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DESIGN LIMITS AND LOADING COMBINATIONS FOR METAL PRIMARY REACTOR CONTAINMENT SYSTEM COMPONENTS

A. INTRODUCTION

General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," requires, in part, that the design bases for structures, systems, and components important to safety reflect appropriate combinations of the effects of normal and accident conditions with the effects of natural phenomena such as earthquakes. This guide delineates acceptable design limits and appropriate combinations of loadings associated with normal operation, postulated accidents, and specified seismic events for the design of components of metal primary reactor containment systems. 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 conditions and functional requirements of components which provide a pressure boundary for the primary reactor containment function should be reflected in the application of appropriate design limits (e.g., stress or strain limits) for the most adverse combination of loadings to which these components might be subjected. For components constructed in accordance with Subsection NE (Code Class MC) of Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, provision of a design specification is required which stipulates the design requirements for the components (e.g., the mechanical and operational loadings). However, neither Section III nor any other published code or national standard provides adequate guidance for selecting combinations of loadings for design or for identifying Seismic Category I components (i.e., components that should be designed to remain functional under the effects of the Safe Shutdown Earthquake [SSE]). This conclusion is supported by B-1223.4(a) of Appendix B to Section III, "Owner's Design Specification" which states, in part, "The system's function, the environmental conditions under which these functions are performed, and the loading combinations must be evaluated from the system standpoint. This Section [III] does not provide guidance in the identification of these system functions, conditions, and loading combinations." It is apparent from a review of recent applications for construction permits in which ASME Code design specifications are reflected that adequate guidance for selecting loading combinations is not presently available. For essentially identical components that perform a containment function, the loading combinations and associated design limits are not consistent among different applications for construction permits. However, components that perform a primary reactor containment function are identified as Category I for seismic design purposes by Regulatory Guide 1.29 (Safety Guide 29), "Seismic Design Classification."

To further provide a consistent basis for the design of metal containment system components, this guide delineates acceptable design limits for appropriate combinations of loadings. The intent of this guide is to address only the most adverse combinations of loadings resulting from those events or conditions identified herein (e.g., those combinations of loadings that result in the limiting or controlling design condition). These loadings are associated either with conditions for which the containment function is required in combination with specified seismic events (i.e., one-half the SSE and SSE) or with other conditions (appropriately combined with specified seismic events) producing possible mechanisms for failure that could affect the function and/or structural integrity of structures, systems, and components important to safety. Included in the latter are the loadings associated with the vibratory motion of the SSE, design external pressure (if applicable), and other loadings that induce compressive stresses. The effects of natural phenomena other than earthquakes, such as tornadoes, hurricanes, and floods, are not considered in this guide. The scope of this guide is limited to primary reactor containment components that are completely enclosed within Seismic Category I structures (e.g., concrete shield buildings). These structures are often designed to withstand applicable design basis natural phenomena in addition to earthquakes and therefore offer protection against those phenomena for structures, systems, and components located therein. In addition to the loading combinations addressed in this guide, primary reactor containment components enclosed within Seismic Category I structures should be designed to withstand the effects of pertinent natural phenomena not otherwise protected against.

The approach set forth in this guide is directly related to Section III of the ASME Code. Design limits as specified in Section III are adopted to provide assurance of maintaining the pressure-retaining integrity of the primary reactor containment. Since primary reactor containment is an engineered safety feature whose function is required in the event of loss-of-coolant accidents within the reactor coolant pressure boundary, the ability to withstand the loadings associated with those accidents is, in effect, a normal design condition for the containment. The design limits provided by Subsection NE of Section III of the Code, in recognition of the containment function, are analogous to the normal operating condition category design limits that are applied to ASME Code Class I components. To accommodate extreme loadings such as the impact forces from jet impingement and associated reactions and still maintain pressure-retaining integrity, Section III selectively provides special design limits.

The primary reactor containment system of metal construction includes all components which perform a containment function such as (1) the containment vessel or vessels, (2) penetration assemblies and access openings, and (3) piping systems attached to the containment vessel nozzles or to penetration assemblies out to and including all pumps and the valves required to isolate the containment. Many of these components, particularly piping, pumps, and valves, perform a dual function, that is, a service function (e.g., steam and feedwater piping) in addition to a containment function. Subsection NE of Section III of the ASME Code requires that these components be constructed in accordance with the rules for either Code Class 1 or Code Class 2 piping, pumps, or valves as determined by their intended service function. In addition, Subsection NE states that components performing this dual function shall meet the more stringent requirements for their intended service function or containment function considered independently or in combination. As a result of investigating piping systems that penetrate containment and perform a containment function, it is concluded that the service function requirements for piping, pumps, and valves of these systems are controlling for design purposes. Therefore, as stated in note 3 to the regulatory position set forth in this guide, Regulatory Guide 1.48, "Design Limits and Loading Combinations for Seismic Category I Fluid System Components," should apply to the design of Code Class 1 or 2 piping, pumps, and valves that are defined as containment system components, including any piping penetration assemblies or portions thereof that are not a part of the containment vessel. The only components that are classified as ASME Code Class MC (i.e., components constructed in accordance with the rules of Subsection NE of Section III of the Code) are metal containment vessels, including parts and appurtenances thereof. Such parts and appurtenances may include mechanical, electrical, and piping penetration assemblies, and bellows-type expansion joints.

