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U.S. Nuclear Regulatory Commission
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Subject: System 80+^{TM} Distribution Systems Design Guide, Section 7

Reference: ABB-CE Letter LD-92-038, Submittal Schedule, March 25, 1992

Dear Sirs:

Enclosed is a draft of Section 7 of the Distribution Systems Design Guide which was discussed at the mechanical and piping systems audit meeting in Charlotte, NC on April 22-23, 1992. This submittal fulfills the commitment of item 5 of the reference letter.

If you have any questions, please call me or Mr. Stan Ritterbusch at (203) 285-5206.

Very truly yours,

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7.0 DISTRIBUTION SYSTEMS ANALYSIS REQUIREMENTS

7.1 PIPING

7.1.1 GENERAL

Seismic Category I piping, as defined in CESSAR-DC, Section 3.2.1, shall meet the analysis requirements of the ASME Boiler and Pressure Vessel Code, Section III, Subarticles NB-3650, NC-3650, and ND-3650.

Category II piping, as defined in CESSAR-DC, Section 3.2.1, shall be analyzed to the same requirements as Category I piping. Category II requirements are conservatively satisfied by analyzing the piping to the same criteria as Category I.

Non-Category I and II piping shall meet the requirements of ASME Code for Pressure Piping, Power Piping, ASME B31.1.

The analysis requirements described in Section 7.1 apply only to Seismic Category I and II piping.

7.1.2 DESIGN CONSIDERATIONS

7.1.2.1 Pressure

The pipe wall thickness shall be sized to accommodate the specified internal pressures and shall meet the requirements of the ASME Code, Section III, Subarticle 3640. Stresses due to the system design pressures and maximum peak pressures shall be included in the acceptance criteria.

7.1.2.2 Gravity

The weight of the pipe, in-line components, contents and insulation shall be included. The weight of water during hydrostatic testing shall be considered for steam or air filled lines.

7.1.2.3 Thermal

The effect of thermal expansion of the system due to the design temperature shall be included. Possible operating modes of the system that may result in more severe thermal expansion stresses than the entire system at design temperature shall be considered. Maximum operating temperature may be used in lieu of design temperature when available.

The effects of anchor movement due to thermal expansion of equipment or other piping shall be considered.

7.1.2.4 Seismic

The effects of earthquake loading shall be considered. The inertia loads and movements, including earthquake anchor movements, and the number of cycles must be included in the analysis.

7.1.2.4.1 Seismic Anchor Movements

Seismic anchor motion shall be included for piping supported by more than one structure by applying; 1) the building seismic movements, and/or 2) equipment seismic movements, as support movements on the pipe.

The support movements shall be assumed in opposite directions for adjacent structures to give the maximum stress in the pipe, unless the relative time phasing of the motions of the supporting structures or equipment is determined by simultaneous time history analyses. The effects of seismic anchor motion on the piping shall be included for the operating basis earthquake (OBE) only. Seismic anchor motion produces secondary stresses and shall not be evaluated with the safe shutdown earthquake (SSE).

7.1.2.5 Wind/Tornado

Exposed piping shall be designed to withstand wind and tornado loads. Simultaneous wind and tornado loads are not considered.

7.1.2.6 Fluid Transient Loadings

7.1.2.6.1 Relief/Safety Valve Thrust

Valve thrust loads should be considered for both open and closed valve discharge cases. All thrust loads should first be considered for their significance. If considered a significant transient, steady state thrust loads must be applied to the piping system. If determined insignificant, then thrust loads need not be applied.

7.1.2.6.2 Water and Steam Hammer

Water and steam hammer are dynamic loadings on piping that are caused by a sudden change in momentum of the flow medium due to a rapid system transient.

Although hammer effects can potentially occur on any line where valve closing time is less than 3 seconds, the effects on small lines are generally neglected and only the largest lines with high pressures, large flow rates, and very rapid closing valves must be evaluated.

7.1.2.7 Pipe Break Loads

Pipe break loadings may consist of pipe whip, jet impingement, differential pressure, support movements, or temperature increases resulting from the rupture of nearby pipes other than the line under consideration.

7.1.2.8 Thermal Stratification

Piping subjected to stratified flow conditions shall be evaluated for the effects of thermal stratification.

7.1.2.9 Missile Loads

Piping subjected to loads described in CESSAR-DC, Section 3.5.1 shall be evaluated for the effects of missiles.

7.1.3 DESIGN LOAD COMBINATIONS

Loading combinations shall be in accordance with CESSAR-DC, Section 3.9.3.1.

Load combinations applicable to Class 1 piping are detailed in Tables 7.1-1 and 7.1-2.

Load combinations applicable to Class 2 and 3 piping are detailed in Table 7.1-3.

7.1.4 ANALYSIS

Static and dynamic analyses, as defined in this section, shall be based on linear elastic analysis methods.

7.1.4.1 Gravity Analysis

The gravity analysis shall include the weight of the pipe or piping component, the weight of the enclosed fluid, the weight of all other sustained mechanical loads, and the weight of any attached insulation. Also, if the system contents vary during operation, the analysis should consider all modes of operation. Weight due to attached support/restraints shall be included if determined to be significant.

7.1.4.2 Thermal Analysis

A thermal analysis of piping systems shall take into account forces and moments resulting from expansion and contraction. For all analyses, the ambient temperature should be taken to be 70°F. Flexibility analyses should be based on the material property values at the temperature under consideration. Therefore the analyses shall be based on the value of Young's modulus at temperature, E_{hot}. ASME Code requires that stresses shall be based on E_{cold}. This may be accomplished by multiplying the analysis results by E_{cold}/E_{hot}.

All possible operating modes shall be evaluated to determine the highest thermal expansion stress. The effects of anchor movement due to thermal expansion of equipment or other piping shall also be considered.

7.1.4.2.1 Specific Thermal Requirements for Class 1 Piping

The thermal analysis shall include a check of the stress intensity range and shall evaluate fatigue (as expressed by cumulative usage) for all normal operating temperature distributions, the transient events experienced in going from one operating mode to another, thermal anchor movements associated with the operating conditions and transients, and all test conditions.

7.1.4.2.2 Thermal Stratification

Piping systems with low flow rates and potentially subjected to stratified flow require evaluation for additional thermal stresses due to thermal stratification. Stratified flow exists when a hotter fluid flows over a colder region of fluid. This condition induces a vertical thermal gradient resulting in increased overall bending stresses and localized thermal gradient stresses.

A linear thermal gradient will cause a convex upward curvature, K, in an unconstrained pipe equal to:

$$K=\frac{\alpha\Delta T}{D} \qquad \text{(Eqn. 7.1-1)}$$

Where: $\Delta T = T_{Top} - T_{Bottom}$ (with $T_{Top} > T_{Bottom}$)
D = Pipe outside diameter
α = Thermal expansion coefficient

The resulting bending stresses should be calculated by allowing the pipe to thermally expand unconstrained and then applying a set of equal and opposite displacements at the rigid support points.

If the temperature distribution in the pipe is nonlinear, the above curvature formula is only approximate and the nonlinear distribution should be considered in terms of its effect on curvature and local thermal stresses. This may be done by means of a finite element analysis comprising a heat transfer analysis to determine the pipe wall temperature variation based on fluid temperature, followed by a thermal stress analysis to determine the initial pipe curvature and maximum stress intensity. This stress intensity should then be used in Equation 11 of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB-3650 as the nonlinear through-wall temperature gradient stress. These analyses consider both steady state and transient conditions.

7.1.4.3 Seismic Analysis

Seismic analysis of a piping system generally involves both dynamic and static evaluations. A dynamic analysis is performed to evaluate the inertia loads developed as the mass of the piping is accelerated due to seismic motion. The static analysis is performed to determine loading resulting from differential seismic movements of structures or large lines to which piping is attached.

7.1.4.3.1 Static Analysis

Standard seismic analysis is a dynamic analysis using the modal superposition and response spectrum method. The design response spectra for earthquake ground motion indicate that at a frequency higher than the frequency corresponding to the zero period acceleration (ZPA), all modes respond like a rigid body without amplification. This cut-off frequency defines the rigid range. If a piping system is so rigidly supported that its lowest natural frequency is higher than the frequency corresponding to the ZPA, then the system will respond like a rigid body. The maximum effect is due to an inertia force equal to the maximum floor acceleration, and therefore, a static analysis is sufficient for predicting the maximum effect due to an earthquake.

The analysis is similar to a gravity analysis. Attention should be paid to the following points in performing the analysis:

A. Inertia loads should be applied separately in x, y, and z directions, and the results of the 3 separate analyses combined by SRSS. The accelerations are obtained from the respective floor response spectra with values corresponding to the zero period.

B. The active supports are seismic supports, rather than gravity supports, i.e., snubbers will be active and low stiffness spring hangers inactive.

7.1.4.3.2 Dynamic Analysis

7.1.4.3.2.1 Response Spectrum Analysis

7.1.4.3.2.1.1 General

The response of a flexible system to seismic forces depends upon its natural frequencies and the frequencies of excitation. For these systems, it is necessary to know the natural frequencies, and the seismic excitation which is usually defined as acceleration response spectrum.

To determine the system natural frequencies, each pipe shall be idealized as a mathematical model consisting of lumped masses connected by elastic members. Lumped masses shall be located at carefully selected points in order to adequately represent the dynamic and elastic characteristics of the pipe system. Using the elastic properties of the pipe, the flexibility for the pipe shall be determined. The flexibility calculation shall include the effects of torsional, bending, shear, and axial deformations (i.e., the degrees of freedom). Node point spacing shall be selected to obtain accurate dynamic results. As a minimum, the number of degrees of freedom should be taken as equal to twice the number of modes with frequencies less than the frequency corresponding to the ZPA.

Once the flexibility and mass of the mathematical model are calculated, the frequencies and mode shapes for all significant modes of vibration shall be determined. Piping stresses and displacements shall then be determined utilizing standard modal response spectra analysis techniques.

7.1.4.3.2.1.2 Response Spectrum

A response spectrum is a curve which represents the peak acceleration response verses frequency of a single degree of freedom spring mass system which is excited by an earthquake motion time history. It is a measure of how a structural system with certain natural frequencies will respond to an earthquake applied at its supports.

The response spectra curves for the System 80+ have been developed using several ground motion time history analyses. These analyses were used to cover a range of possible soil conditions. The resulting floor response spectra may be enveloped or input individually into the seismic analysis to account for all of the various soil cases.

Most analyses will consist of multiple supports with different characteristic response spectrum. To account for this, the applicable response spectra for all structures and elevations supporting the pipe in the dynamic model may be enveloped to determine the response spectra for that piping.

If this method is determined to be overly conservative, multiple-spectra method may be used. The response spectrum of the individual support locations may be input separately and the results of the multiple excitation combined. This method may not be used in combination with variable damping.

7.1.4.3.2.1.3 Spectrum Peak Broadening

To account for possible uncertainties, the initially computed floor response spectra are usually smoothed, and peaks associated with the structural frequencies are widened. The method used to determine the amount of peak widening, associated with the structural frequency, shall be as detailed in ASME Code, Section III, Division I, Appendix N, Section N-1226.3.

7.1.4.3.2.1.4 Damping

Damping values are provided in CESSAR-DC, Section 3.7.1.3 and are summarized below;

	OBE	SSE
Piping diameter ≤ 12"	1%	2%
Piping diameter > 12"	2%	3%

Alternately, when using response spectra analyses, variable damping values per ASME Code Case N-411-1 "Alternative Damping Values for Response Spectra Analysis of Class 1, 2, and 3 Piping, Section III, Division I" is acceptable. However, no combination of the two damping criteria is to be used. The variable damping curve is provided in CESSAR-DC, Table 3.7-41.

7.1.4.3.2.1.5 Modal Cutoff and Rigid Range Acceleration Effects

The number of modes included in the analysis shall be chosen to correspond with the range of seismic excitation frequencies up to a maximum of the frequency corresponding to the ZPA. There is no limit on the number of modes.

At modal frequencies above the frequency corresponding to the ZPA, pipe members are considered rigid. The acceleration associated with these rigid modes is usually small. However, in certain situations the response to high frequency modes may significantly affect support loads, particularly axial restraints on long runs. The effects of rigid range accelerations may be evaluated by approximating the higher mode response using the spectral acceleration at the frequency corresponding to the ZPA and combining this response with the dynamic analysis results in an additional mode (using the square root of the sum of the squares, SRSS).

7.1.4.3.2.1.6 Modal and Direction Result Combination

As stated in CESSAR-DC, Section 3.7.3.7, the seismic response of each mode shall be calculated and combined with the other modal responses using the methods described in Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis."

If the modes are not closely spaced (two consecutive modes are defined as closely spaced if their frequencies differ from each other by 10 percent or less of the lower frequency), the results may be combined by the square root of the sum of the squares (SRSS). Closely spaced modes shall be combined by one of the following methods: 1) grouping method, 2) 10 percent method, and 3) double sum method.

The responses due to each of the three separate directions of seismic excitation shall be combined by SRSS.

7.1.4.3.2.1.7 Seismic Anchor Movements

The effects of seismic anchor motion shall be considered in the seismic analysis. For models with piping in more than one building, it shall be assumed that the buildings move 180° out of phase. Movements within all buildings except the Reactor Building shall be assumed to be in phase. Within the Reactor Building there may be differential movements between the Reactor Building, the Containment Vessel, Reactor Interior Structures, and the NSSS. These movements, when applicable, shall be assumed to act 180° out of phase. The resulting relative movement shall be applied as static support displacements with all dynamic supports active.

Support loads shall be obtained and defined for both OBE and SSE motions.

7.1.4.3.2.1.8 Fatigue

The cyclic load basis for fatigue analysis of the OBE earthquake shall be 200 full load cycles for NSSS piping and 75 full load cycles for Class 1 piping systems other than NSSS piping.

7.1.4.3.2.2 Time History Analysis

7.1.4.3.2.2.1 General

Time history analysis can be used as an alternative method to response spectrum analysis for any piping system.

For those piping systems analyzed by time history methods, development of mathematical models, which define flexibility and mass, and calculation of natural frequencies and mode shapes, as described in Section 7.1.4.3.2.1.1, should first be performed.

7.1.4.3.2.2.2 Piping Dynamically Decoupled from the NSSS

Most piping systems can be dynamically decoupled from the nuclear steam supply system (NSSS), following guidelines of Section 7.1.5.2.2. The surge line, which is functionally part of the NSSS, is included in those piping systems which can be shown to meet the decoupling criteria, and should therefore be analyzed separately from the rest of the NSSS.

The solution of the differential equations of motion, which describe the dynamic response of a system to a seismic excitation, can be obtained by the method of modal superposition or by the method of direct integrations, using time history analysis. These methods are described in CESSAR-DC, Section 3.7.2.1.1.2.

The mathematical model should be subjected to seismic excitations at the anchor points (terminal ends) and at building supports. For statistically independent earthquake motions, input excitations in all three translation directions and, as applicable, in all three rotational directions should be applied simultaneously to the anchor points and building supports.

Input of multiple time history excitations, which allow calculation of the effects of both differential motion and inertia, should normally be used in a multiply supported system such as a piping system. An acceptable alternate time history method, as described in ASME Code, Section III, Division I, Appendix N, Section N-1228.4, is to input an "envelope" time history excitation to calculate the inertia response, and separately to determine the effects of differential support motion using a static analysis. The ASME Code defines the envelope excitation as a time history whose response spectrum envelopes the response spectra for the individual support motions.

7.1.4.3.2.2.3 Piping Dynamically Coupled to the NSSS

The only piping system that is dynamically coupled to the NSSS for the purpose of structural analysis is the main coolant loop piping. The main coolant loop piping should be seismically analyzed as an integral part of the reactor coolant system structure, using methods described in CESSAR-DC, Sections 3.7.2.1.2 and 3.7.2.6.2.

