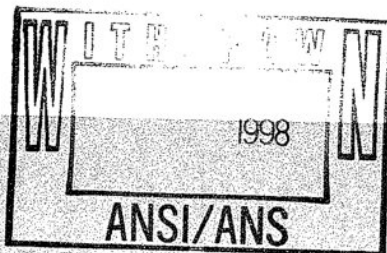


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design basis for protection of light water nuclear power plants against the effects of postulated pipe rupture



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American National Standard
Design Basis for Protection of Light Water Nuclear Power
Plants Against the Effects of Postulated Pipe Rupture

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Foreword

(This Foreword is not a part of American National Standard Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture, ANSI/ANS-58.2-1988.)

The piping in nuclear power plants is designed, fabricated and tested to the stringent requirements of the ASME Boiler and Pressure Vessel Code and the ASME Code for Power Piping. As a result, the experience with nuclear plant piping is very favorable. Nevertheless, the Nuclear Regulatory Commission (NRC) requires that nuclear plant safety be based on a defense-in-depth philosophy, and that protection against postulated piping accidents be provided by designing the containment system, emergency core cooling systems, and other protective features against the effects of these postulated accidents. This standard provides guidelines in order to achieve a consistent approach to providing plant protection except that the design of the containment system and emergency core cooling systems is not addressed.

Working Group ANS-58.2 of the standards committee of the American Nuclear Society, was reactivated in February 1984 to incorporate the LBB approach (Section 12) and to review and update the portions of the standard addressing postulated rupture locations and configurations (Section 4) and jet impingement effects (Section 7). In addition, substantial modifications were made to the portions of the standard addressing compartment pressurization effects (Section 8) and flooding effects (Section 10) to reflect developments in American National Standard Subcompartment Pressure and Temperature Transient Analysis in Light Water Reactors, ANSI/ANS-56.10-1987 and American National Standard Design Criteria for Protection Against the Effects of Compartment Flooding in Light Water Reactor Plants, ANSI/ANS-56.11-1988, respectively, since the issuance of ANSI/ANS-58.2-1980. Finally, the entire standard was reviewed and changes made where appropriate for consistency with Sections 4, 7, 8, 10 and 12.

Since the issuance of ANSI/ANS-58.2-1980, the leak-before-break (LBB) approach has been accepted as an alternative to the practice of providing protection against postulated pipe ruptures of arbitrary size. The LBB approach is a mechanistic fracture mechanics method of determining pipe rupture behavior that may be used to either eliminate or reduce the effects that need to be considered at a postulated rupture location.* Currently regulatory authorities have limited the application of the LBB approach to only excluding consideration of dynamic effects associated with pipe ruptures (e.g., pipe whip, missile generation, jet impingement loads, etc.). Recognizing that the technical basis for the LBB approach is sound and its application will probably be extended sometime in the future, this standard presents a consistent technical application of the approach. Where this standard may not agree with current regulatory practice, it is so indicated.

There are four areas where the position provided in this standard is less restrictive than the corresponding current NRC position. First, the NRC requires application of the LBB approach to all points in a given run of pipe including the end points at each anchor. This standard allows application of the LBB approach to any point in a given run of pipe where the rupture locations have been postulated in accordance with the rupture locations criteria of Section 4. Second, at locations where leakage cracks based on the LBB approach have been postulated instead of full-sized circumferential or longitudinal breaks or instead of arbitrarily sized through wall cracks, the NRC currently requires that the evaluation of environmental and flooding effects be based on the

*Information regarding the development of the LBB approach is provided in NUREG-1061, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee, Volumes 3 and 5, *Evaluation of Potential for Pipe Breaks, and Summary.*"

flow rate from the circumferential break, longitudinal break or through-wall crack being replaced, instead of the flow rate from the leakage crack. Third, the NRC position on the fatigue usage factor basis for postulating break locations is more conservative than this standard (0.1 compared to 0.4). Although the 0.1 fatigue usage factor is considered to be conservative, recent studies have led to a concern relating to the degree of conservatism in the design fatigue curves in the ASME Code that provides the basis of this fatigue usage factor. These curves were developed based on highly polished specimen fatigue tests in air and are shown to be less conservative than when Code allowable fabrication flaws and high temperature water environment are taken into consideration. For the present, the NRC has chosen to retain the fatigue usage factor of 0.1 to bound these concerns. The fourth area pertains to the criteria for postulating intermediate breaks in Class 1 piping not in the containment penetration area. This standard utilizes a higher stress threshold than does the NRC.

Consistent with past practice, this standard does not address event combinations. Specifically, this standard does not provide guidance on the combination of pipe rupture with other events such as water hammer, seismic activity, airplane crashes or acts of sabotage.

Working group ANS-58.2 of the Standards Committee of the American Nuclear Society, had the following membership at the time it developed this standard:

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W. D. Maxham, *Babcock & Wilcox Company*
J. H. Gray, *Sargent and Lundy*
A. Singh, *Electric Power Research Institute*

The members of working group ANS-58.2 wish to express their appreciation to J. M. Healzer from S. Levy, Incorporated for his valuable contribution in reviewing and updating the jet geometry models and evaluation methods described in Appendices C and D, respectively.

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Design Basis for Protection of Light Water Nuclear Power Plants Against Effects of Postulated Pipe Rupture

1. Introduction

The purpose of this standard is to provide the design basis for the protection of light water reactor nuclear power plants from the following potentially adverse effects of a postulated pipe rupture: pipe whip, pipe internal loads, jet impingement, compartment pressurization, environmental conditions and flooding.¹ Specific guidance for the evaluation of internal fluid system loads other than pipe internal loads, missile generation, emergency core cooling system flow requirements, and containment pressurization is not provided in this standard. Guidance on the design basis for containment pressurization is provided in American National Standard for Subcompartment Pressure and Temperature Transient Analysis in Light Water Reactors, ANSI/ANS-56.10-1987 [1].² This standard presents methods for complying with General Design Criterion 4, "Environmental and Missile Design Basis," of Appendix A to Title 10, Code of Federal Regulations, Part 50, "Licensing of Production and Utilization Facilities" [2] and with Title 10, Code of Federal Regulations, Part 100, "Reactor Site Criteria" [3].

Although pipe ruptures could result from random events induced by unanticipated conditions, for any particular piping failure mechanism the actual location of the failure is assumed to be governed by the local conditions of stress and fatigue. Therefore, the point on a given piping run where a rupture would most likely occur would be associated with those points of high relative stress or high relative fatigue usage. These points of high relative stress and high relative fatigue usage can be predicted from anticipated conditions and design loadings. The design rules of this standard are intended to provide protection by postulating

pipe ruptures at those locations with the greatest potential for failure under loading conditions associated with specified seismic events and operational plant conditions.

