3.0 STRUCTURAL EVALUATION

I. Review Objective

In this portion of the dry cask storage system (DCSS) review, the NRC evaluates aspects of the DCSS design and analysis related to structural performance under normal and off-normal operations, accident conditions and natural phenomena events. In conducting this evaluation, the NRC staff seeks a high degree of assurance that the cask system will maintain confinement, subcriticality, radiation shielding, and retrievability of the fuel under all credible loads for normal and off normal accident conditions and natural phenomenon ("accident-level") events.

II. Areas of Review

This chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in evaluating the design and analysis of the proposed cask system, with regard to its structural performance. All storage cask systems include a confinement cask that may have both internal components and integral external components. In addition, some cask systems have a variety of other components that are subject to NRC evaluation and approval.

Recognizing the diversity of the various cask system components, the NRC has broadly categorized the applicable review procedures and acceptance criteria, as follows:

- confinement cask
- reinforced concrete (RC) components
- other system components important to safety
- other components subject to NRC approval

Within these broad categories, the NRC focuses the DCSS structural evaluation, as described in Section V, "Review Procedures," using the following areas of review, as appropriate:

1. scope
2. structural design criteria and design features
    a. design criteria
        i. general structural requirements
        ii. applicable codes and standards
    b. structural design features
3. structural materials
4. structural analysis
    a. load conditions
        i. normal conditions
        ii. off-normal conditions
        iii. accidents
    b. structural analysis methods
        i. finite-element analysis
        ii. closed-form calculations
        iii. prototype or scale model testing
        iv. structural analysis of specific components
    c. structural evaluation
        i. summary structural capability
        ii. fabrication and construction
        iii. structural compatibility with functional performance requirements

III. Regulatory Requirements

1. Structures, systems, and components (SSC) important to safety must meet the regulatory requirements established in 10 CFR 72.24(c)(3) and (4), as well as 10 CFR 72.122(a), (b), and (c)[1].

2. Radiation shielding, confinement, and subcriticality must meet the regulatory requirements defined in 10 CFR 72.24(d); 10 CFR 72.124(a); and 10 CFR 72.236(c), (d), and (l).

3. As stated in 10 CFR 72.122(f) and (h)(l), the storage system design must allow ready retrieval of spent fuel without posing operational safety problems.

4. As stated in 10 CFR 72.102(f), the design-basis earthquake (DBE) must be equal to or greater than the safe-shutdown earthquake (SSE) of nuclear plant sites previously evaluated under 10 CFR Part 100[2] or, in the case of sites licensed before the implementation of 10 CFR Part 100, developed under Topic III-2 of the Systematic Evaluation Program (SEP)[3].

5. As stated in 10 CFR 72.24(c) and 10 CFR 72.236(g), the analysis and evaluation of the structural design and performance must demonstrate that the cask system will allow storage of spent fuel for a minimum of 20 years with an adequate margin of safety.

6. Reinforced concrete structures may have a role in shielding, form ventilation passages and weather enclosures, and providing protection against natural phenomena and accidents. The pertinent regulations include 10 CFR 72.24(c) and 10 CFR 72.182(b) and (c).

IV. Acceptance Criteria

The most important function of the structural analysis is to ensure sufficient structural capability for every applicable section of the cask system to withstand the worst-case loads under accident conditions and natural phenomena events. Withstanding such loads enables the cask system to successfully preclude the following negative consequences:

- unacceptable risk of criticality
- unacceptable release of radioactive materials
- unacceptable radiation levels
- impairment of ready retrievability

Because of the diversity of cask system components that are subject to NRC evaluation and approval, it is inconceivable that staff would be able to define objective structural review criteria that address all possible component configurations. Moreover, no single structural code, (such as the ASME B&PV[4]) covers the design of all spent fuel storage systems. Consequently, the acceptability of any given structure will be contingent upon a combination of adherence to applicable portions of multiple codes and a review of the functional performance of the structure taken as a whole. This combined approach allows the designer to request relief and the reviewer to impose additional restrictions when warranted by specific design features.

In general, the DCSS structural evaluation generally seeks to ensure that the proposed design and analysis fulfill the following acceptance criteria, which reflect the industry codes and standards that the NRC staff has accepted in past DCSS structural evaluations:

With exceptions for the confinement cask, ANSI/AND-57.9[5] generally applies to the design and construction of an independent spent fuel storage installation (ISFSI). Table 3-1 includes extracts of ANSI/ANS-57.9 that apply to the design and construction of ISFSI structures other than the confinement system.

1. Confinement Cask

a. Steel Confinement Cask

The structural design, fabrication, and testing of the confinement system and its redundant sealing system should comply with an acceptable code or standard, such as Section III of the Boiler and Pressure Vessel Code (B&PV)[6] promulgated by the American Society of Mechanical Engineers (ASME). (The NRC has accepted use of either Subsection NB or Subsection NC of this code.) Other design codes or standards may be acceptable depending on their application.

i. The NRC staff evaluates the proposed limitations on allowable stresses and strains in the confinement cask, reinforced concrete components, system components important to safety, and other components subject to review, by comparison with those specified in applicable codes and standards. Where certain proposed load combinations will exceed the accepted limits for localized points on the structure, the applicant should provide adequate justification to show that the deviation will not affect the functional integrity of the structure.

ii. The NRC has accepted the use of applicable subsections of the ASME B&PV Code, Division 1, for components used within the confinement cask but not integrated with it. This includes the "basket" structure used in casks to restrain and position multiple fuel elements.

b. Concrete Containments

i. ACI 359[7] (also designated as Section III, Division 2, of the ASME B&PV Code, Subsection CC) constitutes an acceptable standard for prestressed and reinforced concrete that is an integral component of a radioactive material containment vessel that must withstand internal pressure in operation or testing.

ii. If ACI 359 pertains to a given ISFSI structure, it applies to all aspects of the design, material selection, fabrication, and construction of that structure. The NRC has not accepted the proposed substitution of elements from ACI 318[8] or ACI 349[9] for any portion of ACI 359 with regard to the structure of an ISFSI. ISFSI structures to which ACI 359 applies shall also meet the minimum functional requirements of ANSI/AND-57.9 for subject areas not specifically addressed in ACI 359.

2. Reinforced Concrete (RC) Structures Important to Safety, but not within the Scope of ACI 359

The NRC accepts the use of ACI 349 for the design, material selection and specification, and construction of all reinforced concrete structures that are not addressed within the scope of ACI 359. However, in such instances, the design, material selection and specification, and construction must also meet any additional or more stringent requirements given in ANSI/AND-57.9, as incorporated by reference in NRC Regulatory Guide (RG) 3.60[10]. Section V of this chapter provides additional guidance regarding specific review procedures.

3. Other Reinforced Concrete Structures Subject to Approval

The NRC accepts the use of either ACI 318 or ACI 349 for reinforced concrete structures that are subject to approval but are not important to safety. Section V of this chapter provides additional guidance regarding specific review procedures.

4. Other System Components Important to Safety

The NRC accepts the use of ANSI/AND-57.9 (together with the codes and standards cited therein) as the basic reference for ISFSI structures important to safety that are not designed in accordance with the Section III of the ASME B&PV Code. However, both the lifting equipment design and the devices for lifting system components that are important to safety must comply with American National Standards Institute (ANSI) Standard N14.6[11].

The NRC accepts the load combinations shown in Table 3-1 for structures not designed under either Section III of the ASME B&PV Code or ACI 359. These load combinations are based upon ANSI/AND-57.9, with supplemental definition of terms and combinations.

The principal codes and standards include the following references that may apply to steel structures and components:

a. American Institute of Steel Construction (AISC), "Specification for Structural Steel Buildings — Allowable Stress Design and Plastic Design"[12]

b. AISC, "Load and Resistance Factor Design Specification for Structural Steel Buildings"[13]

c. American Welding Society, "Structural Welding Code Steel," AWS D1.1[14]

d. American Society of Civil Engineers, "Minimum Design Loads for Buildings and Other Structures," ASCE 7[15] [however, note that load combinations established on the basis of ANSI/AND-57.9 (DCSS SRP Table 3-1) are to be used.]

e. ACI 349-85, Appendix B[16], for embedments or 10.14 for composite compression sections, as applicable, when constructed of structural steel embedded in reinforced concrete.

5. Other Components Subject to NRC Approval

For structural design and construction of other components subject to NRC approval, the principal codes and standards include the following:

a. ASCE 7

b. Uniform Building Code[17] (UBC)

c. AISC, "Specification for Structural Steel Buildings—Allowable Stress Design and Plastic Design"

d. AISC "Code of Standard Practice for Steel Buildings and Bridges"[18]

e. ASME B&PV Code, Section VIII[19]

V. Review Procedures

In evaluating the structural design and performance of a proposed DCSS, select and emphasize aspects of the following review procedures, as appropriate for the particular DCSS, in relation to the acceptance criteria summarized in Section IV, above:

- Description of Structures, Systems, and Components Important to Safety

  Verify that the applicant's safety analysis report (SAR) clearly identifies the proposed structural design and construction of SSC that are important to safety and necessary for effective functional performance and safety of the DCSS. Review the SAR and supplemental material submitted by the applicant to assess compliance with the applicable scope and content requirements defined in 10 CFR 72.24 or 72.230. (Focus in particular on requirements and conditions of use related to design, construction, implementation, operation, and maintenance of structural SSC. (10 CFR 72.28 requires applicants to propose conditions of use in license applications for approval under Subpart L.) Request any additional information required from the applicant at an early stage in the review process.

- Applicable Codes, Standards, and Specifications

  NRC guidelines recommend that the safety evaluation report (SER) prepared by the NRC staff include a table (in the design criteria evaluation section) summarizing the applicable reference sources. This table should identify all source documents cited in the SAR, their usage (e.g., description of model, prior NRC approval of cask system elements, design code, construction code), and acceptability for that usage is recommended. The sources of interest include documents directly referenced in the SAR; sources of material incorporated by reference; and codes, standards, specifications, and other sources of criteria that further define the design and construction of the proposed structures. If not tabulated, the consolidated review and assessment of reference sources should otherwise be included in the SER.

- Loads and Load Combinations

  Verify that the loads and load combinations are as specified in Chapter 2, of this SRP. If the applicant has not adequately justified any deviations from the acceptance criteria for loads and load combinations, identify the deviations as unacceptable and transmit them to the applicant for further justification.

  The SAR should include a comprehensive table of load combinations and safety margins for selected structural sections of components important to safety (or otherwise subject to NRC evaluation); this table should be included in the SER. The summary table should include sufficient structural sections and forms of loadings (e.g., shear, flexure, axial, and combined stress situations) to verify that the lowest margins of safety are represented for the various components. In addition, this table can be used to summarize the structural capacity evaluation.

- Design and Analysis Procedures

  Determine that the applicant's design and analysis procedures and assumptions are conservatively defined on the basis of accepted engineering practice. Review the behavior of the structure under various loads, and the manner in which these loads are treated in conjunction with other coexistent loads; assess compliance with the acceptance criteria defined in Section III of this chapter.

- Structural Acceptance Criteria

  Review the proposed limitations on allowable stresses and strains in the confinement cask, reinforced concrete components, system components important to safety, and other components subject to review. Compare the proposed limitations with those specified in the applicable codes and standards. Where the applicant proposes to exceed the accepted limits for certain load combinations at localized points on the structure, evaluate the justification provided to ensure that the deviation will not affect the functional integrity of the structure. If the justification is not acceptable, request additional justification and bases.

