U.S. ATOMIC ENERGY COMMISSION

May 1973

REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 1.46

PROTECTION AGAINST PIPE WHIP INSIDE CONTAINMENT

A. INTRODUCTION

General Design Criteron 4, "Environmental and Missile Design Bases," of Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," requires, in part, that structures, systems, and components important to safety be appropriately protected against dynamic effects that may result from equipment failures, including the effects of pipe whipping. This guide describes an acceptable basis for selecting the design locations and orientations of postulated breaks in fluid system piping within the reactor containment and for determining the measures that should be taken for restraint against pipe whipping that may result from such breaks. This guide applies to light-water-cooled reactors. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

The design procedures for fluid piping systems as contained in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code,[1] Section III, apply only to the assurance of pressure-retaining integrity. If a piping failure (i.e., a break or rupture resulting in a loss of pressure-retaining integrity) is postulated, the Section III design procedures do not provide for protection against dynamic effects (e.g., plastic hinge formation and pipe whipping) of that part of the piping system which remains intact. The Atomic Energy Commission has developed an acceptable basis for selecting the locations and orientations of piping breaks to be used for determining appropriate measures for the protection of structures, systems, and components important to safety that are within the reactor containment. This basis is directly related to the design limits and piping procedures contained in Section III of the ASME Code (i.e., Subsections NB-3600, NC-3600, and ND-3600 for design of Code Class 1, 2, and 3 piping, respectively).

[1] Hereinafter, referred to as "ASME Code"

ASME Code Class 1 Piping

The locations for which breaks should be postulated to occur for ASME Code Class 1 piping are based on the regions of piping runs or branch runs with the greatest potential for failure under cyclic loading conditions (i.e., locations of high primary plus secondary and peak stress intensities associated with specified seismic events and operational plant conditions). A piping run interconnects components such as pressure vessels, pumps, and valves that act to restrain pipe movement beyond that required for design thermal displacement. A branch run differs from a piping run only in that it originates at a piping intersection as a branch of the main pipe run. Terminal ends of the piping run or branch run (e.g., connections to component nozzles and to other piping) and other points of constraint or limited flexibility (e.g., short-radius elbows, tees, branch connections, and anchors) are piping locations and piping components that may sustain stress intensities which, because of the application of secondary and peak stress indices provided by the Section III design rules, can be substantially greater than the stress intensities occurring in straight runs of piping and long-radius elbows. On the basis of high stress intensities and related considerations (e.g., reactor vessel nozzle safe ends) which indicate a greater probability of failure relative to straight pipe, piping break locations should be postulated to occur at the terminal ends of the piping run or branch run. Similarly, breaks should be assumed to occur at any intermediate locations between terminal ends of piping runs or branch runs that exhibit stress intensities above conservatively derived limits based on the stress levels actually existing in the fluid system piping. The limits selected on this basis are elastically calculated primary plus secondary stress intensities of 2 S_m for ferritic steel and 2.4 S_m for austenitic steel. For stress intensity values calculated on an elastic basis that are 2 S_m or below in ferritic and 2.4 S_m or below in austenitic piping materials, the resulting strains in both materials are well within the 0.2% offset strain specified as the minimum yield strength by the applicable material specifications. Consequently, such piping locations are expected to behave elastically under the specified plant conditions. The 2 S_m or 2.4 S_m limit also is within the 3 S_m design limit specified in Section III for elastic-plastic fatigue exemption.

When peak stress intensities in piping are evaluated, the allowable number of stress cycles determined by Section III of the ASME Code is lower than the stress cycles allowed for the primary plus secondary stress intensity limit. Therefore, the cumulative usage factor (U) is limited to a value of 0.1 to provide a margin on allowable cycles for peak stress intensities that is equivalent to the margin on allowable cycles derived solely from the primary plus secondary stress intensity limit. The cumulative usage factor limitation also accounts for fatigue strength reduction effects where unanticipated service conditions or unexpected and excessive nonlinear thermal gradients may develop in piping components.

The limits on stress intensity and cumulative usage factor selected to determine piping break locations are based on the assumption that, despite the accepted conservatism in the ASME Code piping design rules, the system piping may suffer structural degradation of an unanticipated nature in service or may have its design margins unknowingly reduced by faulty design, improperly controlled fabrication, installation errors, or unexpected modes of operation. Therefore, the above limits provide additional margin over significant design basis stress cycles (for a 40-year plant life) which is available to account for these uncertainties.