Section 3, Definitions, defines the terms used in this standard. Locations and characteristics of postulated ruptures to be considered are specified in Section 4, Postulated Rupture Locations and Configurations, and requirements for demonstrating adequate protection are specified in Section 5, Protection Requirements.

Section 6, Evaluation of Pipe Whip and Pipe Internal Load Effects; Section 7, Evaluation of Jet Impingement Effects; Section 8, Evaluation of Compartment Pressurization Effects; Section 9, Evaluation of Environmental Effects; and Section 10, Evaluation of Flooding Effects specify the bases and assumptions to be used for determining the potential damage from the effects of pipe whip and pipe internal loads, jet impingement, pressurization of compartments, environmental conditions, and flooding, respectively. A recommended procedure for assessing the potential damage to required systems and components is provided in Section 11, Procedure for Assessing the Potential Damage to Required Systems and Components.

Section 12, Leak-Before-Break Approach, specifies the criteria for the leak-before-break (LBB) approach that may be used to eliminate or reduce the effects that need to be considered at a postulated rupture location.

2. Scope

This standard addresses the design basis for the protection of light water reactor nuclear power plants from the potentially adverse effects of postulated pipe ruptures.

3. Definitions

This section defines terms applicable to this standard.

¹Guidance on the design basis for missile protection exists in draft form as proposed American National Standard for Plant Design Against Missiles, ANS-58.1; assigned correspondent: W. H. D'Ardenne, General Electric Company, 175 Curtner Ave., San Jose, Calif. 95125.

²Numbers in brackets refer to corresponding numbers in Section 13, References.

active failure. A malfunction, excluding passive failures, of a component to complete its intended nuclear safety function on demand.

Examples of active failures include the failure of a valve or check valve to move to its correct position, or the failure of a pump, fan or diesel generator to start.

Spurious action of a powered component originating within its actuation or control system shall be regarded as an active failure unless specific design features or operating restrictions preclude such spurious action. An example is the unintended energization of a powered valve to open or close.

branch run. A piping run that originates as a branch of the main run and ends at a terminal end, another main run, another branch run or is free-ended, with the exception of the following:

(a) free-ended branches of the main run throughout which there is no significant restraint to thermal expansion may be considered part of the main run.

(b) branch lines which are included with the main run piping in the stress analysis computer mathematical model may be considered part of the main run, and the connection of the branch run to the main run may be treated as an intermediate location, provided that:

(1) the levels of stress and fatigue in the branch runs and their connections to the main run are accurately determined relative to those in the main run, including consideration of possible dissimilar metal connections between branch runs and the main run, and

(2) the loadings on the branch runs as well as the main run are accurately applied in the computer analysis, including all conditions for which either Level A or Level B service limits have been specified for the branch run system, such as rapid valve operation, and

(3) the branch lines are shown to have a significant effect on the main run behavior (such as when the branch run and main run piping sizes are similar).

Branch run connections to the main loops of PWR plants, or to the recirculation loops of BWR plants, shall be treated as terminal ends, unless otherwise justified.

compartment. A cavity, subcompartment or

compartment.

component enclosure. A structure enclosing required systems and components designed in such a manner that the effects of a rupture in piping outside the enclosure are prevented from affecting the nuclear safety function of the required systems and components inside.

high energy piping system. Any system, or portion of a system, where the maximum operating pressure exceeds 275 psig, or the maximum operating temperature exceeds 200 °F, during normal plant operating conditions. Piping systems that operate above these limits for only a relatively short portion (less than approximately two percent) of the time during which they perform their intended function, may be classified as moderate energy. An example of such a system could be the residual heat removal system in some plant designs.

hot standby. The plant condition during which no electric power is being generated and the plant can be returned to power operation in a minimal amount of time.

loss-of-coolant accident (LOCA). The loss of reactor coolant at a rate in excess of the reactor coolant normal makeup rate, from breaks or openings in the reactor coolant pressure boundary inside primary containment up to, and including, a break equivalent in size to the largest justified pipe rupture (or in the absence of justification, a double-ended rupture of the largest pipe) in the reactor coolant pressure boundary.

main run. A piping run that interconnects terminal ends.

moderate energy piping system. Any system, or portion of a system, where the maximum operating pressure is 275 psig or less and the maximum operating temperature is 200 °F or less during normal plant operating conditions. All piping systems pressurized above atmospheric conditions and not classified as high energy shall be classified as moderate energy piping systems.

normal plant conditions. Plant operating conditions (excluding testing) in the course of system startup, operation in the design power range, hot standby, and system shutdown.

nuclear safety function. Any function that is necessary to ensure: (a) the integrity of the reactor coolant pressure boundary, (b) the capability to shut down the reactor and maintain it in a safe shutdown condition, or (c) the capability to prevent or mitigate the consequences of plant conditions that could result in potential offsite exposures that are comparable to the guideline exposures of the Code of Federal Regulations, Title 10, "Energy," Part 100, "Reactor Site Criteria" [3].

nuclear safety-related. Of significance or importance because it applies to: (a) structures, systems, or components designed to perform a nuclear safety function, (b) drawings, specifications or procedures, analyses, and other documents used to determine or describe parameters affecting structures, systems, or components that are designed to perform a nuclear safety function, or (c) services to design, purchase, fabricate, handle, ship, store, clean, erect, install, test, operate, maintain, repair, refuel, and modify structures, systems, or components that are designed to perform a nuclear safety function.

operating basis earthquake (OBE). The earthquake that, considering the regional and local geology and seismology, and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant. It is that earthquake which produces the vibratory ground motion for which those nuclear safety-related features of the plant necessary for subsequent operation without undue risk to the health and safety of the public are designed to remain functional.

passive failure. The blockage of a process flow path or failure of a component to maintain its structural integrity or stability, such that it cannot provide its intended nuclear safety function upon demand.

piping run. A section of piping with at least one terminal end or originates as a branch of another section of piping.

pipe whip. Rapid motion of a pipe resulting from a postulated pipe break.

pipe whip restraint. A device, including its anchorage, used to control pipe whip.

piping enclosure. A structure (such as pipe chase, compartment or building) enclosing piping and designed in such a manner that the effects of a rupture in the piping, at a location within the enclosure or at a location upstream or downstream of the boundary of the enclosure (such as with a pipe chase between buildings), are contained by the structure, and thus are prevented from affecting the nuclear safety function of adjoining or proximate required systems and components.

piping network. An interconnected system of main or branch runs, or both, utilized in the analytical model.

postulated pipe break. A postulated circumferential or longitudinal break (see 4.2).

postulated pipe rupture. A postulated circumferential break, longitudinal break, through-wall crack, or leakage crack (see 4.2).

primary containment. The principal structure of a unit that acts as the barrier, after the fuel cladding and reactor coolant pressure boundary, to control the release of radioactive material. It includes: (1) the containment structure and its access openings, penetrations, and appurtenances; (2) those valves, pipes, closed systems, and other components used to effect isolation of the containment atmosphere from the environment; and (3) those systems or portions of systems that, by their system functions, extend the containment structure boundary (e.g., the connecting steam and feedwater piping) and provide effective isolation.

reactor coolant normal makeup. Makeup to the reactor coolant pressure boundary by the system(s) relied upon to maintain reactor coolant inventory during normal operation.

reactor coolant pressure boundary. All those pressure-containing components, such as pressure vessels, piping, pumps, and valves that are: (a) part of the reactor coolant system, or (b) connected to the reactor coolant system up to and including any or all of the following: (1) the outermost primary containment isolation valve in system piping that penetrates the primary containment, (2) the second of two valves normally closed during normal reactor operation in system piping that does not penetrate primary containment, or (3) the reactor coolant system safety and relief valves.