- Materials, Quality Control, and Special Fabrication Techniques

  Review the information provided in the SAR regarding materials, quality control programs, and special fabrication techniques, if any, and compare the proposal with the acceptance criteria in Section II of this chapter. If the applicant proposes to use a new material not addressed in prior approvals, the applicant must provide sufficient test and user data to establish the acceptability of the material. Similarly, review and evaluate any new quality control programs or construction techniques to ensure that they will not degrade the structural quality, integrity, or function of the DCSS.

- Testing, and In-Service Surveillance Requirements

  Review the proposed pressure test procedures for the confinement cask by comparison with the procedures described in ASME Code, Section III, Subsection NB-6000. Also review the proposed acceptance test and maintenance requirements for trunnions by comparison with those described in the ASME Code and ANSI N14.6, as applicable. Review any other proposed testing and in-service surveillance programs on a case-by-case basis. Also review SAR Section 9 to verify that the applicant has include all appropriate acceptance tests, and address all required evaluations in Section 9 of the SER.

- Conditions for Use of Structures

  Review the structural evaluation to determine if conditions of use or technical specifications (or "license conditions") should be associated with the structural design or proposed fabrication and construction. Review the appropriateness of and need for any proposed technical specifications related to structural design and construction. Determine whether any additional technical conditions related to structural performance are needed and, if so, provide input to the conditions of use discussed in the SER. Also describe the basis for the suggested conditions in the structural evaluation section of the SER.

  Structure-related conditions of use may be linked to evaluations performed under other sections (such as a field verification that maximum concrete temperatures predicted from thermal analysis will not be exceeded). 10 CFR 72.44(c)(4) suggests a minimum structural license condition. Similarly, 10 CFR 72.234(a) suggests a minimum structural condition of approval for certification; this standard also incorporates 10 CFR 72.236(j) by reference to 72.236.

The remainder of this section provides specific review procedures for each of the four categories of cask system components, including the confinement cask, reinforced concrete components, other safety-related system components, and other components subject to NRC approval. Within each of these broad categories, the specific review procedures focus the DCSS structural evaluation using the areas of review identified in Section II of this chapter.

1. Confinement Cask

The structural review of the confinement cask addresses drawings, plans, sections supporting computations, and specifications for those structural components comprising confinement barriers. The review also addresses structural and sealing interfaces and connections that are necessary to complete the confinement system (as defined in 10 CFR Part 72). In addition, this review includes evaluation of components that serve no structural function, in order to confirm that they do not impair the functioning of the confinement cask.

a. Scope

The SAR must describe all SSC important to safety in sufficient detail to allow evaluation of their structural effectiveness. In addition, the SAR must identify all codes and standards applicable to SSC important to safety.

The discussion in the SAR must demonstrate that all SSC important to safety will be designed and fabricated to quality standards commensurate with the importance to safety of the function to be performed. In addition, SSC important to safety must be designed to accommodate the combined loads anticipated during normal, off-normal, accident, and natural phenomenon events with an adequate margin of safety.

b. Structural Design Criteria and Design Features

i. Design Criteria

The NRC generally considers the following design criteria to be acceptable to meet the structural requirements of 10 CFR Part 72:

(1) General Structural Requirements

The proposed cask must maintain confinement of radioactive material under normal and off-normal operations, accident conditions, and natural phenomenon events. In addition, neither the cask nor any basket within the cask may deform under credible loading conditions in a manner that would jeopardize the subcritical condition or retrievability of the fuel.

The design must adequately protect the spent fuel cladding against gross rupture caused by degradation resulting from design or accident conditions. In addition, the design must ensure that the spent fuel will not experience accelerations that would damage its structural integrity or jeopardize its subcritical condition or retrievability.

The applicant must analyze the cask to show that it will not tip over or drop in its storage condition as a result of a credible natural phenomenon event. A tipover or drop is always assessed as a bounding condition during handling operations.

Radiation shielding in the cask system is required to protect the public and workers at the ISFSI, and such shielding must not degrade under normal or off-normal conditions or events. The shielding function may degrade as a result of a design-basis accident (e.g., loss of liquid neutron shielding resulting from a drop accident). However, the loss of function must be readily visible, apparent, or detectable. (Any permissible degradation in shielding must be shown to result in dose rates sufficiently low to permit recovery of the damaged cask, including unloading if necessary). In addition, the procedures specified in the SAR for use after such a DBA should include procedures for testing the effectiveness of the shielding.

(2) Applicable Codes and Standards

The structural design, fabrication, and testing of the confinement system and its redundant sealing system should comply with acceptable code or standards. Use of codes and standards previously accepted by the NRC expedites the evaluation process. Use of other codes and standards, definition of criteria composed of extracts from multiple codes and standards with overlapping scopes, or substitution of other criteria, in whole or in part, in place of acceptable published codes or standards requires a custom NRC review and may delay the evaluation process.

An accepted code for design, fabrication, and test of steel confinement casks is Section III of the ASME B&PV Code. (Specifically, the NRC has accepted use of either Subsection NB or NC.) Other design codes or standards may be acceptable depending on their application. The NRC has accepted use of the applicable subsections of the ASME Code for cask system components used within the confinement cask but not integrated with it. This includes the "basket," which is a structure used in casks to restrain and position multiple fuel elements.

The NRC has also accepted applicable subsections of Division 1, of the ASME Code, for structural external integral elements of the confinement (e.g., Subsection NF for integral supports).

The NRC accepts use of Regulatory Guides 7.11[20] and 7.12[21] as bases for determining the potential for brittle fracture. These regulatory guides also incorporate a portion of NUREG/CR-1815[22] by reference.

The applicant may define the fatigue limits of the cask structural materials on the basis of the provisions of Reference 3 or the guidance provided in Regulatory Guide 7.6[23]. However, since casks are typically subjected to non-cyclic loads, fatigue may not be a significant concern.

ii. Structural Design Features

Review the cask-related descriptive information presented in SAR Section 1, as well as any related information provided in SAR Section 3. The drawings, figures, tables, and specifications included in the SAR should fully define the structural features of the cask. These may include the cask body (including an inner shell, an outer shell, and a lead gamma shield), inner and outer lids and bolts, port covers and bolts, vent port covers to be welded in place, neutron shields and shell, trunnions, fuel basket, and impact limiters (if used).

Coordinate with the confinement review (Chapter 7 of this SRP) to verify that the SAR clearly identifies the confinement boundaries. These boundaries include the primary confinement vessel; its penetrations, seals, welds, and closure devices; and the redundant sealing system. Ensure that the applicant has provided proper specifications for all welds and, if applicable, that the applicant has adequately designed and specified the bolt torques for closure and locking devices.

Review the list of weights and calculation of the cask center of gravity. Verify that the applicant used the appropriate limiting cases in the structural evaluations.

Review the cask structural materials that are in direct contact with each other to verify that they will not produce a significant chemical or galvanic reaction and the attendant corrosion or combustible gas generation.

Review confinement boundary weld designs for compliance with the design code used for the confinement boundary. Acceptable requirements appear in ASME Code Section III, Subsections NB-3352 and NC-3352, "Permissible Types of Welded Joints," and NB-4240 and NC-4240, "Requirements for Weld Joints in Components."

The NRC has previously accepted alternative confinement boundary weld designs (such as NB-5200 or NC-5200, typically for Category C welded joints). These acceptable alternatives achieve equivalent structural integrity, but do not meet all the provisions of NB-3352 or NC-3352 for full penetration welds, or do not meet the NDE requirements for full volumetric nondestructive examination. The NRC has also accepted alternative designs for the welds of the head or flat end plate to the cylindrical portion of the confinement vessel. However, the NRC has required the alternative designs to include redundant welds to provide redundant sealing of the confinement systems.

In addition, welds must be well-characterized on drawings using standard welding symbols and/or notations, as discussed in American Welding Society (AWS) Standard A2.4[24].

c. Structural Materials

The information provided on structural materials must be consistent with the application of accepted design criteria, codes, standards, and specifications selected for the storage cask system. For example, if the applicant elects to use design criteria from Section III of the ASME B&PV Code, the materials selected for the cask must be consistent with those allowed by the ASME Code subsection related to design. Acceptable requirements include the ASME-adopted specifications given in Section II, Part A, "Ferrous Metals"; Part B, "Nonferrous Metals"; Part C, "Welding Rods, Electrodes, and Filler Metals"; and Part D, "Properties."

In reviewing the structural materials, consider the sources of information; properties used in the structural evaluation (including those that affect performance under both static and dynamic loadings for normal, off-normal, and accident conditions and natural phenomenon events); and suitability for the proposed life of the ISFSI. Preferred sources include industry and Government codes, standards (including NUREG-3760[25]), and specifications. Review the applicability and acceptability of all other sources, such as manufacturer's test data and handbooks. Published articles, research reports, and texts have generally not been accepted by the NRC as primary sources of information concerning material properties.

The intent of this portion of the DCSS structural evaluation is to determine the acceptability of all materials that have a structural role in confinement system structures and other structures important to safety (e.g., the basket, impact limiters, and shielding). However, this review should also include evaluating the suitability of the materials for the proposed structural and opertional application, as well as the material properties that may affect structural design and evaluation over the approved period of use. For example. The reviewer should be familiar with the information contained in NRC bulletin 96-04 “Chemical, Galvanic, or other Reactions in Spent Fuel Storage and Transportation Casks”[26]

The reviewer must consider the suitability of materials to be used in Structures Systems and Components (SSC) important to safety. The material properties and characteristics needed to satisfy these functional safety requirements must be maintained over the 20-year approval period. For some components, the life cycle may include conditions experienced during cask fabrication, loading, transport, emplacement, storage, transfer, retrieval, and decommissioning. Service conditions include normal, off-normal operations, accidents, and natural phenomena events.

Where historical data are available, they may furnish reasonable assurance that the material is suitable for a given component, provided that the service conditions are sufficiently similar to those of the precedent. Where such analogies are not available, the knowledge, judgement and experience of the reviewer must be used to ensure the use of good engineering practice. When additional information is required, a brief literature search may suffice. When necessary, the required information may be requested of the applicant.

Analyze the potential for corrosion and ensure that the applicant established and used appropriate corrosion allowances for the structural analyses. Also consider the static and dynamic (where appropriate) stresses and the limits used for the structural design and evaluations.

When dissimilar metals are connected electrically, a galvanic cell is established in which electrochemical interactions are enhanced. For example, if bolts are anodic to a large component of a cask system, the bolts may corrode quickly and impair their ability to function successfully as a fastener in the cask system. The galvanic series lists metals in terms of their electrochemical potential, which is a parameter that may be useful in establishing the likelihood of problems in either aqueous systems or vapors of moderate to high humidity. Because different metals may be used within a cask system, it is important to note the possible interactions between dissimilar-metal systems and to evaluate the possibilities for unfavorable interactions in relation to functions that are important to the safety of the systems. For example, in the presence of a large ferrous cathodic surface area, zinc will corrode at a rapid rate. The products of this reaction are gaseous hydrogen, ions and zinc compounds. These reaction products must be tolerable and they must not impair any safety function.