7.1.4.4 Equipment Nozzles

When appropriate, the following effects of equipment nozzles should be considered in the analyses:

A. Equipment response spectra
B. Equipment nozzle displacements and rotations
C. Equipment nozzle flexibility

7.1.4.5 Wind/Tornado Analysis

Exposed piping must be designed to withstand forces generated by wind and tornados. Maximum wind speeds provided in CESSAR-DC, Section 3.3 are listed below;

A. Wind loading: 130 mph max wind speed

B. Tornado loading:

  1. 330 mph maximum wind speed
  2. 260 mph rotational wind velocity
  3. 70 mph translational wind velocity

Tornado loads are based upon the NRC Staff interim position based on Regulatory Guide 1.76.

7.1.4.6 Fluid Transient Analysis

Transient fluid dynamic loadings on pipe shall be evaluated and the resulting loads included in the piping analysis. The loads considered shall be those significant loads due to fast valve closure, steam hammer, water hammer, relief valve discharge, and multiple relief valve discharge. Potential loadings shall be evaluated and defined for each problem on a case-by-case basis. Multiple safety valve discharges shall be analyzed so as to maximize piping stresses and support/restraint design loads unless another discharge sequence can be justified. Discharge sequences considered shall include the possibility of the instantaneous and simultaneous discharge of all valves in the same vicinity.

7.1.4.6.1 Safety/Relief Valve Thrust

Safety/relief valves produce transient and steady-state loads on the valve inlet piping and discharge piping (if used). The thrust load, F, is a function of fluid type (water or steam), design pressure, and valve throat area. An acceptable method of calculating the valve thrust loads is as follows:

A. Water Discharge:

$$F_{STATIC}=0.0022\left(\frac{GPM}{ID}\right)^2 \qquad \textbf{(Eqn. 7.1-2)}$$

Where: GPM = rated valve discharge in gallons per minute
ID = inside diameter of the discharge pipe in inches

A dynamic load factor of two should be included for the dynamic loading unless a lower value is justified.

B. Steam Discharge:

Use the procedure of ASME Code, Section III, Appendix O, with the caution that negative (below atmospheric) discharge pressures are meaningless and the equation does not apply for those cases.

Relief valves cause both dynamic and static loading conditions. To simplify analysis, however, essentially all relief valve thrust loads are evaluated statically. Closed discharge and piped relief valves have an additional complicating factor since transient forces develop at each intermediate turn in the piping during the initial phase when the flow along the pipe is being established.

These transient loads should be treated as water/steam hammer. As the transient phase ends, all of the intermediate forces cancel each other out, leaving only the steady state thrust force at the exit point of the fluid from the discharge system. For closed discharge systems, the steady state thrust force is zero at the valve outlet.

Dynamic relief valve thrust loads shall be applied to the piping model as static loads with snubbers active and a dynamic load factor applied to the loads.

7.1.4.6.2 Water and Steam Hammer Analysis

Water and steam hammer are both dynamic loading conditions on the piping. Forcing functions, using actual time history analyses, may be used in the dynamic analysis. However, when justified, simplified conservative approximations of the forces may be used in a static evaluation.

The simplified method determines the worst net force developed in a segment of piping and applies it assuming it can occur in either direction along the local x axis of the pipe. This net force that develops depends on flow rates, fluid velocities, valve closing time, the length of straight runs of pipe, and the fluid involved.

7.1.4.6.2.1 Water Hammer Forces

Two equations exist for determining the resultant force, F_n, on any straight segment of piping due to water hammer. The proper one to use depends on the ratio of L/L_s for the pipe segment in question, where L (ft) is the length of straight pipe of the segment and L_s (ft) is the distance travelled by the shock wave during the valve closure. L is available from the piping drawings and is shown as an example for piping run 2 on Figure 7.1-1. The distance travelled by the shock wave (1) may be calculated:

$$L_s = c \times t \qquad \textbf{(Eqn. 7.1-3)}$$

Where: c = sonic velocity in water (4,700 ft/sec)
t = valve closure time (sec)

A. For $(L/L_s) < 1.0$

$$F_n = \frac{\dot{m}c}{g} \qquad \text{(Eqn. 7.1-4)}$$

Where: m = mass flow rate of water (lbm/sec)
c = 4,700 (ft/sec)
g = 32.174 lbm-ft/lbf-sec^2
F_n = resultant net force (lbs) along pipe run

B. For $(L/L_s) > 1.0$

$$F_n = \frac{\dot{m}L}{gt} \qquad \textbf{(Eqn. 7.1-5)}$$

Where the above defined terms apply and:

L = length of straight pipe run (ft)
t = valve closure time (sec)

One of the above equations would be used to calculate the net force to be applied for each straight segment of piping until a point is reached where the pressure waves are damped out at a tank, closed valve, equipment connection, or connection to a large header.

7.1.4.6.2.2 Steam Hammer Forces

Since steam is a compressible fluid, the calculation of resultant forces along each straight run shall be performed by the following six steps and terms:

A. Terms

$\dot{m}$ = steam mass flow rate (lbm/sec)
P = design pressure (psig)
T = steam temperature (saturated) at P (°F)
h = enthalpy of steam at T and P (BTU/lbm)
v = specific volume of steam at T and P (ft^3/lbm)
v_{1000} = specific volume at P and 1000°F (ft^3/lbm)
L_s = distance travelled by shock wave (ft)
c = sonic velocity at P and T (ft/sec)
F_n = net force exerted on pipe segment (lbs)
t = valve closure time (sec)
TF = temperature factor
V = steam velocity (ft/sec)
A = flow area of pipe (in^2)
L = pipe length between turns (ft)

B. Net Force Calculation

1. Compute temperature factor (TF)

$$TF=\frac{v_{1000}}{v} \qquad \text{(Eqn. 7.1-6)}$$

2. Calculate length (L_s) over which the pressure wave propagates during the valve closure time (t)

$$L_s=c\times t$$

3. Calculate initial steam velocity (V)

$$V=\frac{\dot{m}v}{A} \qquad \text{(Eqn. 7.1-7)}$$

4. Using Figure 7.1-2, pick the curve (or interpolate a curve) that represents the steam velocity (V) above. From this curve determine the slope at the steepest section of the plot. At this steepest point, the abscissa difference is the ratio L/L_s. Multiplying this abscissa difference by the slope provides the pressure rise ratio $\Delta P/P$:

(Abscissa Difference) x (Slope) = $\Delta P/P$

5. The force exerted along any segment is then:

$$F=P\times TF\times A\left(\frac{\Delta P}{P}\right) \qquad \text{(Eqn. 7.1-8)}$$

6. As with water hammer, this force must be determined for each straight segment of pipe until a point is reached (equipment, tank, closed valve, etc.) where the pressure wave would be damped.

7.1.4.7 Pipe Break Analysis

Pipe break loads are any loads that may be applied to unbroken pipe resulting from ruptures of nearby piping. Pipe break loadings include, but are not limited to, the effects of the following: pipe whip, jet impingement, differential pressure, temperature increase (localized or overall), and support/anchor movement (including reactor coolant loop and containment vessel). Effects of a ruptured pipe on other portions of itself need not be considered, except to demonstrate that a whipping pipe is restrained.

In general, pipe break loads are defined for each piping problem on a case-by-case basis. These loads shall be applied by the piping analyst as applicable to the appropriate piping problem. See Section 7.1.8 for further details of Postulated Pipe Breaks. Pipe break loadings due to two or more assumed pipe breaks shall be considered to act individually.

7.1.4.8 High Energy and Moderate Energy Requirements

High and moderate energy piping systems must be evaluated for postulated pipe breaks. Intermediate break locations are based on potential high stresses and fatigue limits determined by the piping stress analysis results. For the postulated pipe break evaluation requirements see Section 7.1.8.

7.1.4.9 Non-Rigid Valves

Normally, valves are specified to be rigid. Non-rigid valves (indicating that the valve has modes of vibration < ZPA) are identified by the applicable valve seismic report. The effects of the non-rigid valve will be considered in the piping analysis.

7.1.4.10 Expansion Joints

Expansion joints allow limited relative lateral and axial displacements and bending rotations between the ends of the joint, depending on the type of joint in use. Expansion joints shall be considered in the analysis.

7.1.5 ANALYSIS TECHNIQUES

7.1.5.1 Model Boundaries

Piping models ideally run from anchor to anchor (equipment nozzle, or penetration). Where this is not feasible, the piping may be separated by decoupling, overlapping, isolation, or in-line anchors as described in the following subsections to form more manageable models for analysis. These subsections present minimum requirements that may be upgraded at the discretion of the analyst. If the piping cannot be separated to form smaller analysis models by these methods, the analyst may consider the use of an intermediate anchor to separate models subject to the considerations of Section 7.1.5.5.

7.1.5.2 <u>Decoupling</u>

7.1.5.2.1 General

Small branch lines may be decoupled from larger run piping regardless of seismic classification. Decoupling may also be applied for in-line pipe size changes (such as at a reducer or reducing insert). For consistency with the following text, the smaller line should be considered the "branch" and the larger line should be considered the "run". To be decoupled, piping must meet the size, section modulus, or moment of inertia ratios as detailed in the following paragraphs.

7.1.5.2.2 Decoupling Criteria

Branch lines meeting the following criteria may be decoupled from the main run:

A. $D_b/D_r \leq 0.25$, or
B. $Z_b/Z_r \leq 0.10$, or
C. $I_b/I_r \leq 0.04$

Where: D_b = branch nominal pipe size
D_r = run nominal pipe size
Z_b = branch section modulus
Z_r = run section modulus
I_b = branch moment of inertia
I_r = run moment of inertia

An appropriate stress intensity factor (SIF) shall be included on the branch and main run lines at the point where the piping is decoupled. Mass effects of the branch line should be considered in the analysis of the run line, if significant. The branch point shall be considered as an anchor in the analysis of the branch pipe. Thermal and seismic anchor movement analyses of the decoupled branch lines shall be performed with the thermal, seismic inertial, seismic anchor movement (SAM), or pipe break movements of the larger pipe header applied as anchor displacements and/or rotations to the smaller branch line if these movements are significant.

Piping may also be decoupled at flexible hose provided each interfacing analysis considers the flexible hose weight and significant stiffness, and the flexible hose qualifies for the net end displacements of the interfacing analysis problems. Analysis results of the interfacing problems do not have to be combined. The flexible hose should not be allowed to experience large tensile loads.

7.1.5.3 Overlapping

7.1.5.3.1 General

Overlapping is used to separate seismically analyzed piping problems. Isolation of non-seismic piping from seismic piping is addressed in **Section 7.1.5.4**.

Seismic piping that cannot be separated by decoupling as described in Section 7.1.5.2 may be separated using an overlap region. The overlap region should have enough rigid restraints and include enough bends in three directions to prevent the transmission of motion due to seismic excitation from one end to the other. The following criteria present minimum requirements which should be upgraded if required to satisfy this condition.

7.1.5.3.2 Overlap Criteria

A section of piping to be considered an overlap region must meet the following criteria:

A. The section contains a minimum of four (4) restraints in each of three perpendicular directions. If a branch is encountered, the balance of restraints needed beyond that point will be included on all lines joining at the branch.

B. The restraints in the section are so spaced that the pipe span between any two restraints, taken as simply supported beams, have a fundamental natural frequency (bending and torsion) not less than the frequency corresponding to the ZPA.

C. In lieu of criteria B, a dynamic analysis of the overlap region should be made with pinned boundaries extended beyond the overlap region either to the next actual support or to a span length equal to the largest span length within the region. The fundamental frequency determined from this analysis should be greater than the frequency corresponding to the ZPA.

The overlap piping shall be included in all models adjacent to the overlap region. An effective axial restraint on a run can be counted at each point of lateral restraint on that same run. Hanger design loads and movements in the overlap region shall be obtained by enveloping the results of all models adjacent on the overlap region. Pipe stresses and valve accelerations shall be checked in each separate analysis.

7.1.5.3.2.1 Restrained Elbow (or Tee)

Adequately restrained elbows or restrained tees may be used to terminate or separate analysis models. Restrained elbows and restrained tees must meet the criteria of Figures 7.1-3 and 7.1-4 respectively. Results of all analyses shall be combined to obtain pipe stresses and hanger loads for the restrained elbow and restrained tee configurations.

7.1.5.4 In-line Anchors

An in-line anchor is a device restricting all six degrees of freedom, thereby isolating each run. In-line anchors should only be used to separate piping models, if practical, based on the following considerations:

A. Anchors may prove to be impractical, especially on large diameter piping (>4" nominal pipe diameter) or on lines with high thermal and/or seismic movements.

B. The addition of anchors may add terminal end break locations to high and moderate energy piping.

C. The use of anchors may be limited by high piping thermal expansion loads or the practicality of the anchor design and installation.

D. Anchor load results from the piping on both sides of an anchor must be combined to obtain the design loads for the anchor. If the piping on one side of the anchor is unanalyzed, appropriate loads shall be developed to represent the unanalyzed pipe. As an example, plastic hinge moments may be us

7.1.5.5 Support Considerations

The proper participation and orientation of each support/restraint shall be included in the piping analysis. Participation shall be consistent with how the support type performs during the loadings under consideration. Some loading conditions create pipe movements that may affect the analyzed support orientation, such as vertical supports with large lateral thermal movements. The effects of such pipe movements on the analyzed support orientation shall be evaluated.

7.1.6 ACCEPTANCE CRITERIA

7.1.6.1 ASME Class 1 Piping

The allowable stress limits for the specified loading combinations for ASME Class 1 piping are shown in Tables 7.1-1 and 7.1-2.

7.1.6.2 ASME Class 2 and 3 Piping

The allowable stress limits for the specified loading combinations for ASME Class 2 and 3 piping are shown in Table 7.1-3.

7.1.6.3 Allowable Nozzle Loads

Loads applied to equipment nozzles must not exceed allowable values provided by the equipment vendor. In lieu of specific values, generic allowable equipment nozzle loads may be used provided the equipment is specified to these design nozzle load values.

7.1.6.4 Allowable Penetration Loads

Loads and displacements on containment penetration assemblies, as shown in CESSAR-DC, Figure 3.8-2, must meet the manufacturer's allowables.

7.1.6.5 Welded Attachments

Per ASME Section III, Subarticle NC/ND 3645, external and internal attachments to piping shall be designed so as not to cause flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that such attachments be so designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

Local stresses due to all support loads acting on a welded attachment shall be evaluated and added directly to the nominal pipe stresses at the point of the attachment. The sum of the stresses shall be compared against the allowable stresses given in Tables 7.1-2 and 7.1-3.

7.1.6.6 Functional Capability Requirements

CESSAR-DC, Section 3.9.3.1.4.2 requires that ASME Class 2 and 3 piping be evaluated for functional capability. Appendix 7B provides the functional capability requirements for ASME Class 2 and 3 stainless steel elbows as stated in Texas Utilities' letter TXX 3423.

7.1.6.7 Valve Requirements

Valve accelerations shall meet the allowable manufacturer's requirements for seismic acceleration. The loads on supports attached to valve operators shall also be evaluated.

7.1.6.8 Expansion Joint Requirements

Expansion joints shall be evaluated to ensure compliance with vendor allowables.

7.1.7 PIPE SUPPORT DESIGN REQUIREMENTS

7.1.7.1 General

The design of pipe supports must meet the intended functional requirements of the stress analysis as well as meeting the specified stress limits for the support components. Support components may include typical structural steel members as well as manufactured catalog items for typical support components. In addition, the support design must not invalidate any assumptions used in the analysis of the piping system.

In addition to loads defined by the stress analysis, any additional forces the support may be subjected to must be considered in the support qualification.

7.1.7.2 Design Considerations

LATER

7.1.7.3 Load Combinations

Load combinations shall be in accordance with CESSAR-DC, Section 3.9.3.1 and are detailed in Table 7.1-4.