If less than two intermediate break locations are determined between terminal ends of the piping run or branch run by application of the stress intensity and cumulative usage factor limits discussed above, or if it appears that adequate pipe whip protection may not result from breaks postulated at these intermediate break locations, additional intermediate break locations selected on a reasonable basis should be postulated for each piping run or branch run. A reasonable basis for locating intermediate piping breaks should consider such factors as: (1) points of maximum stress intensity and/or cumulative usage factors (excluding terminal ends) in the piping run or branch run, (2) length of the piping run or branch run over which no protective measures against pipe whipping are provided, and (3) changes in coordinate plane (i.e., X–Y, Y–Z, and X–Z) of the piping run or branch run as determined by tracing the run in both directions starting at each terminal end. Based on a review of piping systems, a minimum of two intermediate break locations should be selected for each piping run or branch run. These break locations are postulated for design analysis purposes. There is not necessarily any correspondence between the number of postulated breaks and the number of pipe whip restraints needed to provide protection. However, the determination of the need for pipe whip restraints should consider the potential consequences of postulated breaks at these locations.

ASME Code Class 2 and 3 Piping

An approach comparable to that taken for Code Class 1 piping should be applied to define design basis break locations for ASME Code Class 2 and 3 piping of fluid systems in which piping breaks may be postulated. The piping design rules for Code Class 2 and 3 piping differ from those applicable to Code Class 1 piping as reflected by the stress limit of 0.8 (S_h + S_A) provided for the determination of intermediate break locations. The stress limit of 0.8 (S_h + S_A) is derived on a basis that is comparable to the stress limit specified for ASME Code Class 1 piping. The limit on stress for locating intermediate breaks in Code Class 2 and 3 piping runs or branch runs is not supplemented by a fatigue limit because the applicable codes (i.e., NC-3600 and ND-3600 of Section III of the ASME Code and the American National Standard Code for Pressure Piping, ANSI B31.1.0-1967) do not require analyses for cyclic loadings (other than that implied in the allowable values of expansion stress range, S_A). However, if such analyses are performed, the limit on the cumulative usage factor provided for Code Class 1 piping should be applied in conjunction with the stress limitation for Code Class 2 and 3 piping.

Pipe Sizes Subject to Breaks

The pipe sizes to which this guide applies and the orientation of the postulated breaks with respect to the pipe axes are based upon (1) current piping fabrication techniques and (2) the results of stress analysis of applicable piping systems. Consideration of these factors indicate that circumferential breaks should be postulated for all piping runs and branch runs above the practical minimum of one-inch nominal pipe size. With regard to postulation of longitudinal breaks, a significant factor to be considered is that a majority of small ASME Code Class pipe lines (defined herein as less than four inches nominal pipe size) are of seamless construction (i.e., with no longitudinal weld seam and associated stress index). As expected from the type of fabrication and as confirmed by stress analysis, the probability of longitudinal breaks occurring in piping smaller than four inches nominal pipe size is considerably less than the probability of circumferential breaks occurring in these pipe sizes. Therefore, longitudinal breaks need only be postulated for piping runs and branch runs four inches nominal pipe size and larger.

Pipe Whip Protection Measures

Measures for the protection of structures, systems, and components important to safety should be provided after piping break locations are determined for Code Class 1, 2, or 3 fluid system piping. Exceptions may be made for situations where (1) plant features such as concrete encasement or other barriers physically separate piping from other components or restrain piping from whipping or where (2) a plastic hinge is assumed to develop at a pipe whip restraint and whip of either end of the ruptured pipe in any direction cannot damage a structure, system, or component important to safety. Further exceptions are made if the internal fluid energy level in piping is not sufficient to propel a broken pipe. For example, if the piping system is pressurized at 275 psig or less in conjunction with a design temperature of 200°F or less (as specified for ANSI 150 psig class welding end or flanged end pipe fittings), then protection against pipe whipping need not be considered. In addition, pipe whip protection need not be provided when the energy associated with the plastic hinge formation is not sufficient to impair the safety function of any structure, system, or component to an unacceptable level (e.g., a system damaged by pipe whip may be capable of performing its safety function but not capable of completely fulfilling its design function such as delivering design rated flow).

Although a limited number of postulated piping break locations are determined herein for any specific Code Class 1, 2, or 3 piping run or branch run, installation of all restraints necessary to provide the required pipe whip protection measures for structures, systems, and components important to safety will also provide protection against a substantially greater number of postulated piping break locations (i.e., protection is provided for a major portion of the pipe run or branch run). Piping locations where breaks are not postulated nor protection provided are restricted to those locations whose probability of failure is sufficiently low as to be acceptable without the need for restraints.

C. REGULATORY POSITION

1. ASME Section III Code Class 1 piping[2] breaks should be postulated to occur at the following locations in each piping run[3] or branch run:

a. The terminal ends;

b. Any intermediate locations between terminal ends where the primary plus secondary stress intensities (circumferential or longitudinal) derived on an elastically calculated basis under the loadings associated with specified seismic events[4] and operational plant conditions[5] exceed 2 S_m[6] for ferritic steel and 2.4 S_m for austenitic steel;

c. Any intermediate locations between terminal ends where the cumulative usage factor U[7] derived from the piping fatigue analysis under the loadings associated with specified seismic events and operational plant conditions exceeds 0.1;

d. At intermediate locations in addition to those determined by regulatory positions 1.b. and 1.c. above, selected on a reasonable basis[8] as necessary to provide protection. As a minimum, there should be two intermediate locations for each piping run or branch run.