Additional material requirements apply for structural designs governed by the ASME B&PV Code, Section III, Subsection NB or NC. Specifically, these requirements include examination before fabrication, testing and analyses, and traceability. In particular, the SAR must acknowledge compliance with the requirements of the following Section III paragraphs, or their equivalent:

- NB-2121 or NC-2121, "Permitted Material Specifications"
- NB-2130 or NC 2130, "Certification of Material"
- NB-2500 or NC-2500 "Examination and Repair of Pressure-Retaining Material"
- NB-2400 or NC 2400, "Welding Material"

A DCSS serves to confine spent fuel and maintain safe storage conditions throughout its service life. Construction Codes, e.g. ASME B&PV Code Section III, give reasonable assurance that the as-fabricated material will provide the necessary integrity. It is noted that the ASME Code Section III applies specifically to maintaining pressure boundaries and supporting structures in nuclear power plants. It may not necessarily be applicable to all DCSS. However, designers may choose to cite it as the code to which selected components are to be fabricated. Codes such as the ASME B&PV are not likely to address all the potential performance problems (e.g. cracking, creep, corrosion, etc.) which may arise from environmental, electrochemical or dynamic-loading. These and other effects are specific to the individual application and are frequently, outside the intended application of the code. Thus, even where codes have been judiciously applied, the reviewer must establish that sufficient background, experience and knowledge exists to provide reasonable assurance on the long-term performance.

For a material that is not normally welded many questions must to be answered to ensure that the process chosen for fabrication will yield a durable component. Cracking problems with weldments are numerous and expert advise or appropriate research and development may be warranted for a new welding application.

The reviewer should ensure that bolts are properly heat treated. Improper heat treatment may result in bolt cracking either under normal conditions (if tempered too little) or under off-normal (accident) conditions (if tempered too much).

The SAR should also include tables detailing material properties and allowable stresses and strains (as appropriate).

A list of all materials used and the proposed service conditions for those materials, during loading, storage, and unloading is a useful aid during the review. A table of this type is included here as Appendix B. This table illustrates various types of information that the reviewer needs from an application, to aid in determining the suitability of the materials for the service conditions. It includes the name and safety classification of each component part of the dry cask storage system and, where applicable, the function , the material specification(s) to which it is produced, and the nominal values for the following parameters: strength, surface finish or coating, materials (if dissimilar) with which it is in direct contact. If welded, the list includes the welding process and filler metal. Other tabulations include the stress (nominal and maximum) in service, the residuals (chemicals/foreign matter) on the surface of the component after loading and after storage, the service temperatures (for the storage period, during loading and during unloading), the internal pressure (min, max) and the type/composition of gas or liquid in the container. The tabulation should include all materials used for components with an important-to-safety function, e.g. confinement, transport, criticality control, shielding. In addition, materials that coat or in other ways support or interact (physically, chemically, or electrochemically) with the important-to-safety materials should be tabulated. Information in this table can aid the reviewer to formulate the types of performance-related questions that are important for each component of a storage system.

Verify that the properties used are appropriate for the load conditions of interest (e.g., static or dynamic, impact loading, hot or cold temperature, wet or dry conditions). Review SAR Section 12 to ensure that the applicant considered any appropriate restrictions regarding temperature or environmental conditions for the materials. Verify that the SAR clearly references acceptable sources of all material properties.

Coordinate with the thermal review to determine the appropriate temperatures at which allowable stress limits should be defined. For most cask materials, the stress limits should be defined at the maximum temperature for each material, as established by the SAR thermal analysis.

Materials that function as neutron absorbers and gamma shields should be fabricated from materials that can perform well under conditions of service that are appropriate for these components over the 20 year licensing period. Coordinate with the criticality and shielding reviews to ensure that during storage and accident conditions the materials do not creep or slump to an extent that impairs the capability to perform its safety function

Ensure that the applicant considered the potential for brittle fracture, especially for cask system components that may be subject to impact during exterior handling and transfer operations. The potential for brittle fracture of some components important to safety has resulted in conditions of use that preclude transfer operations under extremely low temperature conditions. Ensure that any assumptions about internal heat generation for the brittle fracture analysis are defined on the basis of the maximum storage life and the possibility of a partial load in the cask. Verify that SAR Section 12 addressed any necessary restrictions regarding cask handling at low temperatures, and that these restrictions are addressed in Section 12 of the SER.

If the cask has impact limiters, the applicant should thoroughly test and verify their nonlinear impact characteristics. In addition, the applicant should tabulate and describe the crush characteristics and properties of the limiters in the directions that are to be used.

d. Structural Analysis

i. Load Conditions

To meet the structural requirements of 10 CFR Part 72, the DCSS design must accommodate the full spectrum of load conditions, including all anticipated normal, off-normal, and accident-level conditions (including natural phenomenon events). The system should not experience any deformation or loss of safety function capability under normal operating conditions. However, the system may experience some deformation, but no loss of safety function capability, in response to accident.

(1) Normal Conditions

Normal conditions and events are those associated with cask system operations, including storage of nuclear material, under the normal range of environments. The SAR should state the assumed limits of normal use environments, in order to support evaluation of cask system suitability for use at a specific site.

Loads normally applicable to a confinement cask include weight, internal and external pressures, and thermal loads associated with operating temperature. The loads experienced may vary during loading, preparation for storage, transfer, storage, and retrieval operations. The weight is the maximum or design weight (including tolerances) of the cask as it is stored and loaded with spent fuel. However, depending on the operation and procedures, the weight should also include water fill. The applicant should evaluate all orientations of the cask body and closure lids during normal operations and storage conditions, including loads associated with loading, transfer, positioning, and retrieval of the confinement cask.

Internal pressures result from hydrostatic pressure, cask drying and purging operations, filling with non-reactive cover gas, out-gassing of fuel, refilling with water, radiolysis, and temperature increases. Temperature variations and thermal gradients in the structural material may cause additional stresses in the cask and closure lids. Coordinate with the thermal review (Chapter 4 of this SRP) to determine the conservative (or enveloping) values and combinations of the cask internal pressures and temperatures for both hot and cold conditions. Use the temperature gradients calculated in SAR Section 4 to determine thermal stresses. Note that if the confinement system has several enclosed areas, all areas may not have the same internal pressures. In some casks, enclosed areas consist of the cask cavity and the region between the inner and outer lids.

Required evaluations include weight plus internal pressures and thermal stresses from both hot and cold conditions. Verify that the applicant included the maximum thermal gradient, as determined in the thermal analysis, when evaluating thermal stresses.

(2) Off-Normal Conditions

The review should identify and evaluate all off-normal events and conditions described in Chapter 11 of this SRP. Review the off-normal conditions and events for those that affect the confinement cask structure. The confinement cask components should satisfy the same structural criteria required for normal conditions, as discussed above.

The SAR should clearly identify anticipated off-normal conditions and events that may reasonably be expected to occur during the life of the cask system at the proposed site. In addition, the SAR should state the environmental limits to support comparison of the cask system design bases with specific site environmental data. Off-normal conditions and events can involve potential mishandling, simple negligence of operators, equipment malfunction, loss of power, and severe weather (short of extreme natural phenomena).

(3) Accident-Level Events and Conditions

Follow the guidance below in reviewing the structural response to accident conditions. Note that the SAR *must* address *at a minimum* each of the following accidents. However, this discussion may not address all of the potential events or accidents that apply to a cask (Chapter 11 of this SRP addresses the identification and evaluation of accidents.)

(a) Cask Drop and Tipover

The SAR should identify the operating environment experienced by the cask and the drop events (end/side/corner) that could result. Generally, applicants establish the design basis in terms of the maximum height to which the cask is lifted outside the spent fuel building, or the maximum deceleration that the cask could experience in a drop. The design-basis drops should be determined on the basis of the actual potential handling and transfer accidents.

Drops of a cask with axis vertical onto an edge may involve subsequent rotation. Drops with the axis generally vertical should be analyzed for the both conditions of a flush impact and an initial impact at a corner of the cask, in recognition that the worst-case loadings for the contents of the cask (versus damage to the cask itself) may result from different orientations at impact.

Applicants should analyze cask tipover regardless of the credibility of occurrence. The NRC will accept cask tipover about a lower corner onto a hard receiving surface from a position of balance with no initial velocity. The NRC has also accepted analysis of cask drops with the longitudinal axis horizontal, which together with analysis of a drop with axis near vertical, could bound a non-mechanistic tipover case.

Until recently, NRC staff has accepted an unyielding surface for determining the bounding cask deceleration loads which can far exceed the decelerations experienced by a cask dropping onto or tipping over the concrete storage pad that will bend and deform. As described in a latter section, prototype or scale model testing can be used to obtain more realistic cask deceleration or equivalent load for quasi-static analyses. Alternatively, applicants can develop an analytical model to calculate cask deceleration loads. In the analytical approach, the hard receiving surface for a drop or tipover accident need not be an unyielding surface and its flexibility may be included in the modeling. However, the analytical model should be validated. The staff has completed a series of low-velocity impact tests of steel billets, and is in the process of developing detailed guidance for using the billet test results to validate a cask-pad-soil interaction model for predicting cask deceleration loads.

(b) Explosive Overpressure

Explosion-induced overpressure and reflected pressure may result from explosion hazards associated with explosives and chemicals transported by rail or on public highways, natural gas pipelines, and vehicular fires of equipment used in the transfer of casks. Explosions may result from detonation of an air-gaseous fuel mixture. With the exception of transfer vehicle accidents, the explosion hazards are typically similar to those for facilities subject to reviews under 10 CFR Part 50[27]. Note that this explosive overpressure differs from that associated with the design-basis radiological sabotage event. The combination of physical security planning and cask design is intended to protect the public against such a threat.

The review for site-specific explosion hazards would be left for the license application for the specific site if explosions are not addressed in the SAR. Alternatively, the SAR can state the level of overpressure, reflected pressure, and/or pressure differentials assumed to result from an explosion; this level would then serve as the quantitative envelope for future comparison with hazards for specific site installations. The pressure criteria for the assumed design-basis wind or tornado may also serve as an envelope for the explosive pressures, for comparison with actual site hazards.

If the SAR includes bounding explosion effects for which the cask system is to be approved, verify that the applicant also provided structural analyses of those effects for cask system structures that may be affected. The SAR should identify the maximum response determined.That response should be sufficiently low such that while damage may occur it would not impair the capability of the component to perform its safety functions. In addition, the SAR should identify any post-event inspection and remedial actions that may be necessary.

(c) Fire

Chapter 4 of this SRP addresses potential fire conditions. Fire-related structural evaluation considerations include increased pressures in the confinement cask, changes in material properties (e.g., temporary loss of strength at elevated temperatures and permanent loss of strength because of annealing), stresses caused by different coefficients of thermal expansion and/or temperatures in interacting materials, and physical destruction (e.g., surfaces of concrete exposed to intense or prolonged high temperatures).

Review and evaluate the discussion in the SAR concerning the treatment of structural effects associated with the presumed fire. Evaluate the appropriateness of the applicant's analysis of those structural effects for the assumed parameters of the design-basis fire. Confirm that the applicant defined the confinement cask pressure capacity on the basis of the cask material properties at the temperature resulting from the fire.