7.1.7.4 Acceptance Criteria

Stress limits for structural members of pipe supports shall meet the requirements defined in ANSI/AISC N690, "Nuclear Facilities-Steel Safety-Related Structures for Design Fabrication and Erection".

Manufactured catalog items shall meet the requirements of MSS-SP-58, "Pipe Hangers and Supports-Materials, Design and Manufacture".

7.1.7.5 Jurisdictional Boundaries

The jurisdictional boundaries shall be as defined in ASME Code, Section III, Subsection NF. However, the acceptance criteria as defined above shall also be applicable for the qualification of support components within the NF boundaries.

7.1.8 POSTULATED PIPE BREAKS

7.1.8.1 Classification

7.1.8.1.1 High Energy

High energy piping systems are those systems or portions of systems that are maintained pressurized at either temperatures in excess of 200°F or at pressures exceeding 275 psig during any of the following normal plant operating modes. For systems containing process fluids other than water, the atmospheric boiling temperature can be applied in place of the 200°F criterion.

- Reactor Startup
- Hot Standby
- Operation at any Power Level
- Reactor Cooldown to Cold Shutdown

Exceptions:

A. Non-liquid piping systems (air, gas, steam) with a maximum pressure less than or equal to 275 psig are not considered high energy regardless of the temperature.

B. Piping which operates at pressures and temperatures meeting high energy requirements is not considered high energy if the total time spent in operation at high energy conditions is less that either of the following:

1. One percent of the normal operating lifespan of the plant, or

2. Two percent of the time period required to accomplish its system design function.

C. Piping of one inch nominal pipe size and less is not considered "high energy."

7.1.8.1.2 Moderate Energy

Moderate energy piping systems are those systems or portions of systems, that during any of the normal plant operating modes are maintained pressurized at a maximum temperature of 200°F or less and a maximum pressure of 275 psig or less including all piping excluded from high energy.

Exceptions:

A. Open-ended vents and drains are not considered moderate energy.

B. Piping of one inch nominal pipe size and less is not considered moderate energy.

7.1.8.2 Postulated Rupture Locations

7.1.8.2.1 Break Locations in ASME Class 1 Piping Runs

Breaks, in accordance with Section 7.1.8.2.5, shall be postulated to occur at the following locations in ASME Class 1 piping:

A. The terminal ends of the pressurized portions of the run.

B. At intermediate locations selected by either one of the following methods:

   1. At each weld location of potential high stress or fatigue, such as pipe fittings (elbow, tees, reducers, etc.), valves, flanges, and welded attachments; or

   2. At all intermediate locations between terminal ends where the following stress or fatigue limits are exceeded:

      - The maximum stress range, S, between any two load sets (including the zero load set) calculated by Eq. (10) in Subarticle NB-3653, ASME Code, Section III, exceeds $2.4S_m$ and the stress ranges calculated by both Eq. (12) and Eq. (13) in Subarticle NB-3653, ASME Code, Section III, exceeds $2.4\ S_m$.

      - U exceeds 0.1.

      Where: S_m = allowable design stress-intensity value, as defined in Subarticle NB-3600, ASME Code, Section III.

      U = the cumulative usage factor as calculated in accordance with Subarticle NB-3600, ASME Code, Section III.

7.1.8.2.2 Break Locations in ASME Class 2 and 3 Piping Runs

Breaks, in accordance with Section 7.1.8.2.5 shall be postulated to occur at the following locations in ASME Class 2 and 3 piping:

A. The terminal ends of the pressurized portions of the run.

B. At intermediate locations selected by either one of the following methods:

   1. At each weld location of potential high stress or fatigue, such as pipe fittings (elbows, tees, reducers, etc.), valves, flanges, and welded attachments; or

   2. At all locations where the stress, S, exceeds 0.8 x (X + Y).

      Where, as defined in ASME Code, Subarticle NC-3650,

      S = stresses under the combination of loadings associated with the normal and upset plant condition loadings and an OBE event, as calculated from the sum of Eq. (9) and (10).

X = equation (9) Service Level B allowable stress.

Y = equation (10) allowable stress.

7.1.8.2.3 Break Locations in Non-Seismic Piping Runs

Breaks, in accordance with Section 7.1.8.2.5 shall be postulated to occur at the following locations in non-seismic piping:

A. The terminal ends of the pressurized portions of the run.

B. At each intermediate weld location of potential high stress or fatigue.

7.1.8.2.4 Break Locations In Piping Runs With Multiple ASME Code Piping Classes

Breaks, in accordance with Section 7.1.8.2.5 shall be postulated to occur at the following locations:

A. The terminal ends of the pressurized portions of the run.

B. At intermediate locations selected by either one of the following methods:

   1. At each weld location of potential high stress or fatigue, such as pipe fittings, valves, flanges, and welded attachments; or

   2. At all intermediate locations between terminal ends where the stress and fatigue limits of Sections 7.1.8.2.1.B.2), 7.1.8.2.2.B.2), or 7.1.8.2.3.B) are exceeded.

7.1.8.2.5 Break Locations

Both circumferential and longitudinal breaks are postulated to occur, but not concurrently, in all high-energy piping systems at the locations specified in Sections 7.1.8.2.1 through 7.1.8.2.4 except as follows:

A. Circumferential breaks are not postulated in piping runs of a nominal diameter equal to or less than 1 inch.

B. Longitudinal breaks are not postulated in piping runs of a nominal diameter less than 4 inches.

C. Longitudinal breaks are not postulated at terminal ends.

D. Only one type of break is postulated at locations where, from a detailed stress analysis, such as finite-element analysis, the state of stress can be used to identify the most probable type. If the primary plus secondary stress in the axial direction is found to be at least 1.5 times that in the circumferential direction for the most severe loading combination association with Level A and Level B service limits, then only a circumferential break is postulated. Conversely, if the primary plus secondary stress in the circumferential direction is found to be at least 1.5 times that in the axial direction for the most severe loading combination associated with Level A and Level B service limits, then only a longitudinal break is postulated.

E. Circumferential and longitudinal breaks are not postulated at locations where the requirements of Section 7.1.8.2.7 are satisfied.

F. Circumferential and longitudinal breaks are not postulated at locations where the criterion in Section 7.1.8.2.6.2 is used.

7.1.8.2.6 Crack Locations

7.1.8.2.6.1 Through-Wall Cracks

Through-wall cracks are postulated in all high-energy and moderate-energy piping systems having a nominal diameter greater than 1 inch at the locations specified in Sections 7.1.8.2.1 through 7.1.8.2.4, except that through-wall cracks are not postulated at locations where:

A. For Class 1 piping, the calculated value of S, as defined in Section 7.1.8.2.1, is less than 1.2 Sm.

B. For Class 2 and Class 3 piping, the calculated values of S as defined in Section 7.1.8.2.2 is less than 0.4 x (X + Y).

C. The requirements of Section 7.1.8.2.7 are satisfied.

D. The criterion in Section 7.1.8.2.6.2 is used.

7.1.8.2.6.2 Leakage Cracks

A leakage crack is postulated in place of a circumferential break, or longitudinal break, or through-wall crack, if justified by an analysis performed on the pipeline in accordance with the requirements of Section 7.1.9.

7.1.8.2.7 Piping Near Containment Isolation Valves

Ruptures are not postulated between the containment wall and the inboard or outboard isolation valves in piping, which is designed in accordance with the rules of the ASME Code, Section III, and which meets the following additional requirements:

A. The limits for postulating intermediate rupture locations, as specified in Section 7.1.8.2.1 for Class 1 piping and 7.1.8.2.2 for Class 2 and 3 piping, are not exceeded in that portion of piping.

B. Following a postulated pipe break of high-energy piping beyond either isolation valve, the stresses in the piping from the containment wall, to and including the length of the isolation valve, are maintained within Level C Service Limits as specified in the ASME Code, Section III.

C. The design and in-service inspection requirements, as specified in the USNRC Branch Technical Position, MEB 3-1 (CESSAR-DC, Section 3.6, Reference 4), are satisfied.

D. The containment isolation valves are appropriately qualified to assure that operability and leak tightness are maintained when subjected to any combination of loadings, which may be transmitted to the valves from postulated pipe breaks beyond the valves.

7.1.8.3 Postulated Rupture Configurations

7.1.8.3.1 Break Configurations

Where the postulated break location is at a tee, elbow, or the following pipe locations, the configurations and types of breaks are determined as follows:

A. Without the benefit of a detailed stress analysis, the following are assumed:

    1. Circumferential breaks are postulated to occur individually at each tee or elbow pipe-to-fitting weld where the criteria in Section 7.1.8.2.3 are exceeded, and longitudinal breaks postulated to occur individually on each side of the tee or elbow at its center and oriented perpendicular to the plane of the fitting.

    2. At a branch run connection, a circumferential break is postulated at the branch run-to-main run weld, or the branch run-to-fitting weld, and the break plane area (A_p) is assumed to be the cross-sectional flow area of the branch.

3. At a welded attachment (lug, stanchion, etc.) a longitudinal break is postulated at the centerline of the welded attachment with an area equal to the pipe surface area that is bounded by the attachment weld.

4. At an axisymmetric pipe location, such as a reducer, circumferential and longitudinal breaks are postulated at each pipe-to-fitting weld where the criteria in Section 7.1.8.2.3 are exceeded. Longitudinal breaks are oriented to produce out-of-plane bending of the piping configuration.

B. Alternatively, where a detailed stress analysis or test is performed, the results are used to predict the most probable rupture location(s) and type of break.

7.1.8.3.2 Crack Configurations

At a postulated leakage crack or through-wall crack location, the orifice is assumed to be located non-concurrently at each and every point about the circumference of the pipe, unless otherwise substantiated.

7.1.8.4 Pipe Rupture Loads

This section applies to all high-energy piping other than that whose dynamic effects due to pipe breaks are eliminated from the design basis by leak-before-break evaluation.

A. Circumferential Breaks

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. The dynamic force of the jet discharge at the break location is based on the effective cross-sectional flow area of the pipe and on a calculated fluid pressure as modified by an analytically determined thrust coefficient. Limited pipe displacement at the break locations, line restriction flow limiters, positive pump controlled flow, and the absence of energy reservoirs are taken into account, as applicable, in the reduction of the jet discharge. Pipe whip 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.

B. Dynamic Force of the Fluid Jet Discharge

The dynamic force of the fluid jet discharge is based on a circular break area equal to the cross-sectional flow area of the pipe at the break location and on a calculated fluid pressure modified by an analytically determined thrust coefficient, as determined for a circumferential break at the same location. Line restrictions, flow limiter, positive pump-controlled flow, and the absence of energy reservoirs are taken into account, as applicable, in the reduction of jet discharge.

Piping movement is assumed to occur in the direction of the jet reaction, unless limited by structural members, piping restraints, or piping stiffness.

C. Pipe Blowdown Force and Wave Force

The fluid thrust forces that result from either postulated circumferential or longitudinal breaks, are calculated using a simplified one-step forcing function methodology. This methodology is based on the simplified methods described in ANSI/ANS 58.2, "Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture." See CESSAR-DC, Section 3.6, References 5 and 6.

When the simplified method discussed above leads to impractical protective measures, then a more detailed computer solution which more accurately reflects the postulated pipe rupture event is used. The computer solution is based on the NRC's computer program developed for calculating two-phase blowdown forces. See CESSAR-DC, Section 3.6, Reference 7.

D. Evaluation of Jet Impingement Effects

Jet impingement force calculations are performed only if structures or components are located near postulated high energy line breaks and it cannot be demonstrated that failure of the structure or component will not adversely affect safe shutdown capability.

7.1.8.5 Pipe Rupture Analysis

7.1.8.5.1 Dynamic Analysis of Pipe Whip

Pipe whip restraints usually provide clearance for thermal expansion during normal operation. If a break occurs, the restraints or anchors nearest the break are designed to prevent unlimited movement at the point of break (pipe whip). A finite difference model will be used to analyze simplified models of the local region near the break. Displacements and strains of the pipe and restraint will be estimated using a power law moment curvature relationship.

B. Finite Difference Analysis

A finite difference formulation specialized to the case of a straight beam and neglecting axial inertia and large deflection effects is used for the analysis of pipe whip. The dynamic analysis is performed by direct numerical time integration of the equations of motion presented in CESSAR-DC, Appendix 3.6A.

7.1.8.5.2 Dynamic Analysis of Unrestricted Pipes

The impact velocity and kinetic energy of unrestricted pipes is calculated on the basis of the assumption that the segments at each side of the break act as rigid-plastic cantilever beams subject to piecewise constant blowdown forces. The hinge location is fixed either at the nearest restraint or at a point determined by the requirement that the shear at an interior plastic hinge is zero. The kinetic energy of an accelerating cantilever segment is equal to the difference between the work done by the blowdown force and that done on the plastic hinge. The impact velocity V_I is found from the expression for the kinetic energy:

$$KE=\frac{1}{2}M_{eq}V_I^2 \qquad \textbf{(Eqn 7.1-9)}$$

Where M_{eq} is the mass of the single degree of freedom dynamic model of the cantilever. The impacting mass is assumed equal to M_{eq}.

7.1.9 LEAK-BEFORE-BREAK (LBB)

7.1.9.1 Design of Piping Evaluated For Leak-Before-Break

The approach being taken toward design certification of System 80+ is to include LBB considerations in the piping design. One aspect of the LBB evaluation pursued for each selected piping system is performance of a preliminary LBB evaluation prior to and independent of pipe routing. This evaluation is used to provide the piping designer with LBB acceptance criteria, in terms of a range of materials, pipe sizes, and NOP and maximum design loads for all locations in the pipe. If the acceptance criteria is met, an acceptable result of the LBB evaluation of the final design is assured. The range of piping parameters developed by this preliminary evaluation forms a "window" of acceptance criteria which the piping designer can utilize to route, design and support the piping system.

For the System 80+ design, the following five piping systems inside containment shall be designed to the requirements of Section 7.1.9.2 to assure leak-before-break (LBB):

- Main Coolant Loop (42-inch ID hot leg and 30-inch ID cold leg)
- Surge Line (12-inch diameter)
- Shutdown Cooling Line (16-inch diameter portion)
- Direct Vessel Injection (10-inch diameter portion)
- Main Steam Line (28-inch ID portion)

7.1.9.2 Piping Design Requirements

The piping design requirements for assuring that LBB is met are given in Table 7.1.9-1 below:

TABLE 7.1.9-1

System 80+ Piping Design Requirements For LBB

Piping System	NOP Plus Max Design Load	Pipe Material	Weld Material
			>
Main Coolant Loop (Hot Leg)	<		>
Main Coolant Loop (Cold Leg)	<	(LATER)	>
Surge Line (12")	<		>
Shutdown Cooling Line (16")	<		>
Direct Vessel Injection (10")	<		>
Main Steam Line (28" ID)	<		

The requirements of Table 7.1.9-1 are established by LBB evaluations using the methodology described in Appendix 7A. In addition to the requirements of Table 7.1.9-1, the five piping systems listed above must meet the LBB applicability criteria outlined in Appendix 7A, Section 1.2.1. NOP and maximum design loads are defined in Appendix 7A, Section 1.1.4. Appendix 7A also discusses design philosophy and offers design guidelines for piping systems evaluated for LBB.

7.1.9.3 Piping Design Procedure

The piping designer shall route, design and analyze the piping evaluated for LBB in accordance with the ASME Boiler and Pressure Vessel Code, considering LBB requirements given above and utilizing guidelines herein. As-calculated piping loads should be compared to the "window" of acceptance criteria in Table 7.1.9-1 established by the LBB evaluations. If the acceptance criteria are met, demonstration of LBB is assured. If the acceptance criteria are not met, the as-calculated loads based on the actual routing should be evaluated for LBB using the finite element analysis methodology described in Appendix 7A, Section 1.3.4. If this LBB evaluation does not assure that LBB is met, an iterative process of generating revised LBB acceptance criteria for a re-sized pipe and redesigning the piping system should be pursued.