1. ASME Code Class MC Vessels and Penetration Assemblies that are Parts or Appurtenances of the Vessel (Excluding Bellows-Type Expansion Joints).

a. For the tests stipulated by NE-6000 of the Code as delineated in regulatory position C.1.a., the applicable design limits of NE-6000 are specified to provide assurance of pressure-retaining integrity. For tests in addition to the ten tests permitted by NE-6000 of the Code, the design limits for Testing Conditions are specified (i.e., the design limits of NE-3226 of the Code which are identical to those of NE-6000). In addition, the design limits of NE-3131(d) of the Code are applicable since Testing Conditions should be considered in the fatigue evaluation.

b. Design limits analogous to the normal and upset operating condition category limits given for ASME Code Class 1 components are specified for the loading combinations delineated in regulatory position C.1.b. The exemption provided by NE-3131(d) of the Code (as outlined in note 5 to the regulatory position) should not be applied to the loadings associated with the vibratory motion of 50 percent of the SSE. Significant stress cycles may result from the occurrence of this seismic event and should be included in the evaluation for cyclic loadings. The loadings delineated in regulatory position C.1.b. are either the design loadings defined in this guide (as supplemented by note 6 to the regulatory position) combined with the loadings associated with the vibratory motion of 50 percent of the SSE or the loadings that occur from flooding the containment for accident recovery combined with the loadings resulting from the vibratory motion of 50 percent of the SSE. The latter loading combination is applicable only if the containment, or portions thereof, is designed to be flooded after the occurrence of the major accident. Flooding design considerations have usually been applied only for boiling water reactor primary containments.

c. For the combination of design loadings and loadings associated with the vibratory motion of the SSE as delineated in regulatory position C.1.c., the design limits of NE-3131(c)(1) or (2) are specified. NE-3131(c) of the Code distinguishes in the application of design limits between areas of the containment structure that are integral and continuous and those that are not (e.g., bolted flanges and mechanical joints). For the integral and continuous regions of the containment, an increase in allowable stress intensity is permitted by NE-3131(c)(2) of the Code to accommodate the effects of the SSE. However, NE-3131(c)(1) of the Code permits no increase in allowable stress intensity for noncontinuous and nonintegral areas of the containment under earthquake loadings.

d. Jet impingement and associated reactions may occur on the containment structure as a result of the occurrence of postulated piping ruptures within the reactor coolant pressure boundary. When the impact forces from jet impingement and associated reactions are considered in combination with design loadings and loadings associated with the vibratory motion of the SSE, as delineated in regulatory position C.1.d., the allowable stress intensities local to the jet and reaction forces are limited to the values specified in either NE-3131.2(a) or NE-3131.2(b) of the Code. These design limits are applied to accommodate the extreme loadings local to the jet impingement or associated reactions without loss of pressure-retaining integrity. NE-3131.2(a) of the Code restricts the allowable stress intensities to the values of NE-3131(c)(2) in regions of the containment structure that are not integral and continuous and in regions where partial penetration welds form part of the containment system boundary in the immediate areas of penetrations and access openings. NE-3131.2(b) of the Code permits the use of 85 percent of the stress intensity values of Appendix F of Section III for areas local to jet impingement and reaction loadings not excluded by NE-3131.2(a).

e. The loading combination delineated in regulatory position C.1.2. encompasses those loadings that produce the greatest potential for shell instability (buckling) of containment pressure-retaining components. The design limits of NE-3131.1 of the Code are specified for this loading combination; however, if a detailed analysis is performed, note 7 to the regulatory position set forth in this guide applies. The factor of 2 between the critical buckling stress and the applied stress as specified in note 7 is based on generally applied margins used where shell buckling is a design consideration. Design loadings (as combined with loadings associated with the vibratory motion of the SSE) include design external pressure, if applicable, and all other concurrent loadings that induce compressive stresses as outlined in note 8 to the regulatory position. In reference to design external pressure, the condition of concern is the maximum net differential external pressure that occurs across the containment vessel. This loading should be evaluated for all containment designs, but may be significant only for cases in which a limited-leakage concrete shield building with annular space surrounds the steel containment vessel.