The NRC has accepted the fire parameters included in 10 CFR Part 71[28] as the basis for characterizing the heat transfer associated with fire during storage. Spalling of concrete that may result from a fire is generally considered acceptable and need not be estimated or evaluated. Such damage is readily detectable, and appropriate recovery or corrective measures may be presumed. The NRC accepts concrete temperatures that exceed the temperature limits of ACI 349 for accidents, provided that the temperatures result from a fire. However, corrective actions may need to be taken for continued safe storage.

(d) Flood

Review the applicant's evaluation of the cask system design with regard to the structural consequences of a flood event. The SAR may stipulate an assumption that the cask system not be used at any site where there is potential for flooding. In this case, the cask would have to be placed on a reactor site at a location above the maximum probable flood. (SAR Section 12 should state this condition.) Alternatively, a license application for a site with flooding potential would require a full analysis.

One possible structural consequence of a flood is that a vertically stored cask may tip over or translate horizontally (slide) because of the water velocity. Another possible consequence is that external hydrostatic pressure will exceed the capacity of the cask. The applicant may state the critical water velocity and hydrostatic pressure as bounds for the SAR flood analysis.

The NRC accepts application of the requirements of ANSI/ANS-57.9, Section 6.17.4.1, to the flood case for overturning and sliding of stored confinement casks and other cask system structures (with a safety factor of 1.1 for accidents cases). The applicant should state the basis for estimation of lateral pressure on a structure as a result of water velocity.

The NRC accepts the use of Hoerner's *Fluid-Dynamics Drag*[29] for estimating drag coefficients and net lateral water pressure. An approach for calculating the velocity corresponding to the cask stability limit is to assume that the cask is pinned at the outer edge of the cask bottom, that the cask rotates about that outer edge, and that the pinned edge does not permit sliding. The overturning moment from the velocity of the flood water can be compared to the stability moment of the cask (with buoyancy considered). The structural consequences of the flood event are typically bounded by analyses for the drop or tipover accident cases.

Review the analysis of the confinement cask for flood-related hydrostatic pressure. The analysis should include the combined effects of weight, external hydrostatic pressure, internal pressure(s), and thermal stress. Resistance of the confinement cask to flood-related hydrostatic pressure should be analyzed in accordance with Section III, Subsection NB or NC of the ASME B&PV Code (depending on the subsection used for design).

Additional flood consequences include potential scouring under a foundation, damage to access routes, temporary blockage of ventilation passages with water, blockage of ventilation passages and interstitial spaces between the confinement cask and shielding structure with mud, and steep temperature gradients in the shielding structure and confinement cask. While the consequences of these conditions may be analyzed in the SAR, the licensee should consider these factors when siting an ISFSI.

(e) Tornado Winds

Verify that the SAR addresses the potential structural consequences of design-basis tornado or extreme wind effects. Review the load combination analyses for acceptable inclusion of tornadoes and tornado missiles.

Confinement casks may be vulnerable to overturning and/or translation caused by the direct force of the drag pressure while in storage or during transfer operations. ANSI/ANS-57.9 provides acceptable criteria for resistance to overturning or sliding.

Confinement casks are generally not vulnerable to damage from overpressure or negative pressure associated with tornadoes or extreme winds. However, they may be vulnerable to secondary effects, such as wind-borne missiles (see (f), below) or collapse of a weather enclosure. Tornadoes or extreme winds have been a governing load condition in previous reviews for major structures that form part of an ISFSI system. (These structures may provide for shielding, cooling paths, and/or transfer and storage operations.)

Tornadoes typically produce the greatest "design-level" wind effects for American sites. However, there are some potential American sites at which high winds may be more severe than the credible tornado. The SARs for a limited set of potential sites could reflect high wind effects as a basis for structural analysis. If the certificate is to include proven resistance to tornadoes or extreme winds, the SAR documentation must identify the wind levels (e.g., in miles or kilometers per hour), source (tornado or high wind), and specific wind-driven missiles (shape, weight, and velocity) for which the design is to be evaluated.

Regulatory Guide 1.76[30] provides applicable tornado-related parameters.The NRC accepts the use of ASCE 7 for conversion of wind speed to pressure and for typical building shape factors. Conversion of tornado or other wind speeds to pressure in the SAR documentation should assume that the cask system is at sea level.In addition, the SAR should cite the source for drag coefficients used to compute net forces on objects. (Hoerner's *Fluid-Dynamics Drag* is one acceptable source.)

For the design tornado wind pressure, the NRC accepts use of the pressure derived from conversion of wind speed, without gust or importance factors, for tornadoes. If the design-basis wind is caused by extreme winds, the NRC accepts the computational approach given in ASCE 7 for determining pressures. This approach adds gusts, importance, exposure, and height above ground to the analysis. The computational approach of ASCE 7, has also been accepted for normal and off-normal wind loadings.

Tornadoes and high winds can produce a significant negative pressure differential between interior spaces and the outside. This is a function of wind speed and factors relating to the structure. The magnitude of negative pressure depends on other parameters of the tornado or wind, and on wall pressure coefficients (as expressed in ASCE 7). There is no need for the SAR to separately state negative pressure to establish an envelope for approval since negative pressure is insignificant with regard to confinement cask accident pressure analysis.

The NRC does not accept the presumption that there will be sufficient warning of tornadoes that operations such as transfer between the fuel pool facility and storage site may never be exposed to tornado effects. Overturning during onsite transfer is considered by the staff to be a design-basis event. The tornado analysis should determine if tornado-induced overturning is bounded by drop and tipover cases. In addition, the SAR should show that the cask system will continue to perform its intended safety functions (criticality, radioactive material release, heat removal, radiation exposure, and ready retrievability).

(f) Tornado Missiles

Review the applicant's evaluation of the cask system design with regard to the structural consequences of wind-driven missile impact. (Regulatory Guide 1.76 and NUREG-0800[31] describe the effects of tornado missiles.) The SAR should define the missile parameters for which the cask system is to be evaluated. Among the possible missile effects, the SAR should address those that may result in a tipover, and those that may cause physical damage as a result of impact. The damage should not result in unacceptable radiation dose or significantly impair either criticality control, heat removal, or the ready retrievability of the fuel.

The NRC has accepted use of the analytical approaches given in ORNL-NSIC-5, Volume 1, Chapter 6[32], for estimating the potential effects of missile impact on steel sheets, plates, and other structures. Further guidance on analytical acceptable approaches for use in ISFSI design is provided in NUREG-0800, Section 3.5.3, "Barrier Design Procedures." In addition, for analysis and design regarding the ability of reinforced concrete structures to resist missiles, the NRC has accepted use of R.P. Kennedy's "Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects"[33].

Cask systems are not required to survive missile impacts without permanent deformation. However, the maximum extent of damage from a design-basis event must be predicted and should be sufficiently limited. Moreover, the capability of the SSC to perform their safety functions should not be impaired.

(g) Earthquake

Review the applicant's evaluation of the cask design with regard to the structural consequences of the earthquake event. As explicitly stated in 10 CFR Part 72, the design-basis earthquake (DBE) must be no less than the safe shutdown earthquake for a reactor at sites that have been evaluated under Appendix A to 10 CFR Part 100. Cask designs must satisfy the load combinations that encompass earthquake, including those for sliding and overturning in ANSI/ANS-57.9, Section 6.17.4.1). The applicant should demonstrate that no tipover or drop will result from an earthquake. In addition, impacts between casks should either be precluded, or should be considered an accident event for which the cask must be shown to be structurally adequate.

The SAR documentation should include analysis of the potential for impacts between components of the cask system. These could include contact between the confinement shell and its inner components or outer shield, and the rocking and fall back of a vertically or horizontally oriented confinement cask on its supports.

Cask systems are not required to survive a DBE without permanent deformation. However, the maximum extent of damage from a design-basis event must be predicted, and the capability to provide principal safety functions should not degrade.

ii. Structural Analysis Methods

Review the applicant's structural analysis, stresses, and stress combinations resulting from different loads. Look for satisfactory evidence that the applicant properly used acceptable analytical approaches and tools. In addition, the applicant should have performed and reviewed the associated computations internally under an acceptable independent design review (equivalent to ANSI N 45.11) and quality assurance procedures. The scope of the staffs review does not necessarily include performing detailed parallel computations (such as finite element analyses) to validate submitted computations or their results. The reviewer may perform separate, less extensive calculations when these could most readily evaluate suspected problems.

The applicant's analysis of stresses and stress combinations resulting from different structural loads should be consistent with the subsection of Section III of the ASME B&PV Code used in designing the component.

For Class 1 and Class 2 components, respectively, Subsection NB or NC of the ASME B&PV Code, defines the requirements for categorizing stresses and determining allowable stress limits for confinement casks. These references also provide definitions of stress categories and stress intensity limits for normal and off-normal operating conditions. For level D or accident conditions, Appendix F to the ASME B&PV Code provides definitions of the stress intensity limits.

In accordance with these references, stress intensity is defined on the basis of the maximum shear stress theory for ductile materials. Since the maximum shear stress is not identical to the maximum octahedral shear stress, octahedral shear stresses should not be compared with the stress intensity limits. Values for the stress intensity limits are defined in Appendices I and III of the ASME Code. Stresses resulting from inertial and pressure loads should be considered primary stresses since they can be shown to be self-limiting. Thermal stresses resulting from temperature gradients may be considered secondary stresses if they are self-limiting and do not cause structural failure.

(1) Finite-Element Analyses

Because of the complexity of many structural design considerations, load conditions, and structural design computations are often performed using finite-element analysis.

The applicant should perform the finite-element analyses using a general-purpose program that is well benchmarked and widely used for many types of structural analyses. Codes, such as SCANS and CASKS may be used as confirmatory tools, but are not applicable for primary analyses in the SAR because they have simplifying assumptions regarding cask geometry, materials, and structural behavior.

When possible, solutions from finite-element analyses should be compared with closed-form calculations. While they are unlikely to exactly duplicate the complex load conditions analyzed with the finite element program, they can verify simpler portions. For example, the formulas for the stress in a cylinder with end-caps can be used to check the stress state caused by internal pressure in the cask.

To be consistent with the provisions in Section III of the ASME Code, the analyses should use linear material properties. For materials that do not serve in a structural capacity (such as shielding materials), inelastic material properties may be used for cask components that are not stress-limited and respond inelastically to the load conditions for storage casks. The SAR should identify the sources used for the inelastic material properties.

Lead shielding, which is typically not stress-limited, can be modeled either with elastic or inelastic properties. The elastic modulus and limit used for lead in the elastic analysis should be determined on the basis of the potential temperature of the material. An appropriate plasticity model of lead can be used to account for its inelastic behavior.

Nonstructural components of the confinement cask are generally not included in finite element models. However, the models should include any influence these nonstructural components may have on the structural performance of the cask. Possible influences include the nonstructural components' inertial weight, restraint to motion of the structural components, and localized influence on load applications because of geometrical effects.

Bolted connections can be modeled either discretely or with contact conditions. To discretely model the bolted connections, the applicant should use appropriate element types and material properties. With contact conditions, the interfaces joined by the bolts can be modeled as tied.

The number of discrete finite elements used in the model should reflect the type of analysis being performed. That is, regions in the model of high stress or displacement should have a higher number of elements than regions that have a nearly equilibrated state of stress or are in a uniform stress field. Consequently, the applicant should conduct sensitivity studies to determine the appropriate number of nodes or elements for a particular model.

