2.1	Vibration Analysis Program
C.2.2	Vibration Measurement Program
C.2.3	Inspection Program
C.2.4	Documentation of Results

NRC review and approval of the above information on the first COL applicants docket will complete the vibration assessment program requirements for prototype reactor internals.

In addition to the information tabulated above, the first COL applicant will provide the information on the schedules in accordance with the applicable portions of position C.3 of Regulatory Guide 1.20 for non-prototype internals.

Subsequent COL applicants need only provide the information on the schedules in accordance with the applicable portions of position C.3 of Regulatory Guide 1.20 for non-prototype internals. (See Subsection 3.9.2.4 for interface requirements).

3.9.7.2 ASME Class 2 or 3 or Quality Group D Components with 60 Year Design Life

COL applicants will identify ASME Class 2 or 3 or Quality Group D components that are subjected to cyclic loadings, including operating vibration loads and thermal transients effects, of a magnitude and/or duration so severe the 60 year design life can not be assured by required Code calculations and, if similar designs have not already been evaluated, either provide an appropriate analysis to demonstrate the required design life or provide designs to mitigate the magnitude or duration of the cyclic loads. (See Subsection 3.9.3.1.)

3.9.7.3 Pump and Valve Inservice Testing Program

COL applicants will provide a plan for the detailed pump and valve inservice testing and inspection program. This plan will

(1) Include baseline pre-service testing to support the periodic in-service testing of the components required by technical specifications. Provisions are included to disassemble and inspect the pump, check valves, and MOVs within the Code and safety-related classification as necessary, depending on test results. (See Subsections 3.9.6, 3.9.6.1, 3.9.6.2.1 and 3.9.6.2.2)

(2) Provide a study to determine the optimal frequency for valve stroking during inservice testing. (See Subsection 3.9.6.2.2)

(3) Address the concerns and issues identified in Generic Letter 89-10; specifically the method of assessment of the loads, the method of sizing the actuators, and the setting of the torque and limit switches. (See Subsection 3.9.6.2.2)

3.9.7.4 Audit of Design Specification and Design Reports

COL applicants will make available to the NRC staff design specification and design reports required by ASME Code for vessels, pumps, valves and piping systems for the purpose of audit. (See Subsection 3.9.3.1)

3.9.8 References

1. *BWR Fuel Channel Mechanical Design and Deflection*, NEDE-21354-P, September 1976.

2. *BWR/6 Fuel Assembly Evaluation of Combined Safe Shutdown Earthquake (SSE) and Loss-of-Coolant Accident (LOCA) Loadings*, NEDE-21175-P, November 1976.

3. NEDE-24057-P (Class III) and NEDE-24057 (Class I) Assessment of Reactor Internals Vibration in BWR/4 and BWR/5 Plants.

Table 3.9-1

PLANT EVENTS

B. Dynamic Loading Events(8)

		ASME Code Service Limit(10)	No. of Cycles/ Events(1)
12.	Operating Basis Earthquake (OBE) Event at Rated Power Operating Conditions	B	10 Cycles (4)
13.	Safe Shutdown Earthquake (SSE) (5) at Rated Power Operating Conditions	D(9)	1(3) Cycle
14.	Turbine Stop Valve Full Closure (TSVC)(6) During Event 7a and Testing	B	~~200~~ 330 cycles/3 events ~~Cycles~~
15.	Safety Relief Valve (SRV) Actuation (One, Two Adjacent, All or Automatic Depressurization System) During Event 7a and 7b	B	~~200~~ 4596 Events(7)
16.	Loss of Coolant Accident (LOCA)		
	Small Break LOCA (SBL)	D(9)	1(3)
	Intermediate Break LOCA (IBL)	D(9)	1(3)
	Large Break LOCA (LBL)	D(9)	1(3)

NOTES:

(1) Some events apply to reactor pressure vessel (RPV) only. The number of events/cycles applies to RPV as an example.

(2) Bulk average vessel coolant temperature change in any one hour period.

(3) The annual encounter probability of a single event is $< 10^{-2}$ for a Level C event and $< 10^{-4}$ for a Level D event. See Subsection 3.9.3.1.1.5.

(4) 50 peak OBE cycles for piping, 10 peak OBE cycles for other equipment and components.