2. Bellows-Type Expansion Joints that Are Parts or Appurtenances of ASME Code Class MC Vessels

a. For the tests stipulated by NE-6000 of the Code as delineated in regulatory position C.2.a., the applicable design limits of NE-6000, as supplemented by NE-3810(b) of the Code, are specified to provide assurance of both pressure-retaining integrity and functional performance. For tests in addition to the ten tests permitted by NE-6000 of the Code, the design limits for Testing Conditions are specified. Note 9 to the regulatory position also applies since Testing Conditions should be evaluated in accordance with the cyclic design requirements of NE-3810 of the Code.

b. The applicable design limits of NE-3810 of the Code are specified for each of the following loading combinations as delineated in regulatory position C.2.b: (1) design loadings combined with loadings associated with the vibratory motion of 50 percent of the SSE, (2) concurrent loadings associated with flooding the containment for accident recovery and the vibratory motion of 50 percent of the SSE, or (3) design loadings combined with loadings resulting from the occurrence of an SSE and impact forces resulting from jet impingement and associated reactions. Loadings associated with the vibratory motion of 50 percent of the SSE should be evaluated in accordance with the cyclic design requirements of NE-3810 of the Code as stated in note 10 to the regulatory position. Note 11 to the regulatory position provides consistency between the design limits inherent in using the procedures of NE-3810(e) 1 or 2 and NE-3810(e) 3 of the Code. In addition, for the reasons given in note 12 to the regulatory position, the requirements of NE-3810(c) of the Code should be met by testing the major structural assemblies in which bellows-type expansion joints are installed.

C. REGULATORY POSITION

ASME Code[1] Class MC components of primary metal containment systems[2,3] that are completely enclosed within Seismic Category I structures should be designed to withstand the following loading combinations within the design limits specified.

1. ASME Code Class MC vessels, electrical and mechanical penetration assemblies, and other penetration assemblies (excluding bellows-type expansion joints) that are parts or appurtenances[4] of the vessel:

a. The design limits specified in either NE-6222 or NE-6322 of the Code, as applicable, should not be exceeded when the component is subjected to a hydrostatic test, a pneumatic test, or a leak test, and the design limits of NE-3226(a), (b), and (c) plus NE-3131(d) of the Code should not be exceeded when the component is subjected to a hydrostatic test, a pneumatic test, or a leak test in addition to the ten such tests permitted by NE-6222 and NE-6322 of the Code.

b. The design limits specified in NE-3131(a), (b), and (d)[5] of the Code should not be exceeded when the component is subjected to either (1) concurrently applied design loadings[6] and loadings associated with the vibratory motion of 50 percent of the Safe Shutdown Earthquake (SSE), or (2) if applicable, concurrent loadings that result from flooding the containment for accident recovery and the vibratory motion of 50 percent of the SSE.

c. The design limits specified in NE-3131(c)(1) or (2) of the Code, as applicable, should not be exceeded when the component is subjected to concurrently applied design loadings and loadings associated with the vibratory motion of the SSE.

d. The design limits specified in either NE-3131.2(a) or (b) of the Code, as applicable, should not be exceeded when the component is subjected to concurrently applied design loadings, loadings associated with the vibratory motion of the SSE, and impact forces resulting from jet impingement and associated reactions.

e. The design limits specified in NE-3131.1[7] of the Code should not be exceeded when the component is subjected to concurrently applied design loadings[8] that produce the greatest potential for shell instability and loadings associated with the vibratory motion of the SSE.

2. Bellows-type expansion joints that are parts or appurtenances of ASME Code Class MC vessels:

a. The design limits specified in either NE-6222 or NE-6322 of the Code, as applicable, supplemented by the design limits specified in NE-3810(b) of the Code should not be exceeded when the component is subjected to a hydrostatic test, a pneumatic test, or a leak test, and the design limits[9] of NE-3226(a), (b), and (c) of the Code should not be exceeded when the component is subjected to hydrostatic test, a pneumatic test, or a leak test in addition to the ten such tests permitted by NE-6222 and NE-6322 of the Code.

b. The design limits[10,11,12] specified in NE-3810(a), (d), (e), and (g) of the Code should not be exceeded when the component is subjected to either (1) concurrently applied design loadings and loadings associated with the vibratory motion of 50 percent of the SSE, or (2) concurrent loadings which result from flooding the containment for accident recovery and the vibratory motion of 50 percent of the SSE, or (3) concurrently applied design loadings, loadings associated with the vibratory motion of the SSE, and impact forces resulting from jet impingement and associated reactions.