(2) Closed-Form Calculations

The applicant should perform closed-form calculations for relatively simple structural load conditions or conditions for which a formula has been developed. Closed-form calculations are also typically used to check the results of finite-element analyses. In addition, this type of calculation can be used for analyses involving principles of conservation of energy and comparisons of overturning moments.

One source of closed-form equations accepted by the NRC is *Formulas for Stress and Strain* (Roark 1965)[34]. Use of a particular equation or formulation for the load conditions should be justified as appropriate. The most important aspect of the calculations to evaluate is the basis for the assumptions used in the calculations. In many cases, the calculations are faulty in that they fail to include portions of the cask or the load conditions are idealized.

To be consistent with the provisions in Section III of the ASME Code, the analyses should use linear material properties. Linear analysis should be the basis for all closed-form calculations.

(3) Prototype or Scale Model Testing

Applicants may perform prototype or scale model testing in lieu of, or to supplement impact analysis for cask drop conditions. However, use of scale model testing to directly demonstrate that the cask design meets the regulatory requirements may be difficult, because leakage rates and other radiological limits may not correspond to the same scaling factor used for the model. Consequently, impact tests intended to independently demonstrate regulatory compliance are usually prototypical and may be used to assess performance of a specific component like an impact limiter. Applicants should perform a sufficient number of tests to cover all design impact conditions and other uncertainties (such as the hardness of the receiving target surface).

Applicants can also perform drop tests to obtain an equivalent static load to be used for a quasi-static analysis of the cask. Drop tests can also yield key data, such as the spring stiffness of the target surface, which may then be used to perform a dynamic analysis of the cask[35].

A scale model must properly simulate the distribution of the loads (weights), the geometry (dimensions), and the material properties of the cask. If the scale model omits any parts of the cask, the applicant should provide adequate justification and should discuss the resulting effects on test findings. In addition, the applicant should develop a test plan to identify the test conditions, the parameters to be measured during and after the test, and the test acceptance criteria.

(4) Structural Analysis for Specific Cask Components

The following paragraphs present a few specific examples of structural analysis for some of the confinement cask components:

(a) Trunnions

Review the design of the trunnions, their connections to the cask body, and the cask body in the local area around the trunnions. The design of the trunnions can be either non-redundant or redundant. In either case, the design should meet the requirements of ANSI N14.6 for critical loads and the requirements of NUREG-0612[36].

Non-redundant lifting systems should be designed for not less than 6 times the material yield strength and 10 times the material ultimate strength given the design lift weight of the loaded cask. Redundant lifting systems should be designed for not less than 3 times the material yield strength and 5 times the material ultimate strength given the design loaded lift weight of the cask. (Acceptance testing requirements for trunnions are discussed in Chapter 9 of this SRP.)

For a typical trunnion design, the maximum stress occurs at the base of the trunnion as a combination of bending and shear stresses. A conservative technique for computing the bending stress is to assume that the lifting force is applied at the cantilevered end of the trunnion and that the stress is fully developed at the base of the trunnion. If other assumptions are used, the applicant should provide adequate justification. In addition, the applicant should evaluate the stresses and forces in the trunnion connections with the cask body and in the cask body near the trunnions.

(b) Fuel Basket

Review the fuel basket design to assess the applicant’s analysis of the combined effects of weight, thermal stresses, and cask-drop impact forces. The weight supported by the basket should be the maximum or design weight of the spent fuel to be stored. In addition, the applicant should evaluate all credible potential orientations of the cask and basket during cask drop. End or side drops typically produce the greatest structural demand on various basket components. In the end drop, the basket is supported by the bottom of the confinement cask cavity upon impact. In the side drop, the basket structure and points of contact with the confinement cask must support the mass of the basket and loaded fuel.

In previous DCSS evaluations, the NRC has accepted two approaches for analyses regarding the structural capability of basket to acceptably survive cask drop. The first approach uses dynamic analyses in a two-step process. In step 1, the applicant performs a dynamic analysis of the cask body impacting a target surface, and assesses the response of the cask body to determine the maximum response from the cask drop impact. This maximum response can then be translated into a forcing function, which can be applied to the supporting contact points of an appropriate model of the fuel basket.

The second approach uses a quasi-static analysis of the basket subjected to the equivalent acceleration inertial load derived from the cask-drop impact analysis. In this analysis, the applicant should apply the equivalent acceleration inertial load, using an appropriate model of the basket with the location(s) most vulnerable to the impact. Support provided by the inside surface of the cask cavity should be represented by the appropriate boundary conditions on the outside edge of the basket. In addition, the applicant should conservatively select the equivalent acceleration inertial load such that it bounds the possible inertial loads resulting from a cask-drop accident onto the bounding target surfaces. If applicable, the inertial load should also account for dynamic amplification effects by using a dynamic amplification factor.

The applicant should also evaluate the buckling capacity of the cask basket materials. Acceptable guidance for this evaluation is provided in Section III of the ASME B&PV Code and NUREG/CR-6322[37]. For this evaluation, the applicant should select the appropriate end conditions used in the buckling capacity equations on the basis of sensitivity studies. These studies can bound the range of conditions, which are typically either fixed for a welded connection or free if there is no rigid connection.

(c) Closure Lid Bolts

Review the design analysis for the closure-lid bolts to ensure that it properly includes the combined effects of weight, internal pressure(s), thermal stress, O-ring compression force, cask impact forces, and bolt pre-load. Typically, applicants specify the pre-load and bolt torque for the closure bolts on the basis of bolt diameter and the coefficient of friction between the bolt and the lid. Externally applied loads (such as the internal pressure and impact force) produce direct tensile force on the bolts, as well as an additional prying force caused by lid rotation at the bolted joint. The tensile bolt force obtained by adding together the pressure loads, impact forces, thermal load, and O-ring compression force should then be compared with the tensile bolt force computed from the pre-load and operating temperature load alone. The larger of the two calculated tensile forces should control the design. The maximum design bolt force should then be obtained by combining the larger direct tensile bolt force with the additional prying force. The weight is derived from the maximum or design weight of the closure lids and any cask components supported by the lids. Acceptable analytical methods for closure bolts are given in NUREG/CR-6007[38].

Review the bolt engagement lengths. If the lids are fabricated from relatively non-hardened materials, threaded inserts may be used in the closure lids to accommodate the hardened material of the bolts.

iii. Structural Evaluation

(1) Structural Capability

Review the applicant’s structural analyses to assess the tables or statements regarding margins of safety or compliance with ASME Code stress limits, overturning, and other criteria. The comparisons of capability versus demand for the various applicable loading conditions should be presented in the same terms used in the design code (e.g., type of stress). In addition, margins of safety should be included on the basis of comparisons between capacity and demand for each of structural component analyzed. The minimum margin of safety for any structural section of a component should be included for the different load conditions.

(2) Fabrication and Construction

The NRC has accepted fabrication of confinement casks in accordance with Section III of the ASME B&PV Code. If the fabrication, construction, or assembly deviate in any way from the subsection of this standard used for design, the SAR must explicitly state the applicant’s justification for the deviation, and the justification must be acceptable to the NRC.

In reviewing the fabrication and construction of the confinement cask, focus especially on any specifications regarding preparation for welding, materials to be used in the welds, performance of welding, and inspection of welds that do not fully comply with Section III of the ASME B&PV Code.

Welding procedure qualifications and welding performance qualifications should conform with the requirements of Section IX of the ASME B&PV Code[39]. For confinement welds, the SAR documentation should include the bases for detailed welding procedure specifications (WPSs) that identify acceptable ranges of essential welding variables (listed in Section IX of the ASME Code for all approved welding processes).The welding variables should be recorded as quality assurance records during production runs. All welds should be performed by pre-qualified personnel in accordance with written procedures.

Testing of weld integrity may involve a combination of ASME-approved weld test techniques, which do not necessarily result in full radiographic examination, but some volumetric inspection (e.g., ultrasonic testing (UT)) may be necessary.

(3) Structural Compatibility with Functional Performance Requirements

Review the SAR documentation to confirm that the design of the cask structure provides for satisfactory functional performance.This includes operating suitability within specified limiting conditions and satisfaction of the basic safety criteria under all credible events and environmental conditions.

The SER should clearly identify the confinement system and other structures important to safety, each of which should have sufficient structural capability for every applicable section to withstand the worst-case loads under accidents and conditions, to successfully preclude the following:

- unacceptable risk of criticality
- unacceptable release of radioactive materials to the environment
- unacceptable radiation dose to the public or workers
- significant impairment of ready retrievability of stored nuclear materials

This position does not necessarily require that all confinement system and other structures important to safety survive all design-basis accidents and extreme natural phenomena without any permanent deformation or other damage. Some load combination expressions for the DBE and conditions for structures important to safety permit stress levels that exceed yield.The SAR should include computations of the maximum extent of potentially significant transient deformations and any permanent deformations, degradation, or other damage that may occur. Verify that the applicant has performed computations, analyses, and/or tests and that both the tests and results they are acceptable to the NRC in order to clearly demonstrate that any permanent deformations, degradation, or other damage that may occur does not render the system performance unacceptable.

Structures important to safety are not required to survive accidents to the extent that they remain suited for use for the life of the cask system without inspection, repair, or replacement. If the life of structures important to safety may be degraded by accident conditions, there must be SAR commitments and procedures for determining and correcting the degradation, and performing other acceptable remedial action.

Review the proposed technical specifications to ensure that they include adequate restrictions on cask handling and operations to preclude the possibility of damage to the structure or the confined nuclear material. Operating controls and limits of the technical specifications (reviewed under Chapter 12 of this SRP) should be included in both the SAR and the SER, and should describe actions to be taken and inspections to be conducted upon occurrence of events that may cause such damage.

2. Reinforced Concrete Components

This section presents guidance and review procedures for conducting structural evaluations regarding the reinforced concrete components of the cask system. Specifically, the reinforced concrete structures subject to NRC evaluation include SSC that are to be included in the approved cask system. These may be of concern because of their safety function or importance to safety (per 10 CFR 72.24 (c)).

a. Scope

Reinforced concrete structures may play multiple roles in providing radiological shielding or forming ventilation passages, weather enclosures, structural supports, access denial, foundations, earth retention, anchorages, floors, walls, movable shields, bulk fill, and protection against natural phenomena and accidents. Bulk fill may be emplaced within an enclosing structure to provide shielding or strength.

Reinforced concrete structures may be cast at the site, or cast elsewhere. reinforced concrete structures may also comprise *combinations* of cast-in-place and precast sections that are assembled by bolting, welding, fitting, grouting, or placing additional concrete at the site. They may also include concrete cast as part of a composite confinement cask with metallic liner. However, this subsection does not address the metallic liner of a composite confinement cask, its closures, or its internal components.

Embedments and attachments to reinforced concrete structures are analyzed as parts of the reinforced concrete structure unless they are specifically addressed elsewhere in Chapter 3 of this SRP. Embedments and attachments are considered to include components that are cast or grouted into the reinforced concrete structure, inserts, embedded pipes and conduits, or lightning protection and grounding systems.

b. Structural Design Criteria and Design Features

i. Design Criteria

(1) General Structural Requirements

All concrete used in storage cask system ISFSIs, and subject to NRC review, should be reinforced, regardless of the functional role or need for structural strength or integrity. The concrete specifications should state the reinforced concrete design code or standard applicable to its intended use and acceptable to the NRC.