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

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

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

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

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

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

shall, should, or may. The word "shall" is used to denote a requirement; the word "should" is

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

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

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

4. Postulated Rupture Locations and Configurations

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

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

vironmental conditions and flooding, in accordance with Sections 8, 9 and 10. For each postulated through-wall crack, an evaluation shall be made of the effects of environmental conditions and flooding, in accordance with Sections 9 and 10. The evaluation of the required systems and components shall demonstrate that the protection requirements of Section 5 are met. A recommended procedure for performing this evaluation is given in Section 11.

4.2 Postulated Rupture Descriptions

4.2.1 Circumferential Break. A circumferential break shall be assumed to result in pipe severance with full separation of the two severed pipe ends unless the extent of separation is limited (see 6.2.4). The break plane area (A_e) shall be assumed perpendicular to the longitudinal axis of the pipe, and to be the cross-sectional flow area of the pipe at the break location. The break flow area (A_f) for a circumferential break with full separation of the two broken pipe segments shall be equal to the break plane area (A_e). The break flow area (A_f) for a circumferential break with partial separation is described in 6.2.3, 6.2.4 and 7.2(b). The break flow area, discharge coefficient and discharge correlation associated with partial separation breaks shall be substantiated analytically or experimentally. The discharge coefficient associated with full separation breaks shall be assumed to be 1.0 unless otherwise substantiated.

4.2.2 Longitudinal Break. A longitudinal break shall be assumed to result in a split of the pipe wall along the pipe longitudinal axis, but without severance. The break plane area (A_e) shall be assumed parallel to the longitudinal axis of the pipe, and equal to the cross-sectional flow area of the pipe at the break location. The break flow area (A_f) shall be equal to the break plane area (A_e). The break shall be assumed to be circular in shape or elliptical ($2D \times D/2$) with its long axis parallel to the pipe axis, and have a discharge coefficient of 1.0. Any other values used for the area, shape or discharge coefficient associated with a longitudinal break, shall be substantiated by analysis or test data.

4.2.3 Leakage Crack. A leakage crack shall be assumed to be a crack through the pipe wall where the size of the crack and corresponding flow rate are determined by analysis and a leak detection system, etc., as described in 12.3.2(b).

4.2.4 Through-Wall Crack. A through-wall crack shall be assumed to be a circular orifice

through the pipe wall of cross-sectional flow area equal to the product of one-half the pipe inside diameter and one-half the pipe wall thickness. A discharge coefficient of 1.0 shall be used.

4.3 Postulated Rupture Locations

4.3.1 Class 1 Piping. Ruptures, as specified in 4.3.4 and 4.3.5, shall be postulated to occur at the following locations in each piping network designed in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III [5] for Class 1 piping:

- (a) the terminal ends of the pressurized portions of the network, and
- (b) either
 1. intermediate locations of potential high stress or fatigue such as pipe fittings, valves, flanges and welded-on attachments, or
 2. intermediate locations where either U exceeds 0.4^4 or S , from both equation (10) and either equation (12) or (13),⁵ exceeds $2.4S_m$.

where, as defined in Subarticle NB-3600,

- S = primary-plus-secondary stress-intensity range under the combination of loadings for which either Level A or Level B service limits have been specified, as calculated from equation (10), (12) and (13).
- S_m = allowable stress-intensity value.
- U = the cumulative usage factor.

4.3.2 Class 2, Class 3 or Seismically Analyzed ANSI B31.1 Piping. Ruptures as specified in 4.3.4 and 4.3.5 shall be postulated to occur at the following locations in each piping network designed in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III [5] for Class 2 and Class 3 piping, or with the rules of the ASME Code for Pressure Piping, B31, "Power Piping," ANSI/ASME B31.1-1986 [4] for seismically analyzed ANSI B31.1 piping:

- (a) the terminal ends of the pressurized portion of the network, and
- (b) either
 1. intermediate locations of potential high stress or fatigue such as pipe fittings, valves, flanges and welded-on attachments, or

⁴Regulatory authorities may require consideration of a value of U less than 0.4.

⁵Regulatory authorities may require application of only equation (10) which may lead to a lower stress threshold.

2. (i) for Class 2 or Class 3 piping, at intermediate locations where the stress, S , exceeds $0.8(X + Y)$,

where, as defined in Subarticle NC-3600,

S = stresses under the combination of loadings for which either Level A or Level B service limits have been specified, as calculated from the sum of equations (9) and (10).

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

Y = equation (10) allowable stress.

(ii) for seismically analyzed ANSI B31.1 piping, at intermediate locations where the stress, S , exceeds $0.8(X + Y)$

where, as defined in Section 104.8,

S = stresses under the combination of loadings associated with thermal expansion, sustained and occasional loads (including OBE), as calculated from the sum of equations (12) and (13).

X = equation (12) allowable stress.

Y = equation (13) allowable stress.

4.3.3 Non-Seismically Analyzed ANSI B31.1 Piping. Ruptures, as specified in 4.3.4 and 4.3.5, shall be postulated to occur at the following locations in each ASME Code for Pressure Piping, B31, "Power Piping," ANSI/ASME B31.1-1986 [4] piping network that is not seismically analyzed.

(a) at terminal ends of the pressurized portions of the network, and

(b) at each intermediate location of potential high stress or fatigue, such as pipe fittings, valves, flanges and welded-on attachments.

4.3.4 Break Locations. Both circumferential and longitudinal breaks shall be postulated to occur, but not concurrently, in all high energy piping systems at the locations specified in 4.3.1, 4.3.2 or 4.3.3, except as follows:

(a) Circumferential breaks need not be postulated in piping runs of a nominal diameter equal to or less than one inch.

(b) Longitudinal breaks need not be postulated in piping runs of a nominal diameter less than four inches.

(c) Longitudinal breaks need not be postulated at terminal ends.