7.1.10 SMALL BORE PIPING

To simplify the procedure for the design of small bore piping (2 inch nominal diameter and smaller), the procedure provided in NCIG-14, "Procedure for Seismic Evaluation and Design of Small Bore Piping" may be used in lieu of the more rigorous analysis as detailed in Section 7.1.4.

7.1.11 TUBING

7.1.11.1 General

Process and instrumentation tubing is shown to be acceptable based on meeting the applicable support criteria within this section. These criteria only applies to safety-related tubing; they serve as guidelines for non-safety related tubing which is not analyzed and can be field routed (see Section 6.2.4.2.3).

Tubing is supported in two ways, as free tube spans and tube track supports. The criteria for each support mechanism are described in the following sections.

7.1.11.2 Free Tube Spans

The following requirements apply to tubing that is supported as free tube spans (not in tube tracks):

A. The minimum spacing between tube supports (L) shall be two (2) feet unless the supports are used to support an in-line component in which case a tube support shall be located adjacent to the component (on each side).

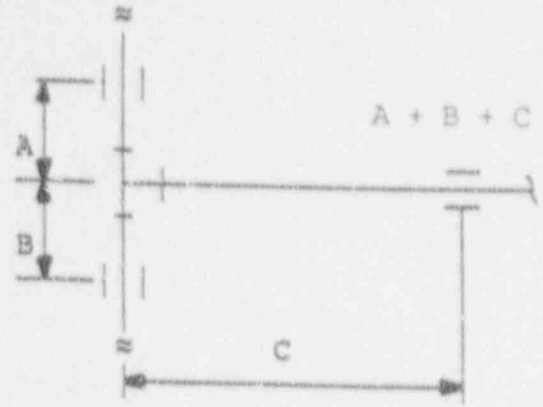
B. The maximum spacing between supports shall be as indicated in Table 7.1.11-1.

C. If heat tracing or insulation is required, span lengths, support designs, and tube details may require amendment.

D. All reservoirs, valves, and other in-line components shall be independently supported.

E. Tube support locations shall be located accordingly if there is a change in direction or fitting in the span (see Table 7.1.11-1).

F. When tees are used in tube routing, tube supports shall be arranged as shown below.



A + B + C ≤ L (L from Table 7.1.11-1)

G. In addition to the requirements listed above, supports for 1" tubing shall be arranged as shown below:

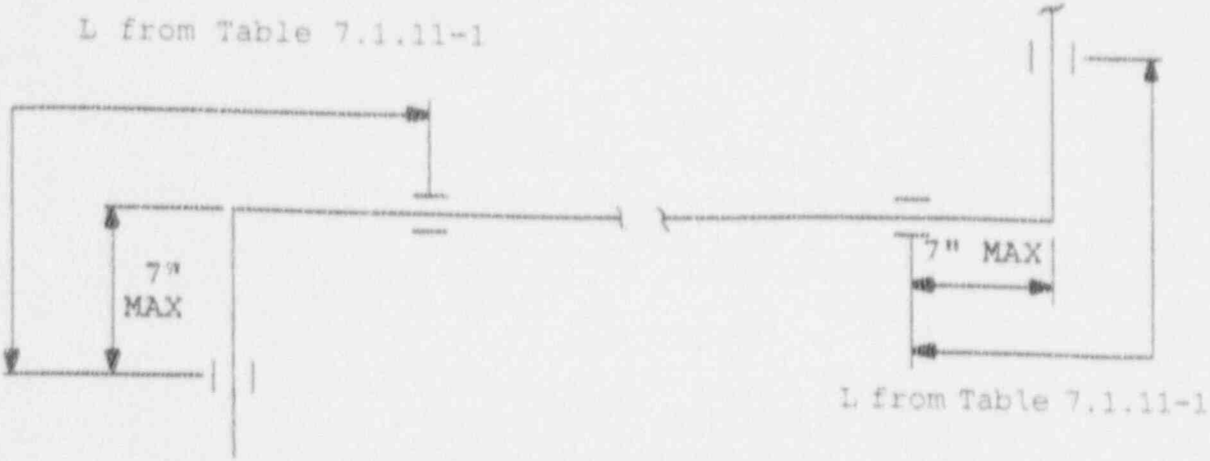


TABLE 7.1.11-1

<u>Maximum Free Tube Span Lengths (L)</u>

Tube Size	Straight Span	Change in Direction	Straight Tube With Fitting	Change in Direction and Fitting
1/4"	6′ - 0"	4′ - 6"	5′ - 6"	4′ - 0"
3/8"	8′ - 0"	6′ - 0"	7′ - 6"	5′ - 6"
1/2"	8′ - 0"	6′ - 0"	7′ - 6"	5′ - 6"
5/8"	8′ - 0"	6′ - 0"	7′ - 6"	5′ - 6"
3/4"	8′ - 0"	6′ - 0"	7′ - 6"	5′ - 6"
1"	8′ - 0"	6′ - 0"	7′ - 6"	5′ - 6"

Table 7.1.11-1 Notes:

1. The maximum allowable internal design pressure is 2950 psig.
2. Tube span lengths will be amended accordingly if insulation is required.
3. The tube span before and after the span containing the change in direction shall be limited to the same length as the span including the change in direction.
4. The allowable spans for copper tubing shall be one-half of the values tabulated.

7.1.11.3 Track Supported Tubes

The following requirements apply to tubing routed in tube racks. Sample lines shall not be installed in tube tracks unless the process fluid temperature is less than 150°F.

Tube track should not be modified by cutting or bending. Tube track should be connected using standard components.

7.1.11.3.1 Uninsulated Applications

The following criteria apply to uninsulated tubing routed in tracks:

A. The maximum number of tubes per track shall be four (4) for 1/4", 3/8", and 1/2" tubing. Tubes larger than 1/2" shall be supported per Section 7.1.11.2.

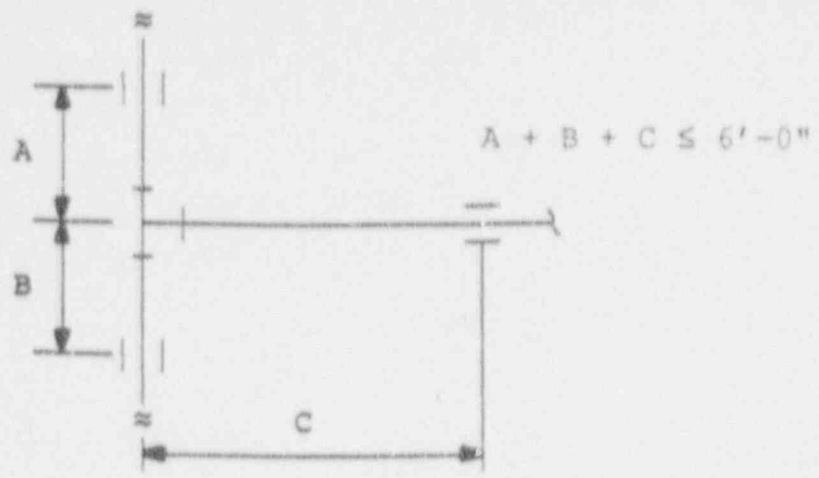
B. The tubing shall be attached to the tube track at a minimum of 2'-0" and a maximum of 3'-0" spacing.

C. The maximum span between track supports shall be 8'-0" for a straight span and 6'-0" if a change in direction occurs in the span. The maximum span length for spans adjacent to spans containing a change in direction is 6'-0".

D. Tube track shall not extend/overhang past the last track support by more than 1'-0".

E. Reservoirs, valves, or other in-line components shall be independently supported.

F. When tees are used in routing of tube track, track supports shall be arranged as shown below:



7.1.11.3.2 Insulated and Heat Traced Applications

The following criteria apply for insulated and heat-traced tubing. Other constraints may also apply based on the specific application.

A. The maximum number of tubes per track shall be two (2) for 1/4", 3/8", and 1/2" tubing.

B. Insulation and heat tracing of 5/8", 3/4", or 1" tubing may require additional analysis.

C. No more than two (2) heat trace cables shall be allowed per track.

D. Insulation shall be fiberglass, no thicker than 1-1/2". The insulation shall surround the tube track and have an inside diameter of 3" for L2x2 angle and C2x1 channel track, and 3-1/2" inside diameter for C4x1 channel track.

E. Tubing shall be attached to the tube track at a maximum of 2'-0" and a maximum of 3'-0" spacing.

F. Reservoirs, valves, or other in-line components shall be independently supported.

7.1.11.4 <u>Support and Mounting Requirements</u>

Tubing that is routed in two or more Seismic Category I structures (Reactor Building, Containment, Main Steam Valve House, Nuclear Annex, Diesel Generator Building, etc.) must be verified to have sufficient flexibility to allow for differential building displacements.

Non-safety related manifold valves, solenoid valves, and instruments located over or near safety-related equipment or components shall be supported using the criteria in this section, unless justified by analysis. This will prevent any damage, degradation, or interference with the performance of equipment required for safety functions.

7.2 HVAC DUCTWORK AND SUPPORT/RESTRAINTS

7.2.1 GENERAL

HVAC ductwork shall be designed and supported to withstand dead weight (DW) and seismic loading, as applicable. The design and analysis guidelines herein apply to the HVAC supports/restraints (S/Rs) to maintain S/R stresses within allowables and limit ductwork deflections to maximum deflection (Δ_{MAX}) criteria. Limiting ductwork displacements to Δ_{MAX} allowables precludes rigorous analysis of the sheet metal ductwork to ensure its integrity.

HVAC ductwork S/R systems shall be designed in accordance with American Institute of Steel Construction (AISC) standards (ANSI/AISC N690 for safety-related systems, Manual of Steel Construction for non-safety related systems).

7.2.2 DESIGN CONSIDERATIONS

7.2.2.1 Gravity (Dead Weight, DW)

Dead weight (DW) loads include the weight of the ductwork itself, in-line components (e.g., dampers), externally mounted components, insulation, plus the weight of the S/R or stiffeners. Other DW loads such as ice, snow, etc. are included where applicable. DW loads are considered for both seismic and non-seismic S/Rs.

7.2.2.2 Seismic

7.2.2.2.1 Safety-Related Ductwork

Seismic S/Rs shall be used for all HVAC ductwork required to perform a safety function. Seismic load determination is discussed in Section 7.2.4.

The OBE and SSE shall be considered separately with the OBE loads used for the Level B load combination and the SSE loads used for Levels C and D. Both horizontal and the vertical components of the seismic excitation shall be applied simultaneously in the direction that will produce worst-case stresses and deflections.

7.2.2.2.2 Overlap Regions

In areas where non-safety related ductwork passes over or near safety-related equipment or components, the support/restraint and duct system must be designed so that it can maintain its structural integrity. This will prevent any damage, degradation, or interference with the performance of equipment required for safety functions.

In lieu of designing the entire ductwork system to withstand a seismic event, those portions of the duct passing over safety-related equipment or components may be isolated from the remaining duct by flexible duct connections and/or walls and supported seismically.

7.2.2.3 Thermal Expansion

Thermal expansion loads are negligible and are not considered.

7.2.2.4 Internal Pressure

Internal pressure loads are negligible and are not considered for the duct S/R system.

7.2.2.5 External Pressure Differential (EPD)

Dynamic external pressure loads resulting from postulated pipe breaks shall be considered for safety-related ductwork or ductwork whose failure could damage, degrade, or interfere with the performance of safety-related equipment. This condition will normally be precluded by ductwork routing away from the affected area.

7.2.3 DESIGN LOAD COMBINATIONS

The loading to be considered for the S/R system for the various Service Levels are as follows:

Service Level	Load Combination
A (Normal)	DW
B (Upset)	DW + OBE
C (Emergency)	DW + SSE
D (Faulted)	DW + SSE + EPD

7.2.4 ANALYSIS AND ACCEPTANCE CRITERIA

7.2.4.1 General

The general analytic/design procedure which shall be used to design HVAC S/R systems is as follows:

A. Determine S/R locations and types using the guidelines given in Section 6.3.5.

B. Determine the response of the S/R system. Two methods of response determination shall be employed.

1. Static Coefficient Method

2. Dynamic Analysis Method

Both the static coefficient method and the dynamic analysis method of response determination can yield an equivalent static approach to the seismic analysis of the S/R system. Descriptions and usage guidelines for these two methods are given in Sections 7.2.4.3 and 7.2.4.4.

C. Calculate S/R loads.

D. Design supports/restraints.

7.2.4.2 Damping Values

Damping values shall be similar to piping systems. A damping value of 5% may be used for both OBE and SSE.

7.2.4.3 Static Coefficient Method

The static coefficient method is a simple conservative analysis method. No determination of natural frequency of the system is made. Instead, the system response is assumed to be the peak of the required response spectra. This response is then multiplied by a static coefficient of 1.5. This coefficient takes into account the effects of both multifrequency excitation and multimode response. Having determined the peak response accelerations for a given system, the S/R loadings can be obtained by multiplying this acceleration by a factor of 1.5 and the participating mass.

This method of response determination will give rise to large S/R loads for the Upset and Faulted conditions. These loads must be safely sustained by the S/R and the structure to which the S/R is attached.

7.2.4.3.1 Static Coefficient Method Calculation

The S/R loadings are calculated by the Static Coefficient Method as follows:

A. Determine Participating Load

To establish the participating load (PL), all ductwork, and the S/R system shall be modeled as a series of simple beams between S/Rs providing similar directions of restraint. The PL shall include the weights of all ductwork and S/Rs included in the segment of ductwork being considered. Weight of other S/Rs, however, may be neglected.

B. Determine Normal Load

The normal load (NL) is the same as the PL when considering the vertical direction only. When determining loading in any other direction, the NL is equal to zero.

C. Determine Upset Load

The upset load (UL) is determined by:

$$UL=NL\pm(PL\times S_{OBE}) \qquad \textbf{(Eqn. 7.2-1)}$$

Where: S_{OBE} = OBE Seismic Coefficient

OBE = Operating Basis Earthquake loading, represented by:

$$OBE=PL\times S_{OBE} \qquad \textbf{(Eqn. 7.2-2)}$$

D. Faulted Load

The faulted load (FL) may be determined by:

$$FL=NL\pm(PL\times S_{SSE}) \qquad \textbf{(Eqn. 7.2-3)}$$

Where: S_{SSE} = SSE Seismic Coefficient

SSE = Safe Shutdown Earthquake loading, represented by:

$$SSE=PL\times S_{SSE} \qquad \textbf{(Eqn. 7.2-4)}$$

The values for S are the peak responses for the different areas and elevations from the "Acceleration Response Spectra Curves", multiplied by 1.5 as indicated in Section 7.2.4.3.

The maximum deflection (Δ_{max}), that may be sustained so that the duct function is not impaired shall be determined by analysis.

7.2.4.4 Dynamic Analysis Method

For the dynamic analysis method the ductwork and S/R system is modelled to best represent its mass distribution and stiffness characteristics. This model is then analyzed to determine if it is rigid or flexible. All systems having natural frequencies greater than the ZPA are considered rigid, where ZPA is the frequency corresponding to the zero period acceleration. For rigid systems, S/R loadings for the various operating conditions may be determined by multiplying the maximum floor acceleration (ZPA), the acceleration at ZPA, and the participating masses. This is an equivalent static analysis.

Flexible systems, i.e., those having natural frequencies less than ZPA, may be analyzed using response spectrum model analysis techniques or time history analysis techniques.