DEFINITIONS

ASME Code Class MC Components. Metal containment vessels including parts and appurtenances thereof that are constructed in accordance with the rules of Subsection NE of Section III of the ASME Boiler and Pressure Vessel Code. Parts or appurtenances of the containment vessel that perform a containment pressure boundary function may include mechanical penetration assemblies (including personnel or equipment hatches), electrical penetration assemblies, piping penetration assemblies, and bellows-type expansion joints.

Design Loadings. Includes all static and dynamic loadings used to design the containment vessel such as design loadings associated with specified seismic events (e.g., 1/2 SSE and SSE), design loadings that are superimposed from other systems or components, and design pressure and temperature loadings (excluding, for the purposes of this guide, jet impingement and associated reactions) from loss-of-coolant accidents due to the occurrence of postulated piping ruptures within the reactor coolant pressure boundary.

Penetration Assemblies. Parts or appurtenances required to permit piping, mechanical devices, and electrical connections to pass through the containment vessel shell or head and maintain leaktight integrity while compensating for such things as temperature and pressure fluctuations and earthquake movements.

Primary Metal Containment System. Includes the following components:

1. The containment vessel or vessels;
2. All penetration assemblies or appurtenances not a part of the vessel;
3. All piping systems attached to containment vessel nozzles or to penetration assemblies out to and including all pumps, instrumentation connections, and the valves required to isolate the containment system and provide a pressure boundary for the containment function.

Safe Shutdown Earthquake (SSE) That earthquake which produces the vibratory ground motion for which structures, systems, and components important to safety are designed to remain functional.

Seismic Category I. Those structures, systems, and components that are designed to remain functional if the SSE occurs.

NOTES

[1] Section III of the ASME Boiler and Pressure Vessel Code including that part of the Summer 1973 Addenda that pertains to Class MC components.

[2] Components of primary reactor containment systems are Category I for seismic design purposes in accordance with Regulatory Guide 1.29 (Safety Guide 29), "Seismic Design Classification."

[3] Piping, pumps, and valves that are defined as components of primary metal containment systems are constructed in accordance with the rules for either Code Class 1 or Code Class 2 components as required by NE-1100, NE-3500, and NE-3600 of Section III. Any piping penetration assemblies or appurtenances that are not a part of the containment vessel should be constructed in accordance with the rules for Code Class 1 or Code Class 2 components as required by the intended service function. Regulatory Guide 1.48, "Design Limits and Loading Combinations for Seismic Category I Fluid System Components," applies to the above components.

[4] Refer to NA-1200 of the Code for definition of parts and appurtenances.

[5] The exception stated in NE-3131(d), "In considering the provisions of NB-3222.4(d), consideration need not be given to the effects of earthquake loadings." should not be applied to the loadings associated with the vibratory motion of 50 percent of the SSE.

[6] Includes operating loadings where specified (e.g., parts or appurtenances such as vessel nozzles or piping penetration assemblies with special service conditions). The requirements of NE-3113 of the Code should be met. Operating loadings need only be included in those combination of loadings delineated in regulatory positions C.1.b., C.2.b.(1)., and C.2.b.(2).

[7] If detailed rigorous analyses of shells that contain the maximum allowable deviation from true theoretical form is performed for instability (buckling) due to loadings that induce compressive stresses, such analyses, considering inelastic behavior, should demonstrate that a factor of at least two exists between the critical buckling stress and the applied stress.

[8] Includes design external pressure, if applicable (e.g., the condition of concern is the maximum net differential external pressure), plus all static and dynamic loadings that induce compressive stresses.

[9] Tests in addition to the ten permitted by NE-6222 and NE-6322 of the Code should be evaluated in accordance with cyclic design requirements of NE-3810 of the code.

[10] Loadings associated with the vibratory motion of 50 percent of the SSE should be included in the evaluation of the cyclic loadings in accordance with the design requirements of NE-3810 of the Code.

[11] If the procedures of NE-3810(e) 1 or 2 of the Code are used, the total combined meridional membrane and bending stress due to pressure and deflection should be limited to that which would be allowed for 10 cycles using the procedures of NE-3810(d) of the Code. This limit will provide consistency with the design limits inherent in using the procedures of NE-3810(e)3 of the Code.

[12] The requirements of NE-3810(c) of the Code should be met by testing the major structural assemblies in which the bellows-type expansion joints are installed (e.g., penetration assemblies). All loadings such as axial compressive loadings that contribute to the instability of the assemblies should be considered. Inclusion of these loadings is particularly important in determining if angulation occurs in major structural assemblies containing two or more bellows-type expansion joints.