2. ASME Section III Code Class 2 and 3 piping breaks should be postulated to occur at the following locations in each piping run or branch run:

a. The terminal ends:

b. Any intermediate locations between terminal ends where either the circumferential or longitudinal stresses derived on an elastically calculated basis under the loadings associated with specified seismic events and operational plant conditions exceed 0.8 ($S_h + S_A$).[9]

c. If a fatigue analysis is performed, any intermediate locations between terminal ends where the cumulative usage factor U under the loadings associated with specified seismic events and operational plant conditions exceeds 0.1;

d. Intermediate locations in addition to those determined by regulatory positions 2.b. and 2.c. above, selected on reasonable basis as necessary to provide protection. As a minimum, there should be two intermediate locations for each piping run or branch run.

3. The following types of breaks should be postulated at the locations identified by regulatory positions 1 and 2 above:

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[2] Piping is a pressure-retaining component consisting of straight or curved pipe and pipe fittings (e.g., elbows, tees, and reducers).

[3] A piping run interconnects components such as pressure vessels, pumps, and valves that act to restrain pipe movement beyond that required for design thermal displacement. A branch run differs from a piping run only in that it originates at a piping intersection as a branch of the main pipe run.

[4] Specified seismic events are earthquakes that produce at least 50 percent of the vibratory motion of the Safe Shutdown Earthquake.

[5] Operational plant conditions include normal reactor operation, upset conditions (e.g., anticipated operational occurrences), and testing conditions.

[6] S_m is the design stress intensity as specified in Section III of the ASME Boiler and Pressure Vessel Code.

[7] U is the cumulative usage factor as specified in Section III of the ASME Boiler and Pressure Vessel Code.

[8] A reasonable basis for locating intermediate piping breaks should consider such factors as (1) points of maximum stress intensity and/or cumulative usage factors (excluding terminal ends) in the piping run or branch run, (2) length of the piping run or branch run over which no protective measures against pipe whipping are provided, and (3) changes in coordinate plane (i.e., X–Y, Y–Z, and X–Z) of the piping run or branch run as determined by tracing the run in both directions starting at each terminal end.

[9] S_h and S_A are stresses calculated by the rules of NC-3600 and ND-3600 for Class 2 and 3 components, respectively, of the ASME Code Section III Winter 1972 Addenda.

a. Longitudinal[10] breaks in piping runs and branch runs 4 inches nominal pipe size and larger;

b. Circumferential[11] breaks in piping runs and branch runs exceeding 1 inch nominal pipe size.

4. Measures for restraint against pipe whipping as a result of the design basis breaks postulated to occur at the locations specified under regulatory positions 1 and 2 above need not be provided for piping where any one of the following applies:

a. The piping is physically separated (or isolated) from other piping or components by protective barriers or is restrained from whipping by plant design features such as concrete encasement;

b. Following a single break, the unrestrained pipe movement of either end of the ruptured pipe in any direction about a plastic hinge formed at the nearest pipe whip restraint cannot damage any structure, system, or component important to safety;[12]

c. The energy[13] associated with the whipping pipe can be demonstrated to be insufficient to impair[14] the safety function of any structure, system, or component important to safety to an unacceptable level;

d. Both of the following piping system conditions are met:

(1) the design temperature is 200°F or less, and

(2) the design pressure is 275 psig or less.

[10] Longitudinal breaks are parallel to the pipe axis and oriented at any point around the pipe circumference. The break area is equal to the sum of the effective cross-sectional flow area upstream of the break location and downstream of the break location or is equal to a break area determined by test data which defines the break geometry. Dynamic forces resulting from such breaks are assumed to cause lateral pipe movements in the direction normal to the pipe axis.

[11] Circumferential breaks are perpendicular to the pipe axis, and the break area is equivalent to the internal cross-sectional area of the ruptured pipe. Dynamic forces resulting from such breaks are assumed to separate the piping axially and cause whipping in any direction normal to the pipe axis.

[12] See 10 CFR Part 50 Appendix A, "General Design Criteria for Nuclear Power Plants."

[13] The determination of this energy may take into account any line restrictions (e.g., flow limiter) between the pressure source and break location, and the effects of either single-ended or double-ended flow conditions, as applicable.

[14] A whipping pipe should be considered as sufficient to rupture an impacted pipe of smaller nominal pipe size and lighter wall thickness.