7.2.4.4.1 Dynamic Analysis Method Calculation

In the dynamic analysis method the stiffness of the ductwork and the stiffness of the S/Rs in specified directions are considered when evaluating a "system" stiffness. If this system stiffness is such that a natural frequency is greater than the ZPA, the duct-S/R system is considered rigid and the maximum floor response acceleration may be used in calculating the seismic S/R loadings. This is the basic objective of the dynamic analysis method.

A. Calculate Participating Load

When calculating the duct-S/R system natural frequency, an appropriate participating mass (or participating load, PL) must be considered. The mass shall consist of the following:

1. Mass of the S/R being analyzed.
2. Mass of applicable length(s) of ductwork assuming the duct run is a series of simply supported beams between S/Rs providing the same direction of restraint.
3. Mass(es) of other S/Rs within the applicable duct span.
4. Mass(es) of equipment.

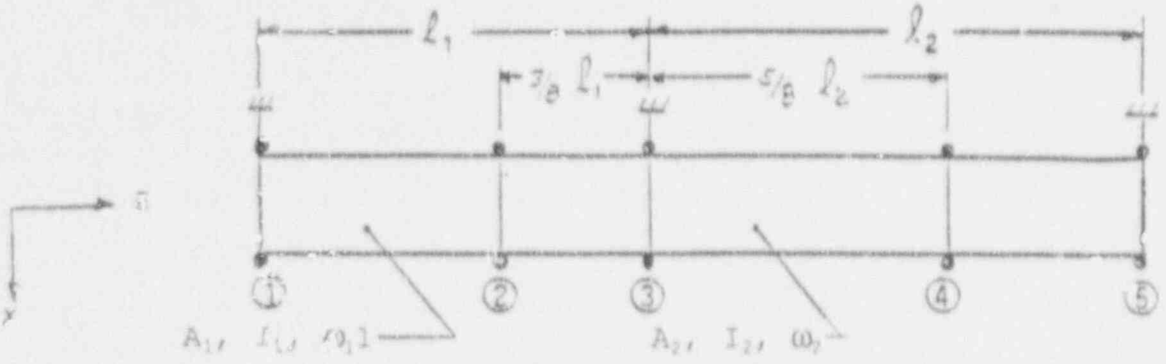
B. The dynamic analysis method is applied to the two generalized categories of S/Rs as follows:

1. Lateral and vertical S/Rs in various combinations.
2. Axial S/Rs.

C. Lateral and Vertical S/Rs

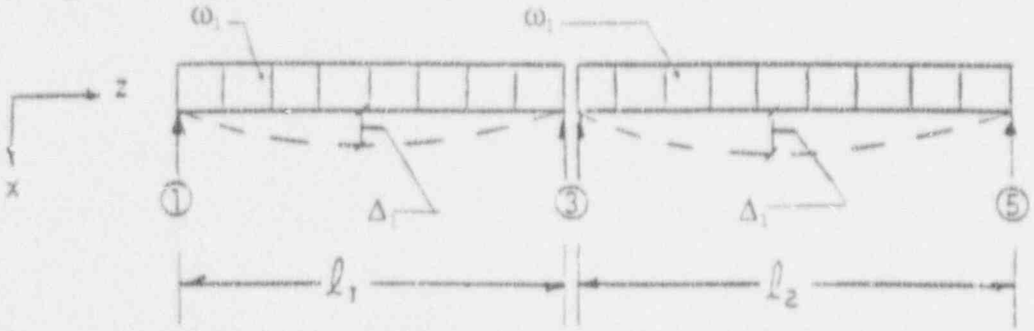
These two functional types of S/Rs may be considered in a single category for determining a ductwork <u>flexural</u> rigidity for both types of S/Rs.

1. Plan View



S/Rs 1, 3, and 5 are lateral-vertical S/Rs (x-y)
S/Rs 2 and 4 are vertical S/Rs (y)

2. Load Model



3. Calculate Duct Stiffnesses (Assumes S/Rs as infinitely rigid)

For the simple beam models and loadings shown, the maximum 1 g lateral ('x') deflections are:

$$\Delta_{1_{MAX}} = \frac{5}{384} \times \frac{\omega_1 l_1^4}{I_{1y}E} \qquad \text{(Eqn. 7.2-5)}$$

$$\Delta_{2_{MAX}} = \frac{5}{384} \times \frac{\omega_2 l_2^4}{I_{2y}E} \qquad \text{(Eqn. 7.2-6)}$$

Where: Δ_{MAX} = Maximum duct deflection (in)
ω = Duct loading per unit length (lbs/in)
l = Duct length (in)
I = Duct section modulus (in^4)
E = Duct modulus of elasticity (psi)

Note: For loading distributions other than that shown, appropriate expressions for Δ_{MAX} should be developed.

$$K_{1_{DUCT}} = \frac{\omega_1 l_1}{\Delta_{1_{MAX}}} \; (lbs/inch) \qquad \textbf{(Eqn. 7.2-7)}$$

$$K_{2_{DUCT}} = \frac{\omega_2 l_2}{\Delta_{2_{MAX}}} \; (lbs/inch) \qquad \textbf{(Eqn. 7.2-8)}$$

Where: K_{Duct} = Duct stiffness (lbs/in.)

4. Calculate participating mass (participating load, PL) in the applicable direction acting on the S/R being analyzed.

$$PL_{S/R_1} = P_{S/R_1} + \frac{\omega_1 l_1}{2} + \frac{\omega_2 l_2}{2} + P_{S/R_2}{}^{*} \qquad \textbf{(Eqn. 7.2-9)}$$

Where: $P_{S/R}$ = S/R weight (lbs)

* Note that only S/R_2 is considered as it falls within the half-span ($l_2/2$) being considered for S/R_1. In general, only those S/Rs falling in the half-spans nearest the S/R being analyzed need to be considered in the participating mass (PL) calculation. The effects of these S/Rs may be shown to be negligible and not considered in the analysis.

5. Calculate $\Delta_{MAX\ S/R}$ in the applicable direction due to a 1 g loading. This calculation may be performed by simplified hand calculation methods or by computer. Note that for this example the applicable direction is in the 'x' direction.

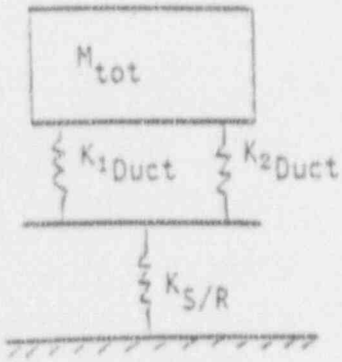
6. Calculate stiffness of the S/R in the direction considered.

$$K_{S/R} = \frac{PL_{S/R}}{\Delta_{MAX_{S/R}}} \; (lbs/inch) \qquad \textbf{(Eqn. 7.2-10)}$$

$$K_{S/R_1} = \frac{PL_{S/R_1}}{\Delta_{MAX_{S/R_1}}} \; (For\, 'x'\, direction)$$

7. Develop the spring-mass model and calculate the equivalent 'system' stiffness.

For the lateral and vertical directions the spring-mass model used is as follows:



$$M_{tot} = \frac{PL_{S/R}}{g} \qquad \textbf{(Eqn. 7.2-11)}$$

Where: $PL_{S/R}$ from Step 4 (lbs)
M_{tot} = Total mass (lbm)
g = 386.4 in/sec^2

The equivalent stiffness is given by:

$$\frac{1}{K_{EQ}} = \frac{1}{K_{1_{Duct}} + K_{2_{Duct}}} + \frac{1}{K_{S/R}} \qquad \textbf{(Eqn. 7.2-12)}$$

--OR--

$$K_{EQ} = \frac{(K_{1_{Duct}} + K_{2_{Duct}})\, K_{S/R}}{K_{1_{Duct}} + K_{2_{Duct}} + K_{S/R}} \; (lbs/inch) \qquad \textbf{(Eqn. 7.2-13)}$$

Note: As an alternate, a single span system model may be used. Effective mass and spring rates of the S/Rs are used. The system frequency of the actual spans on either side of the S/R are determined separately with the lower of the two controlling. Typically, the longer span of duct and/or the duct with the lowest section properties control. Each S/R is required to support a weight of duct equivalent to the weight of the chosen span of duct.

The alternate single span spring-mass model would be as follows:

Where: g = 386.4 in/sec^2

$$M_{tot}=\frac{P_{S/R_1}+\omega l+P_{S/R_2}}{g} \qquad \textbf{(Eqn. 7.2-14)}$$

The equivalent stiffness is given by:

$$\frac{1}{K_{EQ}}=\frac{1}{K_{S/R_1}+K_{S/R_2}}+\frac{1}{K_{Duct}}$$

-OR-

$$K_{EQ}=\frac{K_{Duct}\left(K_{S/R_1}+K_{S/R_2}\right)}{K_{Duct}+K_{S/R_1}+K_{S/R_2}}\;(lbs/inch)$$

Where:

$$K_{Duct}=\frac{\omega l}{\Delta_{MAX}} \qquad \textbf{(Eqn. 7.2-15)}$$

$$K_{S/R}=\frac{P_{S/R}+\omega l}{\Delta_{MAX_{S/R}}} \qquad \textbf{(Eqn. 7.2-16)}$$

$$\Delta_{MAX}=\frac{5}{384}\times\frac{\omega l^4}{I_{Duct}E} \qquad \textbf{(Eqn. 7.2-17)}$$

Both of these spring-mass models will produce frequencies lower than a complete system model.

8. Calculate the natural frequency of the system.

$$fn_{sys}=\frac{1}{2\pi}\sqrt{\frac{K_{EQ}}{M_{tot}}} \qquad \textbf{(Eqn. 7.2-18)}$$

$$fn_{sys}=\frac{1}{2\pi}\sqrt{\frac{K_{EQ}g}{PL_{S/R}}} \qquad \textbf{(Eqn. 7.2-19)}$$

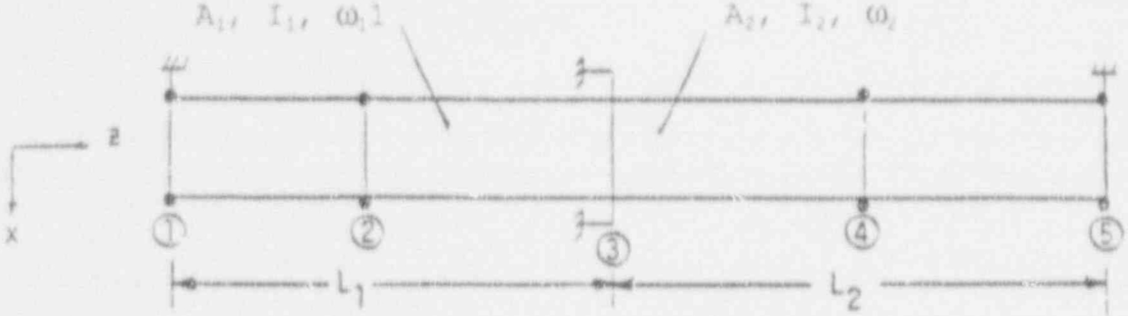
Where: fn_{sys} = System natural frequency (Hz)

9. If fn_{sys} is greater than the ZPA, the system is rigid and the appropriate seismic acceleration coefficient is chosen from the "Acceleration Response Spectra Curves." Upset and Faulted condition loadings are then calculated as outlined in **Section 7.2.4.3**. The values for S in this case are the ZPA acceleration coefficients for the areas and elevations from the "Acceleration Response Spectra Curves."

D. Axial S/Rs

This functional type of S/R is considered in a separate category since an AE/L stiffness is being evaluated for the ductwork.

1. Plan View



S/Rs 1 and 5 are vertical-lateral S/Rs (x-y)
S/Rs 2 and 4 are vertical S/Rs (y)
S/R 3 is an axial S/R (z)

2. Determine applicable lengths of ductwork and calculate ductwork stiffness. Axial direction stiffness is given by:

$$K_{Duct} = \frac{AE}{L} \qquad \textbf{(Eqn. 7.2-20)}$$

Where: A = Cross-sectional area (in^2)
E = Duct section modulus (psi)
L = Applicable length (in.)

Note: If duct area varies in length L, the average area (A_{AV}) can be used, as shown below:

$$A_{AV}=\frac{\Sigma A_i L_i}{\Sigma L_i} \qquad \textbf{(Eqn. 7.2-21)}$$

$$K_{1_{Duct}}=\frac{A_{1_{AV}}E}{L_1}\,(lbs/inch)$$

$$K_{2_{Duct}}=\frac{A_{2_{AV}}E}{L_2}\,(lbs/inch)$$

3. Calculate participating mass (PL) in the applicable direction acting on the S/R being analyzed.

$$PL_{S/R_3}=P_{S/R_3}+(\omega_1 L_1+\omega_2 L_2)+(P_{S/R_1}+P_{S/R_2}+P_{S/R_4}+P_{S/R_5})\ *$$

(Eqn. 7.2-22)

* Note that all S/Rs in the applicable duct lengths are considered in this example. The effects of these S/Rs may be shown to be negligible and not considered in the analysis.

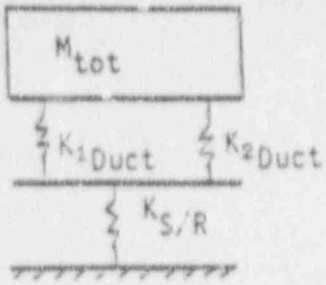
4. Calculate $\Delta_{MAX\ S/R}$ in the applicable direction due to the 1 g loading. This calculation may be performed by simplified hand calculation methods or by computer. Note that for this example the applicable direction is in the 'z' direction.

5. Calculate stiffness of the S/R in the direction considered (z).

$$K_{S/R_3}=\frac{PL_{S/R_3}}{\Delta_{MAX_{S/R_3}}}$$

6. Develop the spring-mass model and calculate the equivalent 'system' stiffness.

For the axial direction, the spring-mass model is as follows:



$$M_{tot} = \frac{PL_{S/R}}{g}$$

Where: $PL_{S/R}$ from Step 3 (lbs)
$g = 386.4$ in/sec^2

The equivalent stiffness is given by:

$$\frac{1}{K_{EQ}} = \frac{1}{K_{1_{Duct}}+K_{2_{Duct}}} + \frac{1}{K_{S/R}}$$

-OR-

$$K_{EQ} = \frac{(K_{1_{Duct}}+K_{2_{Duct}})\,K_{S/R}}{K_{1_{Duct}}+K_{2_{Duct}}+K_{S/R}}\ (lbs/inch)$$

7. Calculate the natural frequency of the system.

$$fn_{sys} = \frac{1}{2\pi}\sqrt{\frac{K_{EQ}}{M_{tot}}}$$

$$fn_{sys} = \frac{1}{2\pi}\sqrt{\frac{K_{EQ}\,g}{PL_{S/R}}}$$

8. If fn_{sys} is greater than the ZPA, the system is rigid and the appropriate seismic acceleration coefficient is chosen from the "Acceleration Response Spectra Curves." Upset and Faulted condition loadings are then calculated as outlined in Section 7.2.4.3. The values for S in this case are the ZPA acceleration coefficients for the different areas and elevations from the "Acceleration Response Spectra Curves."

7.2.5 ALLOWABLE STRESS CRITERIA

All HVAC S/R systems must be able to safely sustain stresses induced by the various loading conditions. The criteria determining the allowable stresses are established using conservative values in compliance with the requirements of CESSAR-DC and ANSI/AISC N690. These values are provided as a basis for evaluating the required structural integrity of the support/restraints.

Stress levels for the various operating conditions shall be as follows:

Normal- Service Level A	Upset- Service Level B	Emergency- Service Level C	Faulted- Service Level D
Basic Stress Allowables	Basic Stress Allowables	1.6 x Basic Stress Allowables	1.7 x Basic Stress Allowables

In addition to satisfying the above stress limits, the S/R system must be designed to safely transfer all loadings to the structure. Concrete expansion anchors must therefore be subject to the margins of safety specified in NRC IE Bulletin No. 79-02.