(d) Only one type of break need be postulated at locations where, from a detailed stress analysis, such as a 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 associated with Level A and Level B service limits, then only a circumferential break need be 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 need be postulated.

(e) Circumferential and longitudinal breaks need not be postulated at locations where the requirements of 4.3.6 are satisfied.

(f) Circumferential and longitudinal breaks need not be postulated at locations where the criteria in 4.3.5(b) is used.

4.3.5 Crack Locations

(a) **Through-Wall Cracks.** Through-wall cracks shall be postulated in all high energy and moderate energy piping systems having a nominal diameter greater than one inch at the locations specified in 4.3.1, 4.3.2 or 4.3.3, except that through-wall cracks need not be postulated at locations where:

1. For Class 1 piping, the calculated value of S as defined in 4.3.1 is less than one-half the limits of 4.3.1(b) Item 2.

2. For Class 2, Class 3 or seismically analyzed ANSI B31.1 piping, the calculated value of S as defined in 4.3.2 is less than one-half the limits of 4.3.2(b) Item 2.

3. The requirements of 4.3.6 are satisfied.

4. The criteria in (b) below, is used.

b. **Leakage Cracks.** A leakage crack may be postulated in place of a circumferential break, longitudinal break, or through-wall crack if justified by an analysis performed in accordance with the requirements of Section 12.

4.3.6 Piping Near Containment Isolation Valves. Ruptures need not be 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 Boiler and Pressure Vessel Code, Section III [5], and which meets the following additional requirements:

(a) The limits for postulating intermediate rupture locations, as specified in 4.3.1(b) Item 2

for Class 1 piping and 4.3.2(b) Item 2 for Class 2 and 3 piping, shall not be 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 shall be maintained within Level C Service Limits as specified in the ASME Boiler and Pressure Vessel Code, Section III [5].

(c) The design and inservice inspection requirements, as specified in 5.2 and 5.3, shall be met.

(d) The containment isolation valves shall be 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.

4.4 Postulated Rupture Configurations

4.4.1 Break Configurations. Where the postulated break location is at a tee, elbow or the following pipe locations, the configurations and types of breaks shall be determined as follows:

(a) Without the benefit of a detailed stress analysis, the following shall be assumed:

1. Circumferential breaks shall be postulated to occur individually at each tee or elbow pipe-to-fitting weld where the criteria in 4.3 is 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 shall be postulated at the branch run-to-main run weld, or the branch run-to-fitting weld, and the break plane area (A_b) shall be assumed to be the cross-sectional flow area of the branch.

3. At a welded attachment (lug, stanchion, etc.) a longitudinal break shall be 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 shall be postulated at each pipe-to-fitting weld where the criteria in 4.3 is exceeded. Longitudinal breaks shall be oriented to produce out-of-plane bending of the piping configuration.

(b) Alternatively, if a detailed stress analysis or test is performed, the results may be used to predict the most probable rupture location(s) and

type of break.

4.4.2 Crack Configurations. At a postulated leakage crack or through-wall crack location, the orifice shall be assumed to be located, noncurrently, at each and every point about the circumference of the pipe, unless otherwise substantiated.

5. Protection Requirements

5.1 General Requirements. Protection shall be provided for required systems and components to ensure that their nuclear safety function can be accomplished following a postulated rupture of plant system piping. General design guidelines are given in more detail in American National Standard Physical Protection for Systems and Components Important to Safety, ANSI/ANS-58.3-1988 [6]. In general, this protection should be provided by one or more of the following methods, listed in order of their preference:

(a) Separation and remote location of piping from required systems and components. Separation is achieved by plant physical layouts that provide sufficient distances between required systems and components and piping such that the effects of the postulated pipe ruptures cannot affect safe shutdown (see 11.2.3).

(b) Provision of piping enclosures.

(c) Provision of component enclosures.

(d) Provision of system redundant design features (such as isolation valves).

(e) Design of required systems and components to withstand the effects of the postulated pipe rupture.

(f) Provision of additional protection such as restraints and barriers.

5.2 Design Requirements. The following design requirements shall be met:

(a) Required structures and components shall be designed to Seismic Category I requirements.

(b) Piping and component enclosures, protective structural barriers, and structures supporting pipe whip restraints utilized to implement 5.1 shall be designed to the Seismic Category I requirements.

(c) Protective features such as pipe whip restraints shall be designed such that a postulated break in one pipe cannot in turn lead to a rupture of other nearby piping if the secondary rupture could effect safe shutdown.

(d) Pipe whip shall be considered capable of causing circumferential and longitudinal breaks, individually, in impacted pipes of smaller nomi-

nal pipe size, irrespective of pipe wall thickness, and developing through-wall cracks in equal or larger nominal pipe sizes with equal or thinner wall thickness. Analytical or experimental⁶ data, or both, for the expected range of impact energies may be used to demonstrate the capability to withstand the impact without rupture; however, loss of function due to reduced flow in the impacted pipe should be considered.

(e) The following requirements shall be met for piping between the containment wall and the inboard and outboard isolation valves (see 4.3.6):

1. The length of these portions of piping shall be kept to the minimum length practicable.

2. Welded attachments, such as for the design of pipe anchors and restraints, which require welding directly to the outer surface of this portion of the process piping (e.g. flued integrally forged pipe fittings do not require such welding) shall be avoided. Where welded attachments are necessary to be used for other design reasons, such welds shall allow 100 percent volumetric examination in service, and a detailed stress analysis shall be performed to demonstrate compliance with stress limits.

3. The portion of piping that passes through the shield building annulus of dual barrier containments shall be provided with an enclosing protective structure (guard pipe) if a postulated rupture (defined in accordance with 4.3.4) in this portion of piping could either affect the pressure integrity of the containment structure, or result in pressurization of the shield building annulus beyond its design limits.⁷

4. Such guard pipes shall be constructed in accordance with the rules of Class MC, Subsection NE of the ASME Boiler and Pressure Vessel Code, Section III [5] where the guard pipe is part of the containment boundary. In addition, the entire guard pipe assembly shall be designed to meet the following requirements and tests:

(i) design pressure and temperature shall not be less than the maximum operating pressure and temperature of the enclosed process pipe under normal plant conditions,

(ii) the Level C service limits of ASME Boiler and Pressure Vessel Code, Section III [5], Par-

agraph NE-3221(c) shall not be exceeded under the loadings associated with containment design pressure and temperature in combination with the SSE,

(iii) guard pipe assemblies shall be subjected to a single pressure test at a pressure not less than the containment test pressure.

5. The number of circumferential and longitudinal piping welds and branch connections shall be minimized. Where guard pipes are used, the enclosed portion of the system piping should be of seamless construction.

(f) The effects of a postulated pipe rupture, including environmental conditions resulting from the escape of contained fluids, shall not preclude habitability of the control room nor access to surrounding areas important to the safe control of reactor operations or needed to cope with the consequences of the pipe rupture.