The structural design of the reinforced concrete structures shall withstand the effects of credible accident conditions and natural phenomenon events without impairing their capability to perform safety functions. The principal safety functions include maintaining subcriticality, containing radioactive material, providing radiation shielding for the public and workers, and maintaining retrievability of the stored fuel.

The NRC has not required that exterior reinforced concrete pavements used for vehicular traffic, parking, or equipment access to the ISFSI storage area be designed as important to safety. Moreover, the SRP does not address the design or evaluation of pavements that are not considered structurally integral with the foundation of an reinforced concrete cask system structure that is subject to review. Nonetheless, reinforced concrete aprons that extend from a structure and are structurally integral with the structure are also elements of the foundation. As such they should be reviewed for compliance with the same code applicable for the attached reinforced concrete structure. If a pavement incorporates points for fastening supports that are important to safety (as may be used for transfer operations) that section of the pavement necessary for the function should be designed as a foundation in accordance with ACI 349.

Reinforced concrete pads that support confinement casks in storage do not constitute "pavements." As such, they should be designed and constructed as foundations under an applicable code, such as ACI 318, ACI 349 or UBC. Such pads typically are not classified as important to safety; however, in some cases they may be.

The applicant should consider the potential for liquefaction or other soil instabilities attributable to vibrating ground motion, and the pad should be designed with this in mind. Inspection Procedure 60851[40] and Regulatory Guide 3.60[41] provides guidance regarding soil engineering and seismic analysis requirements.

Steel embedments in reinforced concrete structures must satisfy the requirements of the design code applicable to the reinforced concrete structure. Similarly, structural steel must satisfy the requirements of the applicable steel design code.

(2) Applicable Codes and Standards

Review the codes and standards identified in the SAR, as well as their proposed applications. This subsection addresses the codes and standards that the NRC has accepted for reinforced concrete ISFSI structures, categorized by application (i.e., concrete containments, reinforced concrete structures important to safety but not within the scope of ACI 359, other reinforced concrete structures subject to NRC approval, and steel attachments to reinforced concrete structures).

ANSI/ANS-57.9 generally applies to ISFSI design and construction (with exceptions for confinement casks). Table 3-1 includes extracts from ANSI/ANS-57.9 that are particularly applicable to reinforced concrete structure design and construction. The table also includes corresponding evaluation guidance for use in reviewing the SAR documentation.

The NRC has not accepted the use of a set of criteria selected from multiple standards and codes, except when the selected criteria meet the most limiting requirements of each code. However, in recognizing a graded approach to quality assurance, the NRC has approved the use of ACI 349 for design and material selection for reinforced concrete structures important to safety (not confinement), but has allowed the optional use of ACI 318 as an alternative standard for construction, as described in this subsection.

Note that codes other than those discussed herein (e.g., the Electric, Life Safety, and Lightning Protection Codes[42] promulgated by the National Fire Protection Association (NFPA)) may apply to the design and construction of the cask system. It is acceptable to include such codes in the design by inclusion in the SAR. Where designs of structures subject to approval are also covered by such other codes, the review should include evaluation of compliance with those codes.

(a) Concrete Containments

ACI 359, also designated Section III, Division 2, of the ASME Boiler and Pressure Vessel Code, Subsection CC, is acceptable for prestressed and reinforced concrete that is an integral component of a radioactive material containment vessel that must withstand internal pressure in operation or testing. ACI 359 should be applied on the basis of containment function, regardless of whether the concrete structure is fixed or portable and regardless of where the concrete structure is fabricated. ACI 359 also applies to structural concrete supports constructed as an integral part of the containment.

If ACI 359 applies to an ISFSI structure, it applies to the entire design, material selection, fabrication, and construction of that structure. The NRC has not accepted the substitution of elements of ACI 349 or ACI 318 for any portion of ACI 359 for an ISFSI structure. In addition, ISFSI structures for which ACI 359 applies shall also meet the minimum functional requirements of ANSI/ANS-57.9, where ACI 359 does not include requirements regarding the specific subject area.

(b) Reinforced Concrete Structures Important to Safety, But Not Within the Scope of ACI 359

The NRC accepts the use of ACI 349 for the design, material selection and specification, and construction of all reinforced concrete structures that are not addressed within the scope of ACI 359. However, in such instances, the design, material selection and specification, and construction must also meet any additional or more stringent requirements given in ANSI/ANS-57.9, as incorporated by reference in RG 3.60.

The following paragraphs identify the portions of ACI 349 and ASTM standards that apply to design (including material selection) and must be met by applicants who choose to use ACI 318 for construction. (The paragraph references are as in ACI 349-90.) Unlisted and excepted sections address construction requirements, for which the NRC accepts substitution of ACI 318.

Chapter 1,	"General Requirements," Sections 1.1 and 1.5 (except references to construction), and Sections 1.2 and 1.4
Chapter 2,	"Definitions"
Chapter 3,	"Materials" (except Sections 3.1, 3.2.3, 3.3.4, 3.5.3.2, 3.6.7, and 3.7)
Chapter 4,	"Concrete Quality," Section 4.1.4
Chapter 6,	"Form Work, Embedded Pipes, and Construction Joints," Sections 6.3.6(k) and 6.3.8
Chapter 7,	"Details of Reinforcement"
Chapter 8,	"Analysis and Design General Considerations"
Chapter 9,	"Strength and Serviceability Requirements" (but see 2.2.d(1), below)
Chapter 10,	"Flexure and Axial Loads"
Chapter 11,	"Shear and Torsion"
Chapter 12,	"Development and Splices Information"
Chapter 13,	"Two-way Slab Systems"
Chapter 14,	"Walls"
Chapter 15,	"Footings"
Chapter 16,	"Precast Concrete"
Chapter 17,	"Composite Concrete Flexural Members"
Chapter 18,	"Prestressed Concrete"
Chapter 19,	"Shells"
Appendix A,	"Thermal Considerations"
Appendix B,	"Steel Embedments" (but note that the load combinations and variation requirements of ANSI/ANS-57.9 must be met in addition to those of ACI 349, Section 9.2, cited at Section B.3.2
Appendix C,	"Special Provisions for Impulsive and Impactive Effects" (except that the load combinations and variation requirements of ANSI/ANS-57.9 must be met in addition to those of ACI 349, Section 9.2

In addition, the following ASTM standard specifications apply to design and material specification (as referenced in ACI 349-90) and are acceptable to the NRC for design and construction of reinforced concrete structures:

> A-36, A-53, A-82, A-184, A-185, A-242, A-416, A-421, A-496, A-497, A-500, A-501, A-572, A-588, A-615, A-706, A-722, C-33, C-144, C-150, C-595, and C-637[a]

(c) Other reinforced concrete Structures Subject to NRC Approval

The NRC accepts use of either ACI 318 or ACI 349 for reinforced concrete structures that are subject to NRC approval but are not important to safety. If ACI 349 is used for design, the NRC accepts use of ACI 318 for construction.The NRC also accepts the following as criteria as an alternative to the temperature requirements of ACI 349, A.4, but only for the specified uses and temperature ranges:

1. *If concrete temperatures of general or local areas are 200 °F in normal or off-normal conditions/ occurrences, no tests to prove capability for elevated temperatures or reduction of concrete strength are required.*

2. *If concrete temperatures of general or local areas exceed 200 °F but would not exceed 300 °F, no tests to prove capability for elevated temperatures or reduction of concrete strength are required if Type II cement is used and aggregates are selected which are acceptable for concrete in this temperature range. The following criteria for fine and coarse aggregates are acceptable:*

    a. *Satisfy ASTM C33 requirements and other requirements referenced in ACI 349 for aggregates, and*

    b. *Have demonstrated a coefficient of thermal expansion (tangent in temperature range of 70 °F to 100 °F) no greater than 6x10-6 in./in./°F, or be one of the following minerals: limestone, dolomite, marble, basalt, granite, gabbro, or rhyolite.*

3. *If concrete temperatures of general or local areas in normal or off-normal conditions or occurrences do not exceed 225 °F, the requirements of 1 and 2, above, apply to the coarse aggregate, but fine aggregate that meets 1, above, and is composed of quartz sands or sandstone sands may be used in place of compliance with 2.*

(d) Steel Attachments to reinforced concrete Structures

Codes and standards applicable for steel attachments to reinforced concrete structures are described in Subsection IV.3 for structures important to safety and in Subsection IV.4 for other structures subject to approval.

ii. Structural Design Features

Review the adequacy of the information provided in the SAR documentation regarding the physical design of reinforced concrete structures. This should include the following as a minimum:

- dimensioning of all surfaces
- locations, sizes, configuration, spacing, welding, enclosure (e.g., spirals, stirrups), and depth of cover of reinforcement
- locations and specifications for control, contraction, and construction joints
- materials, with defining standards or specifications
- review information on the physical design of embedments and attachments. This should include the following as a minimum:

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[a] Note that this list does not include A-616, A-617, A-767, A-775, or C-989, which are listed in ACI 318. These standard specifications apply if ACI 318 is used for construction.

  - locations, configuration, depth of embedment, interfaces; material; connections and connectors; and, protective or functional coatings

  - dimensions, materials, and specifications for welds

c. Structural Materials

i. Reinforced Concrete Components

Review the completeness, accuracy, and acceptability of the identification and stated properties of the reinforced concrete component materials.

Materials and material properties used for design and construction of reinforced concrete structures within the scope of ACI 359 must comply with the descriptions and requirements of that standard.

Materials and material properties used for the design and construction of reinforced concrete structures important to safety but not within the scope of ACI 359 should comply with the requirements of ACI 349.

Materials and material properties used for the design and construction of reinforced concrete structures that are not important to safety, but are subject to approval should comply with the requirements of ACI 318 (or ACI 349 if that code is used for design of the structures).

ii. Embedments and Attachments

Review the completeness and acceptability of the identification and stated properties of the material to be used for embedments, inserts, conduits, pipes, or other items that are to be embedded in the concrete. Embedments must satisfy the requirements of the code used in designing the reinforced concrete structure in which they are embedded (e.g., ACI 359, ACI 349, or ACI 318). Aluminum should not be used for any embedded objects that will be in contact with wet concrete (because of the potential for concrete degradation from an adverse chemical reaction).

Review the completeness and acceptability of the identification and stated properties of the material to be attached to the reinforced concrete structures. The material must satisfy requirements appropriate to its importance to safety. Unless otherwise specified in this SRP, steel structural attachments must comply with the appropriate requirements of ACI-349.

d. Structural Analysis

i. Load Conditions

Subsection V.1.d, above, provides guidance regarding the review of load conditions applicable to ISFSI structures in general. This subsection focuses on load conditions of special concern, and load combinations specifically for reinforced concrete structures. Review the appropriateness, completeness, and correctness of the applicant’s proposed implementation of these load conditions and combinations for the reinforced concrete structures.

Load definitions and load combinations shown in Table 3-1 have been accepted by NRC for analysis of steel and reinforced concrete ISFSI structures important to safety. The load combinations are as included or derived from ANSI/ANS 57.9 and ACI 349.

Structures important to safety should have sufficient capability for every section to withstand the worst-case normal and off-normal conditions without permanent deformation and with no degradation of capability to withstand any future loadings.