7.2.6 ALLOWABLE DEFLECTION CRITERIA

No S/R deflection limitations other than those implied by the stress criteria given in Section 7.2.5 and any S/R system stiffness requirements are imposed.

7.3 CABLE TRAY/CONDUIT AND SUPPORT/RESTRAINTS

7.3.1 GENERAL

Cable tray and conduit shall analyzed in a similar manner as HVAC ductwork, designed and supported to withstand dead weight (DW), thermal (T), and seismic loading, as applicable. The design and analysis guidelines apply to the cable tray and conduit supports/restraints (S/Rs) to maintain S/R stresses within allowables and limit the cable tray and conduit deflections.

Cable tray and conduit S/R systems shall be designed in accordance with American Institute of Steel Construction (AISC) standards (ANSI/AISC N690 for safety-related systems, Manual of Steel Construction for non-safety related systems)

7.3.2 DESIGN CONSIDERATIONS

7.3.2.1 Gravity (Dead Weight, DW)

Dead weight (DW) loads include the weight of the cable tray or conduit itself, fittings, externally mounted components, cable tray covers, fireproofing, plus the weight of the S/R or stiffeners. DW loads are considered for both seismic and non-seismic S/Rs.

7.3.2.2 Seismic

7.3.2.2.1 Safety-Related Cable Tray and Conduit

Seismic S/Rs shall be used for all cable trays and conduit required to perform a safety function. Seismic S/Rs are discussed in Section 7.3.5.

The OBE and SSE shall be considered separately with the OBE loads used for the Level B load combination and the SSE loads used for Levels C and D. Both horizontal and the vertical components of the seismic excitation shall be applied simultaneously in the direction that will produce worst-case stresses and deflections.

7.3.2.2.2 Overlap Regions

In areas where non-safety related cable tray/conduit passes over or near safety-related equipment or components, the support/restraint and cable tray/conduit system must be designed so that it can maintain its structural integrity. This will prevent any damage, degradation, or interference with the performance of equipment required for safety functions.

In lieu of designing the entire cable tray/conduit system to withstand a seismic event, those portions of the cable tray/conduit passing over safety-related equipment or components may be isolated from the remainder of the system and supported seismically.

7.3.2.3 Thermal Expansion (T)

Thermal expansion loads (T) shall be considered.

7.3.2.4 External Pressure Differential (EPD)

Dynamic external pressure loads resulting from postulated pipe breaks shall be considered for safety-related cable tray and conduit whose failure could damage, degrade, or interfere with the performance of safety-related equipment. This condition will normally be precluded by routing away from the affected area.

7.3.3 DESIGN LOAD COMBINATIONS

The design loading to be considered for the S/R system for the various Service Levels are as follows:

Service Level	Load Combination
A (Normal)	DW + T
B (Upset)	DW + T + OBE
C (Emergency)	DW + T + SSE
D (Faulted)	DW + T + SSE + EPD

7.3.4 ANALYSIS AND ACCEPTANCE CRITERIA

7.3.4.1 General

The general analytic/design procedure which shall be used to design cable tray and conduit S/R systems is as follows:

A. Determine S/R locations and types using the guidelines given in Section 6.3.5.

B. Determine the response of the S/R system. Two methods of response determination shall be employed.

   1. Static Coefficient Method

   2. Dynamic Analysis Method

   Both the static coefficient method and the dynamic analysis method of response determination can yield an equivalent static approach to the seismic analysis of the S/R system. Descriptions and usage guidelines for these two methods are given in Sections 7.3.4.3 and 7.3.4.4.

C. Calculate S/R loads.

D. Design supports/restraints.

7.3.4.2 Damping Values

Damping values shall be similar to piping systems. A damping value of 2% may be used for the OBE load case and 4% for the SSE load case.

7.3.4.3 Static Coefficient Method

The static coefficient method is a simple conservative analysis method. No determination of natural frequency of the system is made. Instead, the system response is assumed to be the peak of the required response spectra. This response is then multiplied by a static coefficient of 1.5. This coefficient takes into account the effects of both multifrequency excitation and multimode response. Having determined the peak response accelerations for a given system, the S/R loadings can be obtained by multiplying this acceleration by a factor of 1.5 and the participating mass.

This method of response determination will give rise to large S/R loads for the Upset and Faulted conditions. These loads must be safely sustained by the S/R and the structure to which the S/R is attached.

7.3.4.3.1 Static Coefficient Method Calculation

LATER

7.3.4.4 Dynamic Analysis Method

For the dynamic analysis method the cable tray/conduit and S/R system is modeled to best represent its mass distribution and stiffness characteristics. This model is then analyzed to determine the system response.

7.3.4.4.1 Dynamic Analysis Method Calculation

LATER

7.3.5 ALLOWABLE STRESS CRITERIA

All cable tray/conduit S/R systems must be able to safely sustain stresses induced by the various loading conditions. The criteria determining the allowable stresses are established using conservative values in compliance with the requirements of CESSAR-DC and ANSI/AISC N690. These values are provided as a basis for evaluating the required structural integrity of the support/restraints.

Stress levels for the various operating conditions shall be as follows:

Normal- Service Level A	Upset- Service Level B	Emergency- Service Level C	Faulted- Service Level D
Basic Stress Allowables	Basic Stress Allowables	1.6 x Basic Stress Allowables	1.7 x Basic Stress Allowables

In addition to satisfving the above noted stress limits, the S/R system must be designed to safely transfer all loadings to the structure. Concrete expansion anchors must therefore be subject to the margins of safety specified in NRC IE Bulletin No. 79-02.

7.3.6 ALLOWABLE DEFLECTION CRITERIA

No S/R deflection limitations other than those implied by the stress criteria given in Section 7.3.5 and any S/R system stiffness requirements are imposed.

7.4 REFERENCES

7.4.1 CESSAR Design Certification, System 80+™ Standard Design.

7.4.2 ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, Class 1, 2, and 3.

7.4.3 ASME Code for Pressure Piping, B31, Power Piping, ASME B31.1.

7.4.4 ASME Code Case N-411-1, "Alternate Damping Values for Response Spectra Analysis of Class 1, 2, and 3 Piping, Section III, Division I".

7.4.5 USNRC Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis.

7.4.6 USNRC Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants."

7.4.7 Texas Utilities Letter TXX 3423, " Comanche Peak Steam Station, Functional Capacity of ASME Code Class 2 and 3 Stainless Steel Elbows".

7.4.8 NCIG-14, "Procedure for Seismic Evaluation and Design of Small Bore Piping", EPRI NP-6628 April 1990.

7.4.9 ANSI/AISC N690, "Nuclear Facilities-Steel Safety-Related Structures for Design Fabrication and Erection".

7.4.10 MSS-SP-58, "Pipe Hangers and Supports-Materials, Design and Manufacture".

7.4.11 USNRC Branch Technical Position, MEB 3-1 of Standard Review Plan 3.6.2 in NUREG-0800.

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

7.4.13 AISC Manual of Steel Construction.

7.4.14 NRC IE Bulletin No. 79-02, Revision 2, November 8, 1979.

TABLE 7.1-1

Design Conditions and Load Combinations for ASME Class 1 Piping

CONDITION	LOADS	COMMENTS
1. Design Condition	Design Pressure Weight Other Sustained Mechanical Loads OBE Inertia (1/2 range)	
2. Normal and Upset Conditions (1) (Reference Table 2, Notes 1 and 4)	Range of Operating Pressure Thermal Expansion and Transients Anchor Movements (TAM, OBE, SAM, DFL) OBE Inertia Other Mechanical Loads Dynamic Fluid Loads (2)	Combination used for Eq. 10, NB-3653.1
	Thermal Expansion Thermal Anchor Movement Thermal Transients	Combination used for Eq. 12, NB-3653.6 (if required)
	Weight Other Sustained Mechanical Loads OBE Inertia (1/2 range) Range of Operating Pressures Dynamic Fluid Loads (2)	Combination used for Eq. 13, NB-3653.6 (if required)
3. Emergency Conditions	Maximum Pressure Weight SSE Inertia (1/2 range) Other Sustained Mechanical Loads Dynamic Fluid Loads (2)	
4. Faulted Conditions	Maximum Pressure Weight SSE Inertia (1/2 range) Other Sustained Mechanical Loads Pipe Rupture Loads Dynamic Fluid Loads (2)	

TABLE 7.1-1 (Continued)

Design Conditions and Load Combinations for ASME Class 1 Piping

CONDITION	LOADS	COMMENTS
5. Testing Conditions	Pressure, Temperature, and Hydrostatic Test as defined in established system tests	

NOTES:

1. The method for analyzing Upset Conditions is the same as for Normal per NB-3654.

2. Dynamic Fluid Loads (DFL) are occasional loads such as safety/relief valve thrust, steam hammer, water hammer or other loads associated with Plant Upset or Faulted Condition as applicable. The worst combination of pressure, weight, sustained, seismic, and DFL loads shall be checked.

4. Dynamic loads are combined by the square root of the sum of the squares (SRSS).

TABLE 7.1-2

Code Compliance Criteria for ASME Class 1 Piping

CONDITION	STEP		CHECK FOR CODE COMPLIANCE PER (8)
1. Design Conditions	1A	Primary Stress Intensity Limit	Eq. 9/NB-3652
2. Normal and Upset Conditions (5)(6)	2A.1	Primary Plus Secondary Stress Intensity Range	Eq. 10/NB-3653.1
	2A.2	If EQ.10 is met, calculate Peak Stress Intensity Range (S_p). If not, skip to Step 2B.1	Eq. 11/NB-3653.2
	2A.3	Calculate Alternating Stress Intensity ($S_{Alt.}$)	$S_{Alt.}$ = 1/2 Sp NB-3653.3
	2A.4	Evaluate Cumulative Usage. If acceptable, proceed to check Faulted Conditions	NB-3653.4, 3653.5 NB-3222.4(e)(5)
	2B.1	If EQ.10 is not met, perform Simplified Elastic-Plastic Discontinuity Analysis (4)	Eq. 12/ NB-3653.6(a)
	2B.2	Check Primary Plus Secondary Stress Intensity Range	Eq. 13/ NB-3653.6(b)
	2B.3	Calculate $S_{Alt.}$	Eq. 14/ NB-3653.6(c)
	2B.4	Evaluate Cumulative Usage. If acceptable, proceed to check Faulted Conditions	NB-3653.4, 3653.5 NB-3222.4(e)(5)

TABLE 7.1-2 (Continued)

Code Compliance Criteria for ASME Class 1 Piping

CONDITION		STEP	CHECK FOR CODE COMPLIANCE PER (8)
3. Emergency Conditions		**LATER**	
4. Faulted Conditions	4A	Determine maximum faulted pressure	App. F (8)
	4B	Check Primary Intensity Limit	App. F (8)
5. Testing Conditions (7)	5A	Check General Primary Membrane Stress Intensity	NB-3226 (a)
	5B	Check Primary Membrane Plus Bending Stress Intensity	NB-3226 (b)
	5C	Check External Pressure	NB-3226 (c)
	5D	Incorporate Test Condition into Fatigue Evaluation	NB-3226 (d) NB-3226 (e)

TABLE 7.1-2 (Continued)

Code Compliance Criteria for ASME Class 1 Piping

NOTES:

1. If Eq. 10 is not met, the component may still be satisfactory provided Eq. 12/ NB-3653.6 is met or the requirements of NB-3200 are satisfied.

2. The purpose of this equation is to calculate the value of Sp using the same load sets used to evaluate Eq. 10.

3. S_{ALT} is used in conjunction with the Design Fatigue Curves to determine the allowable number of cycles per NB-3653.4.

4. Qualifying Normal/Upset Conditions using the simplified Elastic-Plastic Discontinuity Analysis per Eq. 12 is necessary only for points that do not satisfy Eq. 10.

5. The method for analyzing Upset conditions is the same as for Normal per NB-3654.

6. These limits must be satisfied for all possible ranges.

7. Alternatively, Test Conditions can be included as part of Normal and Upset Conditions to be checked.

8. Article referenced is taken from the ASME Boiler and Pressure Vessel Code, Section III

TABLE 7.1-3

Design Conditions, Load Combinations, and Code Compliance Criteria for ASME Class 2 and 3 Piping

	CONDITION	LOADS	CHECK FOR CODE COMPLIANCE PER (5)
1.	Normal		
	a. Sustained Loads (4)	Pressure Weight (6)	Eq. 8, NC/ND-3652
	b. Thermal Expansion	Thermal Expansion Thermal Anchor Movements	Eq. 10, NC/ND-3653.2
	c. Sustained Loads + Thermal Expansion	Pressure Weight (6) Thermal Expansion Thermal Anchor Movements	Eq. 11, NC/ND-3653.2
2.	Upset	Pressure Weight (6) DFL (2) OBE (Inertia) OBE (Anchor Movements) (1) or Wind (8)	Eq. 9, NC/ND-3653.1
3.	Emergency	Pressure Weight (6) DFL (2) SSE (Inertia) or Tornado (8)	Eq. 9, NC/ND-3652.1
4.	Faulted	Pressure Weight (6) Pipe Rupture SSE (Inertia) DFL (2)	Eq. 9, NC/ND-3653.1
5.	Functional Capability	Pressure Weight (6) SSE (Inertia) DFL (2) Pipe Rupture	See Note 7

TABLE 7.1-3 (Continued)

Design Conditions, Load Combinations, and Code Compliance Criteria for ASME Class 2 and 3 Piping

NOTES:

1. Stresses due to seismic displacements such as anchor movements may alternatively be considered as secondary stresses and combined with thermal expansion in Eq. 10 or 11 and omitted from Eq. 9.

2. Dynamic Fluid Loads (DFL) are occasional loads such as safety/relief valve thrust, steam hammer, water hammer or loads associated with Plant Upset or Faulted Condition as applicable.

3. Stresses must meet the requirements of either Eq. 10 or Eq. 11 (i.e. both conditions need not be satisfied).

4. If, during operation, the system normally carries a medium other than water (air, gas, steam), sustained loads should be checked for weight loads during hydrostatic testing as well as normal operation weight loads.

5. Articles referenced from the ASME Boiler and Pressure Vessel Code, Section III.

6. Weight loads include all sustained Mechanical Loads.

7. Functional capability is not a standard loading condition as defined by the ASME Code. However, functional capability must be maintained for ASME Class 2 and 3 stainless steel elbows. See Appendix 7B for the acceptance criteria.