(g) Effects resulting from ruptures not constituting a LOCA shall be prevented from initiating a LOCA.

(h) For any postulated pipe rupture the structural integrity of the containment vessel shall be maintained. In addition, for those postulated ruptures classified as a LOCA, the design leak tightness of the containment shall be maintained. If practical, these two objectives should be accomplished by preventing whipping pipes from striking the containment.

(i) In the event of a postulated rupture in the piping in one unit of a multiple unit plant, safe reactor shutdown of the affected unit shall not preclude the capability for safe shutdown of the reactor of the unaffected unit(s).

5.3 Inservice Inspection Requirements. Inservice examination and related design provisions shall be in accordance with the following:

(a) Protective measures utilized to meet the requirements of 5.1 shall not prevent the access required to conduct the inservice examinations specified in the ASME Boiler and Pressure Vessel Code, Section XI [7]. For those portions of fluid systems piping enclosed in guard pipes, inspection ports shall be provided in the guard pipes to permit the required examination of circumferential welds in the process pipe. Inspection ports shall not be located in that portion of the guard pipe passing through a shield building annulus.

(b) When ruptures are not postulated in the piping between the containment wall and the inboard or outboard isolation valves (based on the provi-

⁶For guidance, see ALZHEIMER, J. M., et al, "Pipe-to-Pipe Impact Program," NUREG/CR-3231, Battelle Northwest Laboratory (1987).

⁷The above criteria is applicable even if pipe ruptures are not postulated in the shield building annulus.

sions of 4.3.6), the extent of inservice examinations completed during each inspection interval (per IWA-2400, "Inspection Intervals," ASME Boiler and Pressure Vessel Code, Section XI [7], shall provide 100 percent volumetric examination of all circumferential and longitudinal pipe welds within the boundary of these portions of piping. Exemptions allowed under ASME Boiler and Pressure Vessel Code, Section XI [7] apply if appropriately justified.

(c) The areas subject to examination shall be defined in accordance with ASME Boiler and Pressure Vessel Code, Section XI [7].

5.4 Operability of Systems and Components.

Evaluation of the effects of postulated pipe ruptures requires a detailed system analysis. Required systems and components that could be affected by a pipe rupture shall be evaluated from an operability perspective. Some of the considerations with regard to the operability of systems and components are as follows:

(a) Consideration shall be given to the potential for a random single active failure as required by American National Standard Single Failure Criteria for Light Water Reactor Safety-Related Fluid Systems, ANSI/ANS-58.9-1987 [8], except as noted in 5.4(b) and, when appropriate, the loss of offsite power concurrent with the postulated pipe rupture.

(b) Where the postulated pipe rupture is assumed to occur in one of two or more redundant trains of a dual-purpose moderate-energy required system (i.e., one required to operate during normal plant conditions as well as to shut down the reactor and mitigate the consequences of the pipe rupture), single failures of active components in the other train or trains of that system need not be assumed, provided the system is designed to Seismic Category I requirements, powered from both offsite and onsite sources, and is constructed, operated and inspected to quality assurance, testing and inservice inspection standards appropriate for nuclear safety systems. Examples of systems that may qualify as dual-purpose required systems are service water systems, component cooling systems and residual heat removal systems.

(c) All available Seismic Category I systems and other systems which are analyzed to the requirements of Seismic Category I systems, including those actuated by operator actions, may be employed to mitigate the consequences of a postulated pipe rupture. In judging the availability of systems, account shall be taken of the postulated

rupture and of the assumed single active component failure. The feasibility of carrying out operator actions shall be judged on the basis of ample time and adequate access to equipment being available for the proposed actions in accordance with American National Standard Time Response Design Criteria for Nuclear Safety-Related Operator Actions, ANSI/ANS-58.8-1984 [9].

6. Evaluation of Pipe Whip and Pipe Internal Load Effects

6.1 General Requirements. The release of fluid from a circumferential or longitudinal break in high energy piping could result in significant changes in flow characteristics within the piping system, creating reaction forces which could dynamically excite the piping. If these forces are sufficient to cause pipe whip, nearby required systems and components must be protected or designed to withstand the results of the pipe impact. In addition, required components, if any, within or bounding the broken piping fluid system, must be designed to withstand the pipe break loads. Therefore, as specified in 4.1, an evaluation shall be made of potential pipe whip and pipe internal loads from postulated break locations to ensure protection requirements are met. A ruptured pipe which creates unacceptable effects due to pipe motion shall be provided with pipe whip restraints or barriers or some other method of protection to prevent unacceptable damage, or separated from the required system or component affected in accordance with 5.1.

The fluid forces shall be determined in accordance with 6.2, and the resulting pipe motion, pipe whip restraint loads and associated structural loads shall be established using the criteria in 6.3 through 6.6.

6.2 Fluid Forces. The fluid forces acting on the ruptured pipe are a function of time and space, and depend upon the fluid state within the pipe prior to rupture, the break flow area, frictional losses, plant system characteristics, piping system geometric design, and other factors. Provided in this subsection are requirements necessary for proper consideration of these factors.

6.2.1 Force Calculations Methods. The generalized equation which describes the fluid forces acting on a ruptured pipe is:

$$\begin{aligned} \bar{T} = & - \left[\int_{c.v.} \frac{d}{dt} (\bar{\rho} \bar{u}) dV + \int_{c.s.} \bar{\rho} \bar{u} (\bar{u} \cdot d\bar{A}) \right. \\ & \left. + \int_{A_m} P d\bar{A}_{in} + \int_{A_{out}} P d\bar{A}_{out} - \int_{A_{pipe}} P_a d\bar{A}_{pipe} \right] \quad (\text{Eq. 6-1})^8 \end{aligned}$$

where:

- $\bar{T}$ = dynamic fluid thrust force vector on pipe
- c.v. = control volume
- c.s. = control surface
- V = volume
- $\bar{A}$ = surface area
- ρ = mass density
- u = fluid velocity vector
- P = local pressure at center of elemental area (dA or dS)
- $\bar{A}_{in}$ = area of flow into control volume
- $\bar{A}_{out}$ = area of flow out of control volume
- P_a = ambient pressure around pipe
- A_{pipe} = Pipe external surface area

For longitudinal breaks or circumferential breaks of branch lines at branch connections, both of which are represented in Figure 6-1(B), or a circumferential break in constant area pipe just downstream of a 90 elbow, such as shown in Figure 6-1(A), the generalized equation may be simplified to the following:

$$T_x = - \int_{c.v.} \frac{d}{dt} (\rho u_x) dV - \rho u_e^2 A_e - P_e A_e + P_a A_e \quad (\text{Eq. 6-2})^9$$

where

- T_x = dynamic fluid thrust force acting on pipe in the x direction
- u_x = control volume fluid velocity in the x direction
- u_e = fluid velocity at break plane area
- P_e = fluid pressure at break plane area
- A_e = control volume area at plane of break or break plane area

⁸The derivation of equation (6-1) is given in Appendix A.