(1) Normal Conditions

Review the SAR documentation to ensure adequate inclusion of the following conditions that may be of particular concern for reinforced concrete structures:

- live and dynamic loads associated with transfer of the confinement cask to and from its storage position

- live and dynamic loads associated with installing closures
- load or support conditions associated with potential differential settlement of foundations over the life of the cask system
- thermal gradients associated with the normal range of operations and ranges of ambient temperature
- thermal gradients that may result from impingement of rain on highly heated concrete

(2) Off-Normal Conditions

Review the SAR to ensure adequate inclusion of the following off-normal operations and events that may be of particular concern for reinforced concrete structures:

- live and dynamic loads associated with equipment or instrument malfunctions, or accidental misuse during transfer of the confinement cask to and from its storage position
- situations in which a confinement cask is jammed or moved at an excessive speed into contact with a reinforced concrete structure.
- the impact of reinforced concrete structures by a suspended transfer, confinement, or storage cask
- off-normal ambient temperature conditions (Although they may be less severe than accident conditions, these may be of concern because of different sets of factors in the off-normal and accident load combinations, and because concrete temperature limits for off-normal conditions are the same as for normal conditions. Note that greatly elevated concrete temperatures are allowed for accident conditions, in accordance with ACI 349, Section A.4.)

(3) Accident Conditions and Natural Phenomena events

Review the SAR for adequate inclusion of the following conditions associated with accident and conditions that may be of special concern for reinforced concrete structures:

- loads associated with accidental drops or other impacts during transfer of the confinement cask to and from its storage position
- events that produce extreme thermal gradients in the concrete
- contact caused by earthquake between the confinement cask and the reinforced concrete structures
- drop of a closure into position or onto the structure

The ACI codes are intended to ensure ductile response beyond initial yield of structural components. ACI 349 also imposes conditions on design (beyond those of ACI 318) that effectively increase ductility. In particular, review the proposed reinforced concrete design to ensure that it provides code levels of ductility, by satisfying of the pertinent ACI 349 provisions. Seismic loads are considered to be "impulsive" and, therefore, are subject to the additional design constraints of Appendix C to ACI 349. Other accident conditions or natural phenomenon events may also produce impulsive or impactive loadings requiring the additional requirements of Appendix C to ACI 349.

Check the steel reinforcement schedules and drawings to ensure that any reinforcing steel quantities, sizes, and locations are consistent with the design analysis. Use of more shear and enclosing reinforcement (e.g., stirrups, ties, and spirals) than required does not reduce ductility for the member. Constraints regarding the use of excess steel to ensure that ductility is not reduced do not apply to the shear and enclosure reinforcement.

In particular, consider the following aspects of the design:

- upper limit (60,000 psi, 4219 kgf/cm^2) on the specified yield strength of reinforcement, and lower limit (3000 psi, 211 kgf/cm^2) on concrete specified compressive strength (f'c)
- limit on the amount (cross-section area) of compressive reinforcement in flexural members
- requirements on continuation and development lengths of tensile reinforcement
- specifications for confinement and lateral reinforcement in compression members, in other compressive steel, and at connections of framing members
- aspects of the design that ensure flexure controls (and limits) the response
- requirements for shear reinforcement
- limitations on the amount of tensile steel in the flexural members relative to that which would produce a balanced strain condition
- projected maximum responses to design-basis loads within the permissible ductility ratios for the controlling structural action
- embedments designed to fail in the steel before pullout from the concrete

In addition, review the construction specifications or descriptions (to the extent included in the SAR documentation) to ensure that substitution of materials, use of larger sizes, or placement of larger quantities of steel will be precluded; and that provisions for splicing or development of reinforcing steel will not reduce ductility of the members.

ii. Structural Analysis Methods

Review the analytical documentation regarding the structural analysis methods used for design and verification of the reinforced concrete structures. In particular, ensure that the structural analysis of structures within the scope of ACI 359 comply with the requirements of that standard.

The NRC accepts strength design as presented in the current revision of ACI 349 for reinforced concrete structures important to safety that are not within the scope of ACI 359. If the applicant uses another design approach, the review conducted within the scope of the DCSS SAR evaluation should include in-depth comparison of that approach with the provisions of ACI 349.

The NRC accepts the use of procedures and approaches that are applicable to an ISFSI as described by the regulations referenced in Regulatory Guide 3.53[43]. The NRC also accepts the use of guidance in NUREG-0800 for analysis of natural phenomena; however, the load combinations shown in Table 3-1 and the design and construction requirements of the codes cited above take precedence. For estimation of wind, snow, and rain loads, and for conversion of tornado wind speed to pressure, the NRC accepts ASCE 7. Similarly, the NRC accepts ASCE 4[44] and ASCE 7 as the standards for seismic analysis. In addition, the NRC accepts tornado missile impact analysis in accordance with Kennedy's *Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects.*

(1) Strength Design

Strength (or "ultimate strength") design is the approach usually used in American reinforced concrete design. Strength design is the only design approach that has been accepted for ISFSI reinforced concrete structures not within the scope of ACI 359, and it is the approach used in the current revisions of ACI 318 and ACI 349. These design codes were developed on the basis of extensive empirical experience with concrete construction. The current strength design approach as presented in these codes includes empirically derived requirements and constraints. Determination that a reinforced concrete structure designed by another approach satisfies ACI 349 typically requires clause-by-clause review of the code for compliance.

(2) Allowable Stress Design

Allowable stress design was formerly used as the basis for ACI codes related to reinforced concrete design. However, those codes do not reflect additional experience gained through observations of structural performance and experimental testing, which has since been included in the current approach to strength design. A clause-by-clause comparison of the structural design for compliance with ACI 349 should be performed for reinforced concrete structures not designed using ACI 349.

(3) Analytical Codes and Models

The NRC has accepted the use of different analytical codes and models for structural analysis of reinforced concrete structures. Uses have included development of stresses resulting from seismic events and thermal gradients. The NRC does not require use of computer models and codes for analysis of the responses or stresses of simple ISFSI concrete structures. In addition, the NRC does not require that the codes used have been developed under rigid nuclear safety quality controls (e.g., ASME NQA-2[45]). However, the codes must be appropriately validated for their intended use.

For multi-story and complex reinforced concrete structures, the NRC has accepted the use of analytical codes intended for dynamic analysis. Determine if the use or absence of use of such codes is acceptable for specific analyses. The bases for acceptance may be the simplicity of the structure, extent or details provided in other calculations, or demonstration that the structural demands in the area of analysis are sufficiently low relative to the estimated capacity of the structure. Acceptance, on the basis of one or more of these conditions, should be such that further refinement of the computations would have negligible effect on the conclusion.

iii. Structural Evaluation

(1) Structural Capability

Review the selection or identification of the critical sections of the reinforced concrete structures to determine whether the structures conform with the design criteria regarding safety under the different load combinations. "Critical sections" are those that have the lowest margins of safety under the various loading conditions and types of stress. These sections may be selected on the basis of inspection, testing, sensitivity analysis, and/or finite-element analysis. The following paragraphs provide guidance for evaluating the identification of critical sections.

In particular, loads and stress demands for structures within the scope of ACI 359 (per CC-1100) shall be as defined and described in that standard.

Unless the lowest margins of safety have been determined by finite-element analysis using the applicable load combinations, critical sections should be identified for each structurally distinct element of the reinforced concrete structure. An integrally cast structure may have multiple structurally distinct elements (e.g., the different sides, base, and roof of a vault; and the base, corners, side walls, lips, and any structural discontinuities of an reinforced concrete cylinder such as at a trunnion).

The level of refinement needed in identifying critical sections depends primarily on the margins of safety and secondarily on the importance to safety.

Many reinforced concrete structures are designed primarily to provide radiation shielding. Such structures may have significantly excess capacity for structural loadings because of the use of section thicknesses selected for shielding and satisfying code requirements for minimum reinforcing steel. Structures important to safety may have such high margins of safety that only elementary structural computations are necessary to acceptably demonstrate compliance with all of the applicable load combinations. For simple elementary analysis, the margin of safety for a particular section should consider the highest axial, bending, and shear stresses occurring concurrently.

Intensive analysis is expected in order to prove that the truly critical sections are used when margins of safety are close to the minimum acceptable values.

The critical sections for bending, shear, axial stress, and combined stresses are typically different for a single structural element. They may also differ for different load combinations.

The lowest margins of safety for structural elements may result when different types of stresses exist under different load combinations.

Design and evaluation for accident loads involve structural loadings and responses that are not typically addressed in non-nuclear construction. In such instances, the structural shapes are not typical. Selection of representative sections for analysis by observation and experience may not be adequate without further computations to demonstrate that no other sections would have lower margins of safety. This could involve, for example, analyses of immediately adjacent sections to prove that margins of safety for the stress type increase in both directions from the section.

Table 3-1 identifies and describes loads used in combinations for reinforced concrete structures not within the scope of ACI 359. The symbols and terminology used in the SAR should correlate with these loads. However, if the symbols and terminology used in the SAR are different but acceptable, they may be used in the SER in place of those in Table 3-1, for consistency between the SER and SAR.

The NRC does not require analysis of load combinations for situations in which nuclear material is not present. However, reinforced concrete structures should not be exposed to credible damage that may not be evident or discovered before completion of construction or use. This could reduce the structural capacity or functional capability of the structure below that which is required. (For example, hidden damage could occur in handling and shipping precast reinforced concrete structures.)

Reinforced concrete structures subject to review but not "important to safety" should satisfy the load combinations of ACI 318, as a minimum.

(2) Fabrication and Construction

(a) Code Construction Criteria

Structures that are within the scope of ACI 359 must be fabricated and constructed in compliance with that standard. For reinforced concrete structures that are not within the scope of ACI 359, the NRC accepts construction in accordance with ACI 349 or ACI 318. Selection and validation of the proper concrete mix to meet design requirements is considered a construction function. By contrast, specification of cement type, aggregates, and special requirements for durability and elevated temperatures is considered a design or material selection function and is, therefore, governed by ACI 349 (and/or ACI 359, if applicable).

The following sections of ACI 318 (chapters, appendix, and paragraphing per ACI-318-95) have been accepted by the NRC for construction of ISFSI reinforced concrete structures that are not within the scope of ACI 359:

Chapter 1,	"General Requirements," Sections 1.1.1, 1.1.2, 1.1.3, and 1.1.5 (except references to design and material properties), and Section 1.3
Chapter 2,	"Definitions" (use ACI 349, Chapter 2)
Chapter 3,	"Materials," Sections 3.1 and 3.8 (except A-616, A-617, A-767, A-775, A-884, and A-934)
Chapter 4,	"Durability Requirements"
Chapter 5,	"Concrete Quality, Mixing, and Placing"
Chapter 6,	"Form Work, Embedded Pipes, and Construction Joints" (except references to design and material properties, which are governed by ACI 349)[b]

The following ASTM standard specifications also apply to construction and associated testing and are acceptable to the NRC:

C-31, C-33, C-39, C-42, C-94, C-109, C-150, C-172, C-192, C-260, C-494, C-496, C-685, and C-1017[c]

In addition, the following construction-related standards are identified in ACI 349 and may also be used:

C-88, C-131, C-289, and C-441

For reinforced concrete structures not important to safety, the NRC also accepts construction in accordance with ACI 318.