8. Wind and tornado loads are not combined with earthquake loading.

9. Dynamic loads are combined by the square root of the sum of the squares (SRSS).

TABLE 7.1-4

Loading Conditions and Load Combination Requirements for ASME Code Class 1, 2, and 3 Piping Supports

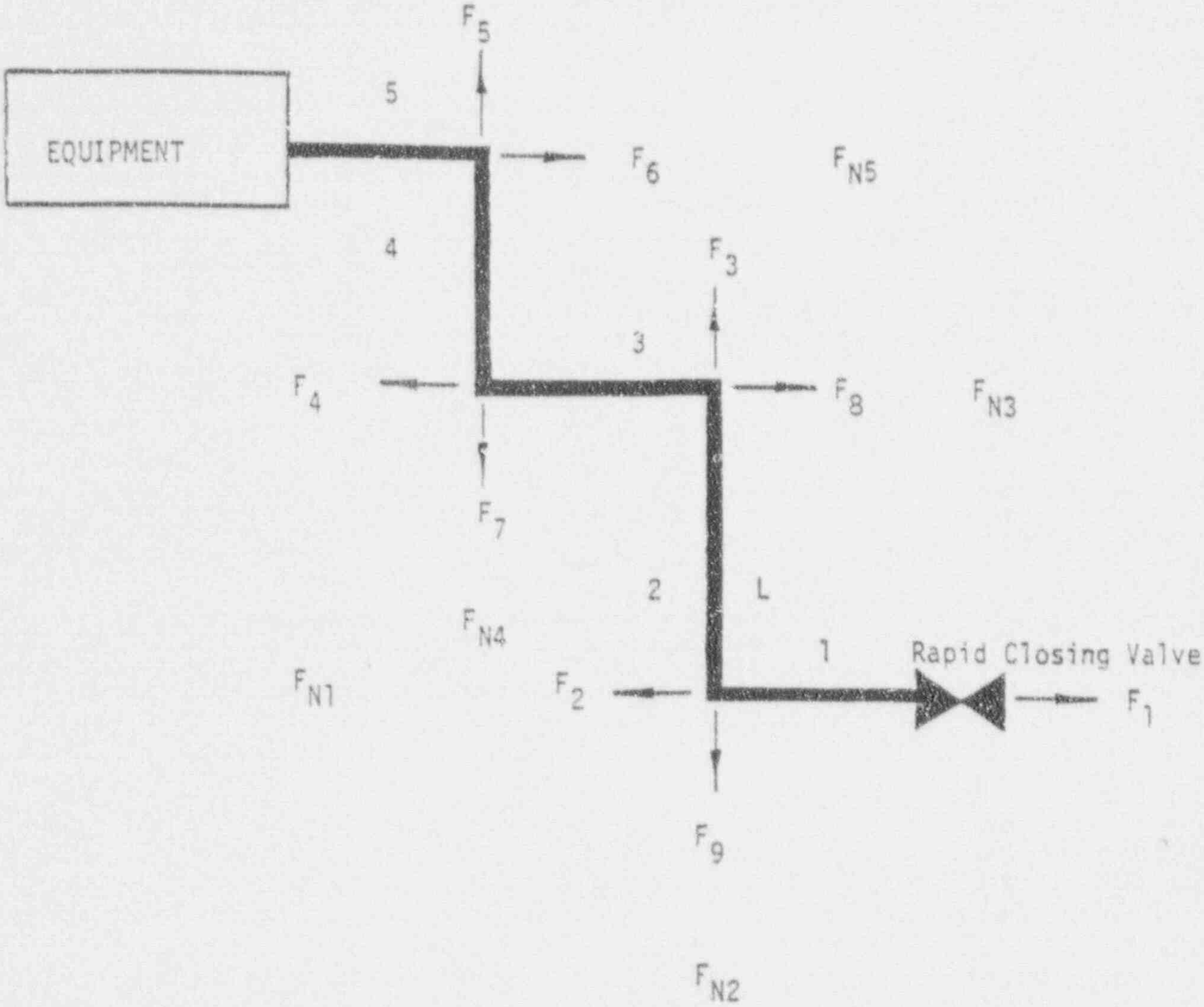
	CONDITION	LOAD COMBINATION
1.	Normal Condition (Service Level A)	Weight Thermal (1)
2.	Upset Condition (Service Level B)	Weight Thermal (1) Dynamic Fluid Loads (2) OBE Inertia OBE Seismic Anchor Mvts or Wind (3)
3.	Emergency Condition (Service Level C)	Weight Thermal (1) Dynamic Fluid Loads (2) SSE Inertia SSE Seismic Anchor Mvts. or Tornado (3)
4.	Faulted Condition (Service Level D)	Weight Thermal (1) Dynamic Fluid Loads (2) SSE Inertia SSE Seismic Mvts Pipe Rupture Loads

NOTES:

1. Thermal conditions (including ambient temperature) to be combined to provide maximum load combinations.
2. Dynamic Fluid Loads due to safety/relief valve thrust, steam hammer, and water hammer.
3. Wind and tornado loads are not combined with earthquake loading.

FIGURE 7.1-1

Water/Steam Hammer Forces



F_i: = Time dependent force develop at change in direction

F_{Ni} = Net resultant force along axis of pipe at worst time (i.e., maximum difference between opposing F_i's).

FIGURE 7.1-2

Percent Pressure Rise vs. Valve Closing Time

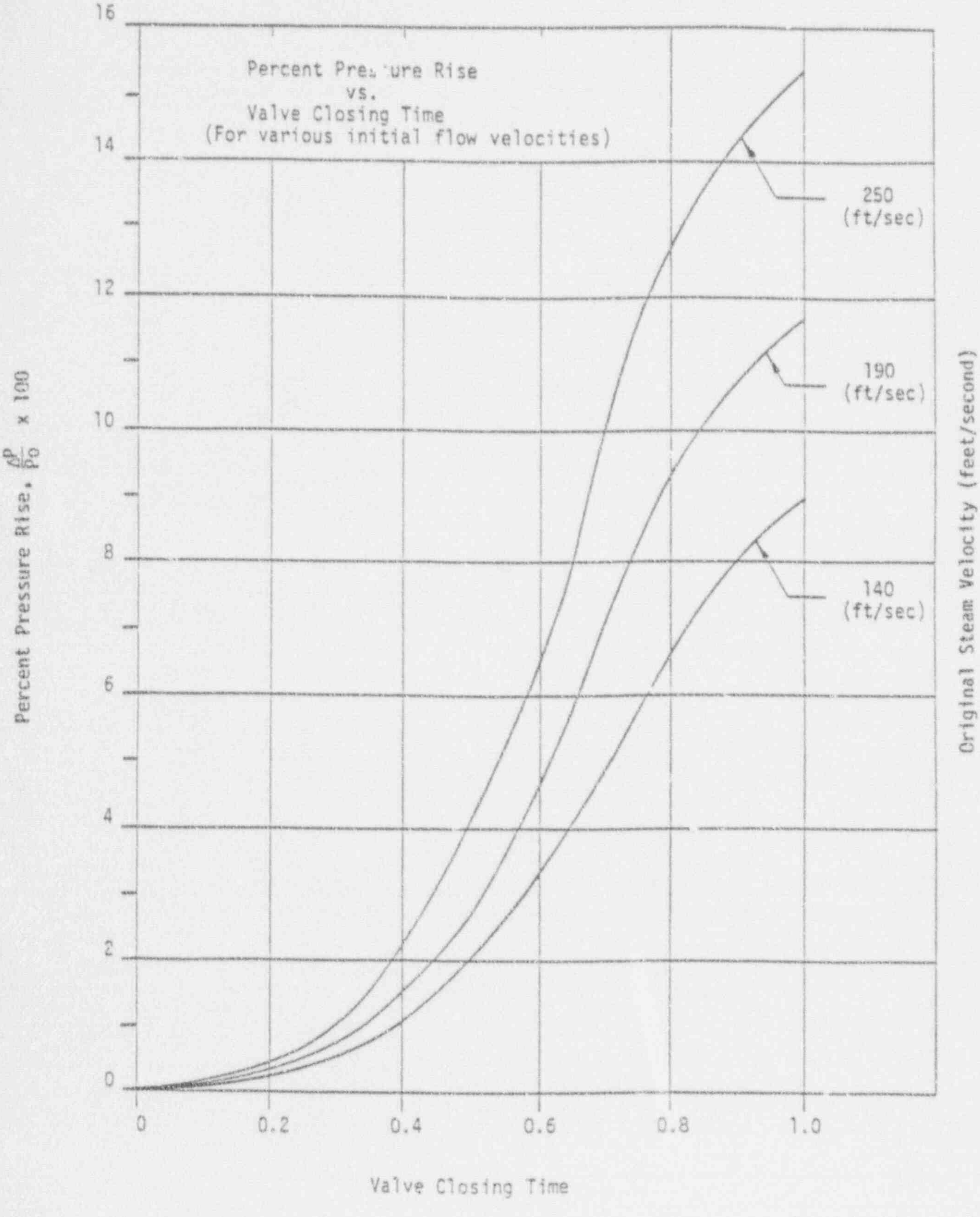
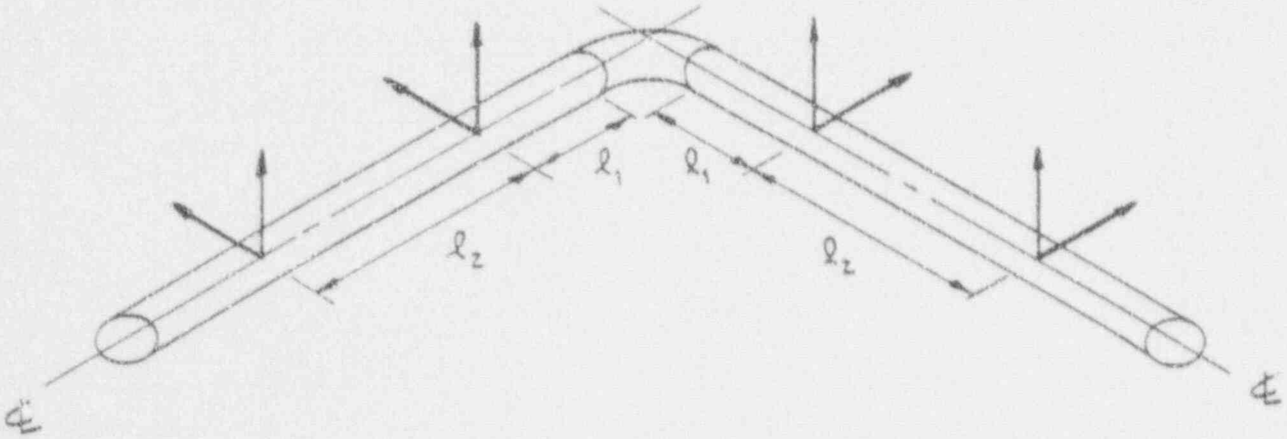


FIGURE 7.1-3

Restrained Elbow



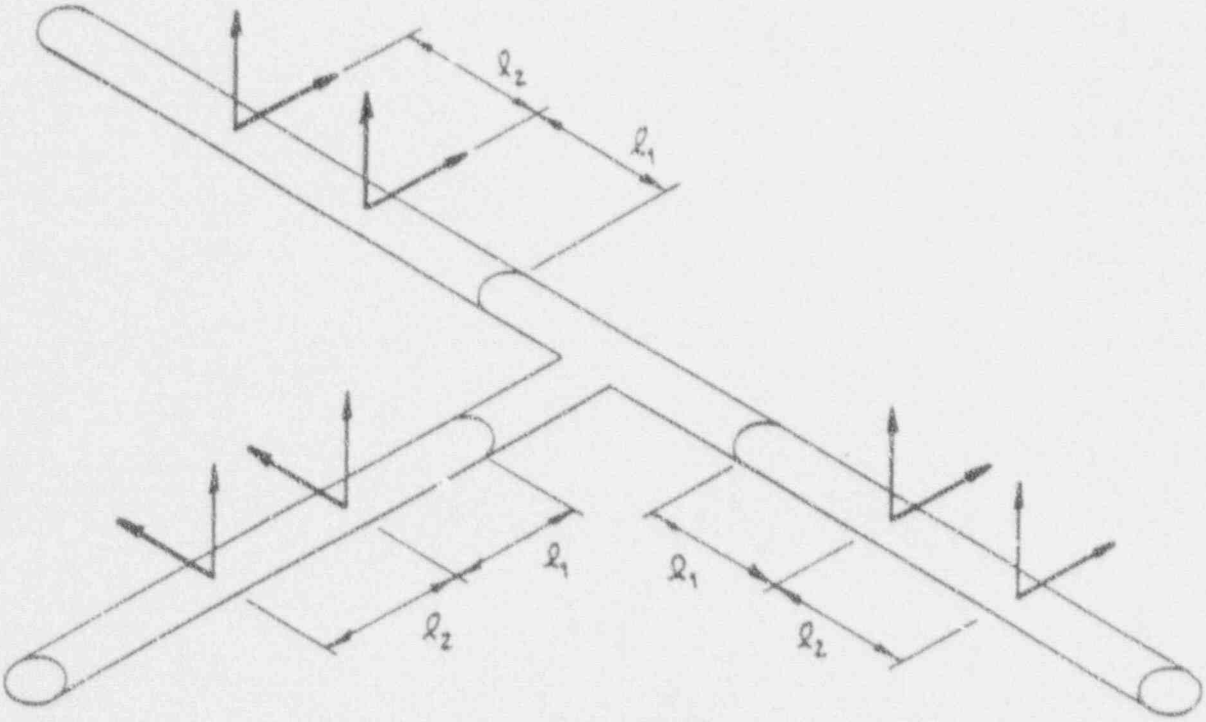
Dimensions ℓ_1 and ℓ_2 are defined as follows:

	NOMINAL	MINIMUM	MAXIMUM
ℓ_1:	6"	Weld Clearance	6"
ℓ_2:	L/4	L/8	L/4

WHERE: L=ANSI B31.1.0 Recommended Weight Span per Table 121.1.4

FIGURE 7.1-4

Restrained Tee



Dimensions ℓ_1 and ℓ_2 are defined as follows:

	NOMINAL	MINIMUM	MAXIMUM
ℓ_1:	6"	Weld Clearance	6"
ℓ_2:	L/4	L/8	L/4

WHERE: L=ANSI B31.1.0 Recommended Weight Span per Table 121.1.4

APPENDIX 7A

1.0 LEAK-BEFORE-BREAK

1.1 PLANT AND PIPING DESIGN CONDITIONS

1.1.1 PIPING DESIGN PARAMETERS

The use of Leak-Before-Break (LBB) technology has, in the past, been limited to the evaluation of piping systems already designed and constructed. The ALWR design certification approach makes it possible to design certain piping systems such that elimination of the dynamic effects of postulated pipe breaks by LBB is assured at the design stage.

In piping design, fluid system requirements normally drive the selection of specific piping parameters. For those piping systems chosen for LBB evaluation, LBB considerations must be integrated into the process of selecting those design parameters. Specifically, the design parameters for which LBB should be considered include pipe size (cross-section), pipe and weld materials, loads and piping system thermal flexibility.

The pipe and weld material should be chosen considering LBB requirements, along with system, stress and fatigue requirements. Within the limitations of fluid system and ASME Code requirements, the piping designer should select pipe and weld materials which have good corrosion resistance, high yield and high toughness characteristics.

Piping system thermal flexibility is governed by the stress requirements of the ASME Code and the duty cycle of loadings. The piping system must be routed such that it is sufficiently flexible to be able to thermally deflect without exceeding stress or fatigue limits. It must also meet criteria for all load combinations associated with earthquakes (see Sections 7.1.4 through 7.1.8).

Increased flexibility of the piping system results in lower pipe loads from thermal loadings. Low normal operation (NOP) loads are advantageous in the LBB crack stability analyses provided that low NOP loads do not result in a leakage crack length that is too long. A smaller NOP load results in a longer circumferential crack length necessary to produce a crack with a detectable flow rate. This longer crack leaves a weaker pipe cross section, which is subjected to load combinations in the stability analyses. This means that the pipe designer must also be mindful of the SSE loading if the pipeline under consideration is to meet LBB requirements. Inclusion of seismic supports must be considered in the overall flexibility of the piping system. A piping system that is made too

APPENDIX 7B

1.0 FUNCTIONAL CAPABILITY REQUIREMENTS

ASME Code Class 2 and 3 stainless steel elbows will be accepted as meeting the functional capability criteria when the following equation is met. Functional capability evaluations are only required on elbows with $D_o/t > 50$.

$$B_1\left(\frac{PD_o}{2t}\right)+B_2\left(\frac{M_1}{Z}\right)\leq 1.8S_y \qquad \textbf{(Eqn. 7B-1)}$$

Where: $B_1 = (-0.1 + 0.4h)$, and $0 \leq B_1 \leq 0.5$

And: $B_1 = 0.5$ for $B_2 = 1.0$

$B_2 = 1.3/h^{2/3}$ for $\propto_o > 90°$

$= 0.895/h^{0.912}$ for $\propto_o = 90°$

$= 1.0$ for $\propto_o = 0°$

but not less than 1.0

Linear interpolation is allowed for values of $\propto_o$ between 0° and 90°.