⁹The derivation of equation (6-2) is given in Appendix A.

Note: For circumferential and longitudinal breaks, A_e is the cross-sectional flow area of the pipe at the postulated break location (see 4.2.1 and 4.2.2).

The first term of equation (6-2) is the acceleration term. For steady state flow conditions, the acceleration term is zero and the remaining three terms define the steady state fluid force.

In order to solve for the reaction thrust force, the various fluid transient characteristics in the piping system must first be established. Computer programs have been developed to predict the transient thermodynamic state properties of the fluid in a piping system following pipe rupture. In these programs the piping system is modeled, the initial thermodynamic state properties of the fluid are defined, and the break area characteristics input. These programs then calculate one or more of the following balances as a function of time: flow, mass, energy and momentum. The reaction forces can be established as a function of time based on the fluid transient parameters calculated and applications of equations (6-1) or (6-2). Simplified methods may also be used for determining fluid forces where demonstrated to be conservative.¹⁰ Requirements for the establishment of the fluid transient parameters are given in 6.2.2 through 6.2.5 and in 4.2.

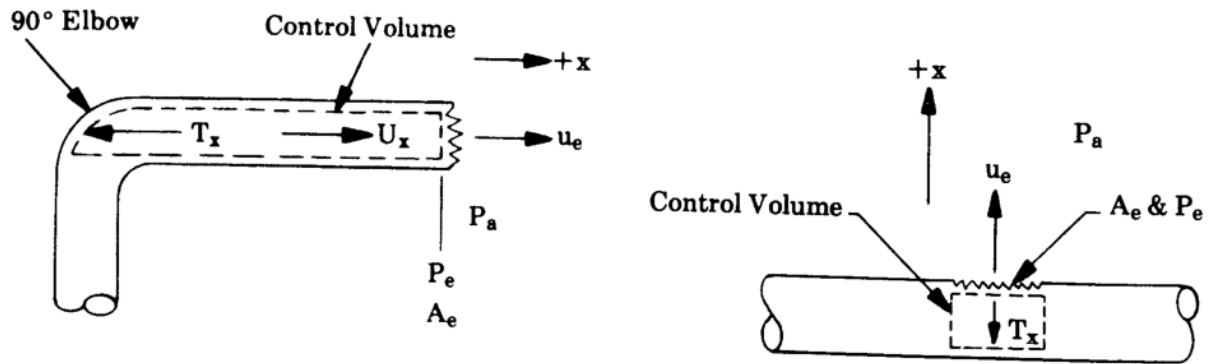
6.2.2 Operating Conditions. For the purpose of design, ruptures shall be postulated to occur only during normal plant conditions, and the following assumptions shall be used to determine the thermodynamic state in the pipe and the attached reservoirs (vessels, heat exchangers, pressurizers, etc.) for the calculation of the fluid reaction forces:

(a) For those portions of piping systems which are normally pressurized during operation, the thermodynamic state in the pipe and the associated reservoirs shall be that corresponding to 100 percent power.

(b) For those portions of high energy piping systems which are normally pressurized only during plant conditions other than 100 percent power, the thermodynamic state and associated operating conditions shall be determined using the most severe mode.

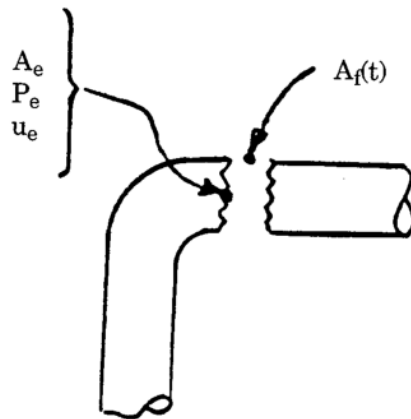
6.2.3 Break Opening Time. For the purpose of analysis, circumferential and longitudinal break

¹⁰One acceptable simplified method is given in Appendix B.



(A) Circumferential Break—
Full Separation

(B) Longitudinal Break



(C) Circumferential Break—
Limited Separation

Fig. 6.1 Control Volume Models

plane areas (A_e) shall be assumed to develop within one millisecond after break initiation, unless otherwise analytically or experimentally substantiated. When circumferential breaks are postulated, it may be assumed that it takes up to ten milliseconds for the broken pipe segments to move sufficiently to achieve a break flow area (A_f) equal to the sum of the upstream and downstream break plane areas ($2A_e$). Partial area breaks (See 6.2.4) should be assumed to take proportionately less time to achieve maximum break flow area. Longer separation times shall be justified.

6.2.4 Pipe Geometry Effects. In calculating forces acting on the piping system, credit may be taken for flow resistance losses between the break and the pressure reservoir(s). Typical components which may be considered are: orifices, nozzles, valves, reduced cross-sections, spargers, elbows, bends and straight pipe. Credit may also be taken for the limited amount of energy in closed ended piping runs (dead end or normally closed valves).

If the pipe is restrained by structural design features (walls, pipe whip restraints, etc.) which limit the break flow area (A_f), following separation, the fluid forces acting on the ruptured pipe shall be determined from a thermal hydraulic analysis based on the limited fluid break flow area, unless otherwise substantiated. In the case of limited separation as shown in Figure 6-1(C), u_e , P_e , and consequently the force on the broken pipe segment, depend on A_f which is time-dependent. A_e , however, is constant.

6.2.5 Critical Flow Models. The critical flow model used to establish the maximum flow through breaks and restricted regions of the piping will directly affect the calculated reaction force. For flashing or steam water mixtures with qualities greater than zero percent at stagnation conditions at the discharge plane, Moody's critical flow model¹¹ or the homogeneous equilibrium model¹² is acceptable. For the subcooled region, the Henry-

Fauske model¹³ is acceptable. Other critical flow models^{14, 15, 16, 17} may be used if they can be justified through experimental data or analysis.

6.3 Piping Response. An analysis shall be conducted of the postulated ruptured piping and pipe whip restraint system response to the fluid dynamic forces specified in 6.2 to evaluate the potential for pipe whip and to establish the pipe whip restraint and associated structural loads.

Two design considerations shall be evaluated: the dynamic event starting at the break initiation, and the steady state condition after pipe motion ceases. Upon occurrence of a pipe break, the system consisting of piping, pipe whip restraints and supporting structures will respond dynamically to the applied fluid dynamic forces. The piping will acquire kinetic energy as it moves toward an impact with restraints or nearby structures or components. The distance across which the pipe moves (i.e. gap between pipe and restraint) shall be taken to be the maximum dimension, from the surface of the restraint to the outer surface of the pipe, which can occur at the operating condition at which the pipe rupture is postulated to occur per 6.2.2. Additional kinetic energy will be acquired during restraint and piping deformations following the impact. The evaluation shall demonstrate that the total energy acquired would be dissipated in the piping, restraints and supporting structure.