(5) One stress or load reversal cycle of maximum amplitude.

Table 3.9-1

PLANT EVENTS

B. Dynamic Loading Events

(Continued)

NOTES:

(6) Applicable to main steam piping system only.

(7) The number of reactor building vibratory load cycles on the reactor vessel and internal components is 29,400 cycles of varying amplitude during the 396 events of safety/relief valve actuation.

The number of reactor building vibratory load cycles on the piping systems inside the containment is 4200 events of single safety/reli[illegible] valve actuation, with 3 stress cycles per event and 396 events of safety/relief valve actuation of all valves or the Automatic Depressurization system valves, with 3 stress cycles per event.

(8) Table 3.9-2 shows the evaluation basis combination of these dynamic loadings.

(9) Appendix F or other appropriate requirements of the ASME Code are used to determine the service Level D limits, as described in Subsection 3.9.1.4.

(10) These ASME Code Service Limits apply to ASME Code Class 1, 2 and 3 components, component supports and Class CS structures. Different limits apply to Class MC and CC containment vessels and components, as discussed in Section 3.8.

Ref. Audit item NO. A-5

Table 5.2-4

REACTOR COOLANT PRESSURE BOUNDARY MATERIALS

Component	Form	Material	Specification (ASTM/ASME)
Main Steam Isolation Valves			
Valve Body	Cast	Carbon steel	SA352 LCB
Cover	Forged	Carbon Steel	SA350LF2
Poppet	Forged	Carbon Steel	SA350LF2
Valve stem	Rod	17-4 pH	SA 564 630 (H1100)
Body bolt	Bolting	Alloy steel	SA 540 B23 CL4 or 5
Hex nuts	Bolting Nuts	Alloy steel	SA 194 GR7
Main Steam Safety/Relief Valve			
Body	Forging	Carbon steel	ASME SA 350 LF2
	or Casting	Carbon steel	ASME SA 352 LCB
Bonnet (yoke)	Forging	Carbon steel	ASME SA 350 LF2
	or Casting	Carbon steel	ASME SA 352 LCB
Nozzle (seat)	Forging	Stainless steel	ASME SA 182 Gr F316
	or Casting	Carbon steel	ASME SA 350 LF2
Body to bonnet stud	Bar/rod	Low-alloy steel	ASME SA 193 Gr B7
Body to bonnet nut	Bar/rod	Alloy steel	ASME SA 194 Gr 7
Disc	Forging	Alloy steel	ASME SA 637 Gr 718
	or Casting	Stainless steel	ASME SA 351 CF 3A
Spring washer &	Forging	Carbon steel	ASME SA 105
Adjusting Screw or		Alloy steel	ASME SA 193 Gr B6 (Quenched + tempered or normalized & tempered
Set point adjustment assembly	Forgings	Carbon and alloy steel parts	Multiple specifications
Spindle (stem)	Bar	Precipitation-hardened steel	ASTM A564 Type 630 (H 1100)
Spring	Wire or	Steel	ASTM A304 Gr 4161 N
	Bellville washers	Alloy steel	45 Cr Mo V67
Main Steam Piping (between RPV and the turbine stop valve)			
Pipe	Seamless	Carbon steel	ASME SA 333 Gr. 6
Contour nozzle	Forging	Carbon steel	" SA 350 LF 2
200A 1500# large groove flange	Forging	Carbon steel	" SA 350 LF 2

Ref. Audit item NO. A-5

Table 5.2-4

REACTOR COOLANT PRESSURE BOUNDARY MATERIALS (Continued)

Component	Form	Material	Specification (ASTM/ASME)
50A special nozzle	Forging	Carbon steel	ASME SA 350 LF 2
Elbow	Seamless	Carbon steel	ASME SA 420
Head fitting/penetration piping	Forging	Carbon steel	SA 350 LF 2

Feedwater Piping (between RPV and the seismic interface restrain

Pipe	seamless	Carbon steel	ASME SA 333 Gr. 6
Elbow	seamless	Carbon steel	ASME SA 420
Head fitting/penetration piping	Forging	Carbon steel	ASME SA 350 LF 2
Nozzle	Forging	Carbon steel	ASME SA 350 LF 2