$h = tR/r^2$

$\propto_o$ = angle of the bend

R = elbow bend radius (inch)

r = mean radius of pipe (inch)

P = pipe design pressure (psig)

D_o = pipe outside diameter (inch)

t = nominal pipe wall thickness (inch)

M_1 = moment associated with plant faulted loads

S_y = yield strength of material at design temperature flexible because of NOP considerations alone may require too many seismic snubbers.

The approach in considering piping system thermal flexibility should be to route the pipe subject to the thermal loadings, other NOP loadings, seismic loadings and stress and fatigue limits. Revisions or limitations to certain thermal modes of operation may need to be considered in order to satisfy thermal flexibility requirements. Determination of a leakage crack length for LBB should be made on the basis of the NOP pipe loads generated or may be conservatively calculated by applying operating pressure alone to the crack model (see Appendix 7A, Section 1.3.3).

1.1.2 LEAKAGE DETECTION SYSTEMS (LDS)

CESSAR-DC, Section 3.6.3.3.1 states the following:

> A leak detection system is recommended by Regulatory Guide 1.45 capable of detecting a leakage rate of...1.0 gpm...or less...from the primary system. NUREG-1061, Volume 3, recommends a safety margin of ten on the leak detection system. Diverse measurement means are provided, including water inventory monitoring, sump level and flow monitoring, and measurement of airborne radioactive particulates or gases....Leak detection system requirements to support the LBB analysis for main steam line piping are met by a combination of humidity detectors, condensation on the containment air coolers, radioactive airborne activity sensors and sump flow and level meters.

The various means of leak detection support, but may not be designed specifically to, the requirements of the LBB evaluation. Regulatory Guide 1.45 requires a LDS system capable of detecting a 1.0 gpm rate or less, independent of LBB requirements. The LBB evaluation, however, depends on these "diverse measurement means", their diverse sensitivities and accuracies, which constitute the LDS, in order to correlate a crack length to a flow rate ten times the leak detection capability. Unless otherwise justified, the LBB evaluations of System 80+ piping systems should be based on a leak detection capability of 1.0 gpm and a safety margin of 10.

1.1.3 CONSIDERATION OF POTENTIAL FOR DEGRADATION SOURCES

CESSAR-DC, Section 3.6.3.1, states the following:

> Piping evaluated for LBB is first shown to meet the applicability requirement of NUREG-1061, Volume 3 (Reference 2.1). The piping is designed to meet the

requirement to have a low susceptibility to failure from the effects of corrosion, water hammer or low- or high-cycle fatigue, or degradation or failure of the piping from indirect causes such as missiles or failure of nearby components.

In order to meet the commitment of CESSAR-DC, Section 3.6.3.1, the LBB evaluation must consider pipe and weld material selection, significant thermal modes of operation, the environment in which the piping is routed, and potential for water hammer within the particular fluid system, as each relates to potential for degradation of the pipe (see Reference 2.1, Section 5.1). Consideration of LBB, in turn, should be integrated into the process of selecting materials (for corrosion resistance), determining modes of operation (for reduction of loads from critical thermal transients), designing the piping system to preclude water hammer, and routing, where possible, to minimize potential of failure of the pipe from indirect causes (see Sections 4.2.1.2, 4.2.1.3, 6.2.9 and 7.1.2.5).

1.1.4 CONSIDERATION OF LOADING CONDITIONS

Loads due to NOP (dead weight, pressure, and normal steady state thermal conditions) should be applied to the pipe section to calculate a crack length that will result in ten times the detectable leakage rate. As previously mentioned, a pressure-only load may be considered in this crack length determination in order to generate a maximum bounding case on leakage crack length. For smaller pipes, this may be too conservative, in which case a full set of NOP loads should be applied to determine crack length.

NOP loads, critical thermal transients (including loads due to thermal stratification, Sections 6.2.10 and 7.1.2.7), SSE loads, and normal operation dynamic transient loads (such as from rapid valve closure), combined in the same manner as prescribed in the piping design specification for the ASME Code design report, should be considered in the stability analyses. The combination of the NOP load and the largest of the design loads (which will be referred to herein as the "maximum design" load) should be applied to the cracked pipe section in the stability analyses, along with the applicable load margin. Minimization of the above loads is, in general, advantageous to the LBB evaluation and should be pursued in the routing and design of the selected piping system (see Appendix 7A, Section 1.1.1 for a further discussion with respect to LBB). In addition, overuse of dynamically activated snubbers to reduce piping response loads due to seismic and dynamic transient excitations must be avoided if possible or at least be balanced against the reduced reliability and maintainability that snubbers may cause in plant operations (see Sections 6.2.3 and 6.2.9).

1.2 CRITERIA

1.2.1 APPLICABILITY OF LBB

CESSAR-DC, Section 3.6.3.1, outlines the LBB applicability requirements for a piping system by committing to the applicability requirements of Reference 2.1 (also see Appendix 7A, Section 1.1.3).

1.2.2 DETECTABLE LEAKAGE RATE REQUIREMENT

Per Reference 2.1, the detectable leakage rate requirement of the leak detection system is 1.0 gpm or less. The leakage crack to be subjected to the crack stability analyses must leak at a rate ten times the capability of the LDS. CESSAR-DC, Section 3.6.3.3, commits to these requirements of Reference 2.1. Unless otherwise justified, LBB evaluations should be based on a leak detection capability of 1.0 gpm.

1.2.3 STABILITY ANALYSIS ACCEPTANCE CRITERIA

CESSAR-DC, Section 3.6.3.9, summarizes the stability analysis acceptance criteria as follows:

A. Cracks which are assumed to grow through the pipe wall leak significantly while remaining stable. The amount of leakage is detectable with a safety margin of at least a factor of 10.

B. Cracks of the length that leak at the rate in A above can withstand normal operation plus maximum design loads with a safety factor of at least √2.

C. Cracks twice as long as those addressed in B above will remain stable when subjected to normal operation plus maximum design loads.

NOP and maximum design loads are defined in Appendix 7A, Section 1.1.4.

1.3 ANALYSIS

1.3.1 DETERMINATION OF LEAKAGE CRACK LOCATIONS

It is a regulatory requirement that LBB be applied to an entire piping system or analyzable portion thereof, typically segments located between anchor points. Therefore, for practicality, locations of higher maximum design loads should be determined in order to reduce the number of locations where the LBB evaluation is to be performed.

A screening process based on comparison of the maximum design load to crack length (i.e., applied moment to the square of the crack length "a") can be used to determine the locations where crack stability is most likely to be challenged. These locations become the basis for locating leakage cracks to be evaluated. Simple criteria may be developed for screening. For example, locations with significantly lower maximum design loading and similar NOP loading may be eliminated from further consideration. Large diameter pipes with low NOP and maximum design loads compared with more highly loaded locations can be eliminated. Smaller pipes are more difficult to screen since the final margin on crack size (2) or final margin on load (2) each have the potential of being the limiting criterion. These two margins are equally limiting for larger pipes, which remain mostly elastic.

1.3.2 FLOW RATE CORRELATION

The leakage crack size must be correlated to the LDS capability. In order to simplify the LBB evaluations and provide safety margin, the value of 250 gpm/in^2 should be used for the leakage rate in the primary system. A value of 40 gpm/in^2 of condensed liquid should be used for the leakage rate in the main steam line. These values account for variables such as surface roughness of the side walls of the crack, the nonparallel relationship of the side walls due to the elongated crack shape, and possible zig-zag tearing of the material during crack formation. The selection of the respective value above as a conservative lower bound is supported by Reference 2.2. For example, in order for 10 gpm leakage to occur at a rate of 250 gpm/in^2, the leakage area must be 0.04 in^2. Similarly, in order for 10 gpm leakage to occur at a rate of 40 gpm/in^2, the leakage area must be 0.25 in^2. These respective crack opening areas should be used to determine the length of the detectable leakage crack for stability evaluations unless another correlation is justified.

1.3.3 PRELIMINARY LBB EVALUATION USING EPRI/GE ESTIMATION OR SIMILAR METHOD (Where Applicable)

The approach being taken toward design certification of System 80+ is to include LBB considerations in the piping design. One aspect of the LBB evaluation pursued for each selected piping system is performance of a preliminary LBB evaluation prior to and independent of pipe routing. This evaluation is used to provide the piping designer with LBB acceptance criteria, in terms of a range of materials, pipe sizes and NOP and maximum design loads for all locations on the pipe. If the acceptance criteria is met, an acceptable result of the LBB evaluation of the final design is assured. The range of piping parameters developed by this preliminary evaluation forms a "window" of acceptance criteria which the piping designer can utilize to route, design and support the piping system.

The preliminary LBB evaluation does not require determination of specific leakage crack locations, detailed analysis of finite element crack models, or prior calculation of NOP or SSE pipe loads. Crack opening areas can be calculated for large diameter pipes using methods such as the EPRI/GE estimation method of elastic-plastic fracture mechanics. The EPRI/GE estimation method relies on a catalog of pre-analyzed pipes for a variety of sizes and material behavior. For smaller diameter pipes, the finite element analyses described in Appendix 7A, Section 1.3.4 are performed.

The evaluation of crack opening areas vs. crack lengths is performed first. The EPRI/GE estimation or similar method requires the material stress-strain properties to be in the form of the Ramberg-Osgood law (Reference 2.3). The preliminary analysis utilizes best available material properties for the range of materials being evaluated. The Ramberg-Osgood law is fit to represent many stress-strain curves of a range within a generic type of material (e.g., three different types or grades of stainless steel). Using the material properties in the form described above, the EPRI/GE method is used to calculate the crack mouth opening displacements for various crack lengths. The crack opening areas are estimated from the crack lengths and opening displacements using an elliptical approximation for the opening areas.

Next, the leakage rates are computed from the crack lengths and opening areas. The pressure-only load and a minimum NOP load are used to create a range of loads and a corresponding range of crack lengths. The results are leakage rate vs. crack length curves.

The J-integral curves are then calculated using the J-integral estimation methods of the EPRI/GE or a similar method. J-integral curves are calculated for the leakage crack sizes for both (NOP + Maximum Design Load) and √2 x (NOP + Maximum Design Load). The applied loads are chosen to create an acceptance range.

For some piping systems, this method creates a "window" of design requirements for the piping design. In cases where this "window" is developed, there may be a larger range of acceptable loads beyond the window than the preliminary estimation method generates, for two reasons:

A. The detailed piping design ultimately provides actual NOP loads, maximum design loads, and piping design parameters for the detailed finite element analysis of the crack in the final LBB evaluation.

B. The crack length in the detailed analysis can be based on calculated rather than conservatively low NOP loads, and will therefore be shorter.

Design of the piping system to the LBB requirements developed using the above approach will therefore assure that LBB will be demonstrated in the final design.

1.3.4 DETAILED FINITE ELEMENT ANALYSIS

Detailed finite element LBB analyses are performed as a preliminary analysis at the design certification stage, for pipes for which the estimation method (Appendix 7A, Section 1.3.3) is too conservative or inapplicable. A finite element analysis model is used to analyze the bounding crack cases in detail. For each location in the piping system where a detailed evaluation is performed, at least two finite element models are developed. One model approximating the leakage crack size at normal operating loads is used to demonstrate safety margin on the loads. The other model, having a crack length twice that of the first model, is used to demonstrate the margin on crack size. Additional crack lengths may be modelled in order to better define the J-integral vs. crack length relationship.

A three-dimensional isoparametric brick element is used in the detailed analysis model. Symmetry is used to minimize the size of each model analyzed. Constraints are imposed on the models based on symmetry. The crack surface area is free from constraint in the direction of the crack opening. External pipe loads are applied to the pipe typically at a distance of five times the radius of the pipe in order to minimize local effects in the cracked region of the pipe.

The detailed analyses of cracks in pipe welds require consideration of the properties of the pipe and the weld materials. Per CESSAR-DC, Section 3.6.3.5, the LBB analysis of cracks in pipe welds results in a bounding case when the material stress-strain properties of the base metal, which has the lower yield, and the fracture properties of the weld, which has the lower toughness, are used in combination for the entire structure analyzed. CESSAR-DC, Section 3.6.3.5 summarizes materials selected for System 80+ piping systems evaluated for LBB. For preliminary LBB evaluations, the stress-strain curve and J-integral are developed from best available information. For final LBB evaluations, the stress-strain curve and J-integral are developed by testing representative samples of piping material to be used in the piping system being evaluated. The ductile fracture parameter, J-integral, is used to characterize the propensity for crack extension and stability in the piping material under consideration.

The primary loading on the pipes are those occurring during NOP. It is this loading condition which is used to determine leakage crack size. Crack opening areas are calculated at each bounding location for normal operating conditions. For a 10 gpm flow rate, the opening areas given in Appendix 7A, Section 1.3.2 are used to determine the leakage crack length.

The NOP and maximum design load combinations are used in the analysis to envelope the loads. The loads applied are as follows:

A. Pressure Loads

The internal pressure is applied to the inner surface of the pipe, and the average pressure is applied to the crack face to account for the pressure drop from internal to atmospheric pressure across the crack. A longitudinal end force equilibrating the pressure is applied remote from the crack. The first incremental load step is scaled to the first yield of the pipe material. Subsequent loading is applied until full pressure is reached.

B. Normal Operation Loads

The axial force and bending moment is applied to the remote end of the model. The loads are applied in small increments. This method of load application allows the analysis to precisely follow the stress-strain curve of the material.

C. Maximum Design Loads (Largest of the Safe Shutdown Earthquake Loads, Critical Thermal Transient Loads, or Normal Operation Dynamic Transient Loads)

The same procedure followed for the NOP loads is used for the maximum design loads. These loads are applied incrementally to the model which is loaded by the pressure and normal operation loads.

To evaluate margin on loads, all the loads used in Steps A to C above are added together and then increased to demonstrate additional margin, per Reference 2.1. The additional loads are applied to the model so that the total load applied is equal to $\sqrt{2}$

times (Pressure + NOP + Maximum Design Load). The resulting J-integral value is compared to the material fracture properties in order to demonstrate crack stability. The final LBB criteria are $J < J_{MAT}$ and $dJ/da < dJ_{MAX}/da$ for the crack sizes and loading previously given.

To evaluate margin on crack size, the model with a crack size twice the assumed leakage crack length is used, per Reference 2.1. The pressure and moment loads are applied in the same fashion. The sum of the loads applied is equal to (Pressure + NOP + Maximum Design Load).

The J-integral technique is used to demonstrate crack stability with the margin on load and margin on crack size. The J-integral is determined in the finite element analysis for pressure, NOP and maximum design loadings the two or more crack lengths for each geometric model. The stability evaluations are made by comparing the J vs. "a" and J_{MAT} vs. "a", where "a" is the crack size. Intersection of the curves illustrates that crack stability is assured, indicating that LBB is demonstrated for the crack evaluated. Crack stability is assured for each location in a given piping system where the loads are within the window analyzed, which demonstrates LBB for that piping system.

2.0 APPENDIX 7A REFERENCES

2.1 NUREG-1061, Volume 3, "Evaluation of Potential for Pipe Breaks."

2.2 NUREG/CR 4572 (BMI-2134), "NRC Leak-Before-Break (LBB) Analysis Methods for Circumferentially Through-Wall Cracked Pipes Under Axial Plus Bending Loads," R. Klecker, F. Brust, G. Wilkowski, May, 1986.

2.3 V. Kumer, M. D. German and C. F. Shih, "An Engineering Approach for Elastic-Plastic Fracture Analysis", EPRI Report No. NP-1931, July, 1981.

2.4 USNRC Regulatory Guide 1.45, "Reactor Coolant Pressure Boundary Leakage Detection Systems."