The evaluation shall also demonstrate that following the dynamic event (when motion ceases), the system would be capable of supporting fluid forces at steady state flow conditions. In some cases the steady state fluid forces can be higher than fluid forces present during the dynamic event. In some systems the initial fluid enthalpy level in the pipe

¹¹MOODY, F. J., "Maximum Flow Rate of a Single Component Two-Phase Mixture," *Journal of Heat Transfer*, American Society of Mechanical Engineers, Series C, Vol. 87 (1965).

¹²HALL, D. G., "An Inventory of Two-Phase Critical Flow Experimental Data Base," EGG-CAAP-5140, Idaho National Engineering Laboratory (1980).

¹³HENRY, R. E. and FAUSKE, H. K., "The Two-Phase Critical Flow of One-Component Mixtures in Nozzles and Short Tubes," *Journal of Heat Transfer*, American Society of Mechanical Engineers Trans. (1971).

¹⁴HENRY, R. E., "An Experimental Study of Low-Quality Steam-Water Critical Flow at Moderate Pressures," ANL-7740, Argonne National Laboratory (1970).

¹⁵FAUSKE, H. K., "The Discharge of Saturated Water through Tubes," American Institute of Chemical Engineers Engineering Program Symposium Series, Vol. 61, No. 59, pp. 210-216.

¹⁶FAUSKE, H. K., "Contribution to the Theory of Two-Phase, One Component Critical Flow," ANL-6633, pp. 75, 150-153, Argonne National Laboratory (1962).

¹⁷HENRY, R. E., "The Two-Phase Critical Discharge of Initially Saturated or Sub-cooled Liquid," *Nuclear Science & Engineering*, Vol. 41 (1970), pp. 337, American Nuclear Society, La Grange Park, Illinois.

is different than in the attached vessel. An example would be a loop containing subcooled water attached to a vessel in which the water is saturated. In any case, the evaluation shall demonstrate that the system satisfies the requirements of static equilibrium.

The interaction effects of both the piping and pipe whip restraints shall be included in the piping response analysis. If the mass of the pipe whip restraint system is significant with respect to the piping system, its dynamic response shall also be considered in the pipe whip analysis. The following methods constitute acceptable alternative analytical approaches for the piping response evaluation.

6.3.1 Complete System Dynamic Analysis.

The piping and pipe whip restraint system shall be modeled in sufficient detail to reflect its dynamic characteristics. Either the lumped-mass or continuous mass approach may be employed. Inertia and stiffness effects of the system and gaps between piping and the restraints shall be included. The pipe rupture time history forcing function(s) shall be applied and time history responses of pipe whip restraint loads and pipe deformations computed by numerical integration. This approach requires the use of digital or analog computer programs.^{18, 19}

6.3.2 Simplified Dynamic Analysis.

A dynamic analysis of a portion of a piping system may be performed instead of an analysis of the complete system. Consideration shall be given to dynamic coupling and forcing functions acting on the portion of the system to be analyzed in the representation of the flexibility and inertial effects of the remainder of the system.

6.3.3 Quasi-Dynamic Analysis.

Dynamic time history analyses may be performed on representative systems to develop design data in the form of curves and graphs to be used for pipe whip restraint location and design. The study shall be parametric in nature considering dynamic coupling, system forcing functions, the effects of gaps, support flexibilities, the pipe size and schedule. This approach allows the pipe whip restraint designer to interpolate between the calculated data and to

avoid repeated reanalysis of standard designs due to small changes in a particular parameter.

6.3.4 Energy Balance Analysis.

As with a dynamic analysis, in an energy balance analysis the system energy shall be demonstrated to be absorbed during the dynamic event and the system shall be shown to maintain the capability to support the steady state blowdown loads.

In an energy balance analysis, time dependence is not considered; therefore a constant blowdown thrust force shall be assumed. The greater of the initial thrust force or the maximum friction limited blowdown force shall be used in the analysis. The energy balance may be performed for the first quarter cycle (initial and final pipe velocity is zero) if the system load deflection relationships are known.

However, since the dynamic inertia effects are unknown in this type of analysis, the energy sharing relationship between the pipe and pipe whip restraints cannot be calculated. Therefore, one acceptable conservative approach is to assume that the pipe whip restraint is capable of absorbing the total system energy by itself. If more realistic energy distributions are assumed, the distribution of energy to each component shall be clearly justified. If each system component can absorb the required energy and the components still have the load capacity to support the steady state blowdown, the system design shall be considered acceptable.

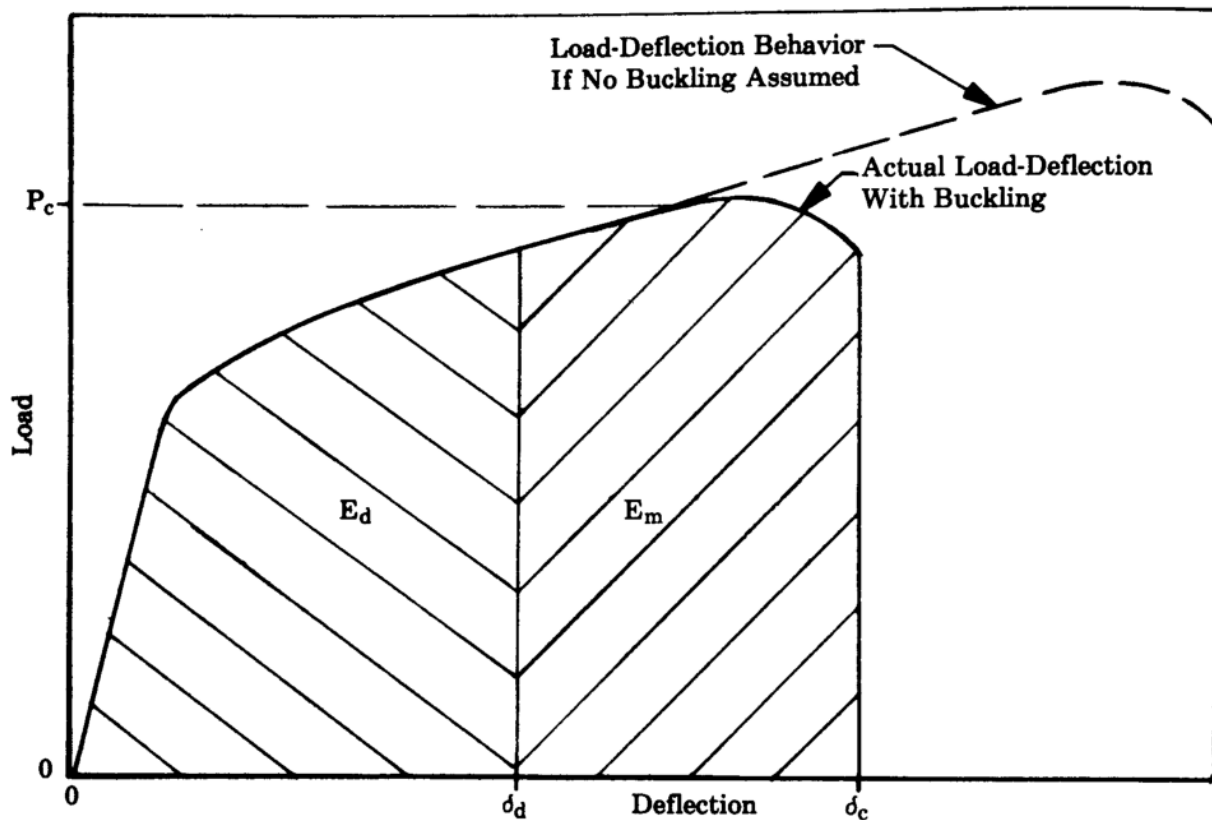
The energy balance method assumes that the maximum stress or strain of the pipe whip restraint occurs at the end of the initial quarter cycle of the response. Experience indicates that this is not always true. It is possible that a maximum deformation slightly higher than that occurring during the initial quarter cycle might occur in the restraint based on detailed time history analysis where rebound effects occur. One of the following alternatives shall be used to account for the potential effects of rebound:

(a) Where energy sharing by both the pipe and pipe whip restraint is assumed, justify that rebound does not cause significant increases in all representative applications by a more detailed time history evaluation of the driving forces or structural responses, or

(b) Apply an amplification factor of ten percent to the thrust reaction force to perform the quarter cycle energy balance analysis, or

¹⁸GUSTIN, P. E. et al, "Non-Linear Dynamic Analysis of Pipe Whip Tests," EPRI Report RP-1324-7, Electric Power Research Institute, Palo Alto, CA (1984).

¹⁹CHOUARD, P. H. et al, "Experimental Studies of Pipe Whip and Impact," RP-1324-5, Electric Power Research Institute, Palo Alto, CA (1984).



where

P_c = load at onset of buckling collapse

δ_c = collapse deflection

δ_d = maximum design deflection at E_d

E_d = maximum design energy absorption ($\leq .5 E_c$)

E_m = design energy absorption margin ($\geq E_d$)

E_c = total energy absorption prior to buckling

= $E_d + E_m$

Figure 6-2
Typical Load-Deflection Behavior for a
Structural Type Pipe Whip Restraint

(c) Reduce the design limit for the pipe whip restraint by 20 percent of the design value obtained based on a material or a pipe whip restraint capacity determination as recommended in 6.6.

6.3.5 Static Analysis. With a static analysis, the jet reaction force shall be represented by a conservatively amplified static loading, and a static analysis performed for the piping and pipe whip restraint system.

The designer shall verify that the parameters used to determine an amplification factor for a standard pipe whip restraint bound, or otherwise properly apply, to other applications. Also, use of optimally designed standard pipe whip restraints in non-optimum applications might result in high amplification factors which should be established by methods other than static analysis.

6.4 Piping Requirements. The postulated ruptured pipe is the initiator of the pipe whip event. Once a pipe has been assumed ruptured, the requirements of the ASME Boiler and Pressure Vessel Code, Section III [6] are no longer applicable since the pressure boundary integrity is no longer being maintained. The pipe is limited in its capability to carry pipe rupture loads by its cross-section characteristics in the form of diameter and wall thickness.

Motion of a pipe may be considered controlled (e.g. pipe whip does not occur) when it is demonstrated that the load carrying capacity of the pipe is greater than the applied loading after the occurrence of the dynamic event, and the energy dissipated in the pipe and pipe whip restraint system during the dynamic event is less than their energy absorbing capacities, utilizing the material design limits of 6.6. The load carrying capacity of the pipe may be determined by test or by a suitable analytical model.^{20, 21, 22, 23}

²⁰GERBER, T. L., "Plastic Deformation of Piping Due to Pipe Whip Loading," American Society of Mechanical Engineers Paper No. 74-NE-1, presented at the ASME Pressure Vessel and Piping Conference, Miami, FL (1974).

²¹LARSEN, et al, "An Approximate Model for an Elastic-Plastic Pipe Element Under Combined Loading," *Journal of Pressure Vessel Technology* (1965).

²²STOKEY, W. F., et al, "Limit Loads for Tubes Under Internal Pressure Bending Moment, Axial Force and Torsion," *Nuclear Engineering and Design* (1966), Vol. 4, No. 2, pp. 193-201.

²³SNOW, A., "Determination of Loads to Create a Fully Plastic Pipe Cross Section," WAPD-TM-663, Westinghouse Electric Corporation (1967).

6.5 Pipe Whip Restraint Requirements. The primary function of a pipe whip restraint is to control pipe motion related to a circumferential or longitudinal break. As used in this context, a pipe whip restraint is considered to be different from a pipe support. In certain instances, a pipe whip restraint may also serve as a pipe support. For such cases, the appropriate design rules for the support (i.e. Subsection NF, "Component Supports," ASME Boiler and Pressure Vessel Code, Section III [5]) shall be applied in addition to the rules of this standard.

Pipe whip restraints which do not serve as pipe or component supports may be designed for one-time usage, and as such may be allowed to have greater distortion, plastic deformation, than is permitted for pipe support design. If an elastic, dynamic system analysis is performed to determine the pipe restraint loadings, care shall be taken that the amount of permanent deformation is kept within the limits necessary to preserve the validity of that analysis. For a plastic, dynamic system analysis, wherein the effects of strain rate and strain hardening are included, the permanent strain in ductile metals shall be limited to those values specified in 6.6.

For structural types of pipe whip restraints where buckling phenomena could occur before fracture by tensile or shear material failure, proper consideration shall be given to ensure adequate energy absorption margins.

Recommendations for allowable ductility ratios for plastic design of structures under dynamic loading are given in Biggs, Norris, Hansen, Namyet and Minami.²⁴ Figure 6-2 represents the general nature of load versus deflection for a typical structural restraint where buckling occurs before material ultimate strain occurs. For this design approach the material design limits of 6.6 are not completely adequate. Therefore, no more than 50 percent of the total energy absorption capacity of the restraint prior to buckling collapse shall be used in the dynamic event analysis. For the steady state condition no more than 80 percent of the load at onset of buckling collapse shall be used for a design limit.

²⁴BIGGS, J. M., et al, *Structural Design for Dynamic Loads*, McGraw-Hill (1959).