(b) Evaluation of Construction Commitments

Review the SAR documentation for inclusion of acceptable specifications for the planned construction and fabrication. Evaluate these specifications against the construction-related requirements in ACI 349 or ACI 318 for reinforced concrete structures not within the scope of ACI 359. For structures that are within the scope of ACI 359, the applicant must commit to fabricate and construct in accordance with ACI 359.

Construction requirements should prohibit the use of aluminum in any forms, chutes, ties, or other objects used in construction that will come in contact with wet concrete. This is because of the potential for concrete degradation as a result of an adverse chemical reaction with aluminum, including the fine particles that may be collected by wet concrete in pipes and chutes.

Construction specifications or drawing notes should preclude use of a greater amount, larger cross-section, or higher-yield of reinforcing steel than that derived by the design analysis. There is no constraint on use of higher strength concrete than that assumed by the design analysis if other properties required of the concrete mix are provided.

(3) Structural Compatibility with Functional Performance Requirements

Review the SAR documentation to ensure that the applicant's analysis of structural responses to DBE demonstrates that the SSC important to safety can continue to perform their intended safety functions. Note that the design codes and load combinations used for reinforced concrete structures important to safety can permit permanent deformation or other damage under design-basis event loading. If structural damage could occur, it is essential that the applicant demonstrate continuing capability with regard to essential functional performance. For reinforced concrete structures, this typically involves shielding the confinement cask from external events, maintaining cooling ventilation, and allowing ready retrieval of the confinement cask. Demonstrating continuing capability involves recognizing the nature and extent of credible damage that may occur and understanding potential interactions between the damaged reinforced concrete structures and other cask system structures important to safety.

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[b] Use ACI 349 for the remainder.

[c] C 1017 is only cited in ACI 318; all others are cited in both ACI 318 and ACI 349.

Under conditions acceptable to the NRC, reinforced concrete structures are not required to survive an accident event with the same capability for a full design life and the same ability to withstand further accidents. Degradation of reinforced concrete structures should be readily apparent in the course of routine inspections and surveillances. Such degradation would also be discovered by the inspections and/or tests that may be proposed as responses to accidents. For example, tornado missile impact may degrade the radiation shielding by cratering a portion of the exterior of the reinforced concrete structure. Such degradation could be adequately repaired. The impact could also cause spalling at an inner, hidden surface, which could affect shielding and cooling air flow. The design should preclude the interior spalling unless the applicant proposes a practical means of detecting and remedying the situation.

The NRC has accepted returning the stored fuel to the spent fuel pool or transfer to an undamaged cask and not making further use of the damaged component, as remedial action for an accident-level event. The NRC may also accept inspection and repair of structural damage, depending on the design and proposed actions and the feasibility of both detection and repair.

3. Other System Components Important to Safety

a. Scope

Subsections V.1.d (i), and (ii), above, provide general guidance for the structural review of cask system components. This portion of the DCSS structural review supplements that guidance by addressing procedures for evaluating all structures that are important to safety (as defined in 10 CFR Part 72), but are not addressed as components of the confinement cask (Subsection V.1, above) and are not constructed using reinforced concrete (Subsection V.2, above). Structures may include items such as gamma and neutron shielding, overpack material, and any respective encasement. This evaluation should include drawings, plans, sections, and technical specifications for these SSC.

b. Structural Design Criteria and Design Features

i. Design Criteria

(1) General Structural Requirements

Structural requirements are driven by the functional roles of the system components and the need to maintain safety. Safety requirements are expressed in the referenced rules, standards, and codes and as criteria specific to the component. The basic safety requirements are that the structural and functional design must preclude the following:

- unacceptable risk of criticality
- unacceptable release of radioactive materials to the environment
- unacceptable radiation dose to the public or workers
- significant impairment of ready retrievability of stored nuclear materials

(2) Applicable Codes and Standards

The NRC accepts the use of ANSI/ANS-57.9 (together with the codes and standards cited therein) as the basic reference for ISFSI structures important to safety that are not designed in accordance with the Section III of the ASME B&PV Code. However, both the lifting equipment design and the devices for lifting system components that are important to safety must comply with ANSI Standard N14.6.

The NRC accepts the load combinations shown in Table 3-1 for structures not designed under either Section III of the ASME B&PV Code or ACI 359. These load combinations are defined on the basis of ANSI/ANS-57.9, with supplemental definition of terms and combinations.

Review the suitability of the applicant's identification of codes and standards that are to be met by the structural design and construction of other components subject to NRC approval. The principal codes and standards include the following references that may apply to steel structures and components:

- AISC,"Specification for Structural Steel Buildings — Allowable Stress Design and Plastic Design"

The NRC has not yet received any applications that propose a steel design on the basis of the AISC's "Load and Resistance Factor Design (LRFD) Specification for Structural Steel Buildings." If such a design was received, the NRC would evaluate the proposal for compliance with the load combinations summarized in Table 3-1 and for consistent application of the LRFD design methodology.

- AWS D1.1,"Structural Welding Code Steel"
- ASCE 7 "Minimum Design Loads for Buildings and Other Structures" [however, note that load combinations established on the basis of ANSI/ANS-57.9 (DCSS SRP Table 3-1) are to be used]
- ACI 349, Appendix B, for embedments or 10.14 for composite compression sections, as applicable, when constructed of structural steel embedded in reinforced concrete [Where requirements do not conflict, the steel must also comply with the requirements of the codes stated above. In addition, ACI 349 defines constraints for obtaining ductile response to extreme loads by ensuring that the strength of steel embedments controls the design; these constraints must not be subverted by overdesign of the steel.]

These documents cite further sources of criteria, which are considered to have the effect of being directly cited or quoted in the basic structural criteria. In addition, the NRC accepts ANSI N14.6 as the basis for design of lifting equipment and components of vessels and other devices provided for lifting, where such equipment is important to safety.

To date, the NRC has not required applicants to design or build steel ISFSI structures important to safety in compliance with ANSI/ANS N690, "Nuclear Facilities — Steel Safety-Related Structures for Design Fabrication and Erection"[46].

For fluid systems that may be connected to a penetration of the confinement barrier outside an enclosing structure licensed under 10 CFR Part 50 (e.g., the fuel pool building), the NRC accepts construction consistent with requirements comparable to those used for Quality Group C, as shown in RG 1.26[47] and NUREG-0800[48], Section 3.2.2. (In this context, "construction" includes materials, design, fabrication, examination, testing, inspection, and certification required in the manufacture and installation of components.) If analysis shows that the maximum conservatively estimated offsite dose would not exceed 0.5 rem to the whole body or any equivalent part of the body, the NRC may accept construction that satisfies Quality Group D. (In this instance, the NRC accepts the analysis procedure identified in RG 1.262, Subsection C.2.d.)

Quality Group C requires construction of piping, pumps, valves, atmospheric storage tanks, and 0–15 psig storage tanks in conformance with Section III of ASME B&PV Code 1, Class 3 (Subsection ND). In addition, Quality Group C requires that supports for these components meet the requirements of Subsection NF.

By contrast, Quality Group D requires compliance with the following codes, as a minimum:

Piping:	ANSI/ASME B31.1, "Power Piping"[49]
Pumps:	Manufacturer's standards
Valves:	ANSI/ASME B31.1 and ANSI B16.34[50]
Atmospheric storage tanks:	AWWA D100, "Standard for Steel Tanks — Standpipes, Reservoirs, and Elevated Tanks for Water Storage"[51] or ANSI/ASME B96.1, "Specification for Welded Aluminum-Alloy Field-Erected Storage Tanks"[52]
0–15 psig storage tanks:	API 620, "Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks"[53]

The NRC accepts the "Boundaries of Jurisdiction" applicable to Section III, Subsections NB-1130 and NC-1130, of ASME B&PV Code 1. These boundaries apply to attachments to penetrations of the confinement barrier outside an enclosure licensed under 10 CFR Part 50. Specifically, these boundaries define whether the attachments must be designed, fabricated, and installed in accordance with Section III, Subsection NB or NC, of ASME B&PV Code 1.

The NRC has not yet received any applications for licensing or approval of a cask system that included masonry important to safety. Masonry is not considered suitable for confinement, but it may be acceptable for enclosures and physical or radiation shielding applications.

In evaluating any future applications that may contain masonry important to safety or otherwise subject to NRC approval, reviewers should focus on the following assessments:

- Determine the acceptability of codes, standards, and specifications used for design, materials, and construction.
- Review the use of and need for any supplementary design or construction criteria appropriate to the analysis or application.
- Evaluate compliance with the codes, standards, specifications, and supplementary criteria. Use of the strength design of masonry procedures (as defined in the Uniform Building Code 32 and ACI 530[54]) would provide the closest parallel to the procedures accepted for reinforced concrete design.
- Evaluate load combinations used for structural analysis and determination of safety margins. These load combinations for masonry structures should include the loads identified in Table 3-1. Specifically, the applicant should select the more conservative load combinations from either those identified in Table 3-1 for reinforced concrete strength design and those specified in the selected masonry code. The appropriate strength reduction factors should also be applied.

The evaluation process may also involve confirmatory staff computations. Specifically, these computations should verify the submitted margins of safety and confirm that the applicant has identified the lowest margins of safety for the significant structural elements.

ii. Structural Design Features

Review the design description in the SAR documentation to ensure that it defines the functional performance required of the structures. The design description should provide for the corresponding capability.

Auxiliary cask system equipment important to safety has often been specially designed. In particular, the structural design features that provide for safety should be supported by design or operational analysis. This analysis should demonstrate that the equipment will meet the basic safety criteria, regardless of problems that may occur in mechanical, electrical, human operator, or other operations.

The NRC has accepted and approved cask system designs that depend on the operation of new mechanical systems for system use. NRC approval does not certify that the mechanical systems will operate as projected, but rather, that proper functioning is necessary to successfully complete a specified operation. Such approval reflects a finding by the NRC staff that, regardless of the system’s success (or lack thereof) in mechanical operation, the basic safety criteria will be met, as stated above.

In accordance with 10 CFR 72.24(i) the SARshall include a schedule showing how the applicant will resolve any safety questions regarding functional adequacy or reliability. The review should focus on resolution of all safety questions before license approval. Safety questions that cannot feasiblely be resolved before license approval should be included in the conditions of use (or license conditions) in the SER.

Review the proposed system design against planned normal, and off-normal, operations and accidents. Determine whether the structural design of the equipment provides for continuing satisfaction of the basic safety criteria. Consider that the equipment could fail to operate at any time (i.e., during operations at the physical limits of speed or range, or during a credible, off-normal, or accident event).

c. Structural Materials

The SAR documentation should fully define the structural materials used for components important to safety that are not addressed in Subsections V.1 and V.2, above. In addition, the SAR should identify properties related to structural performance and resistance or response to thermal, radiation, or other applicable environments.

Confirm that these materials and their properties are derived from acceptable sources. Ensure that the SAR addresses resistance to corrosion in the prospective environments, including the need for protective coatings, protective coating renewal, and/or corrosion allowances. In addition, the SAR should cite controls imposed on material quality, or such controls should be included in codes that are incorporated by reference in the design, fabrication, and construction criteria. The reviewer should be familiar with the information contained within NRC bulletin 96-04: Chemical, Galvanic or other Reactions in Spent fuel Storage and Transportation Casks.

d. Structural Analysis

Subsections V.1.d(i) and (ii) provide guidance regarding structural analysis for cask system structures in general. These subsections provides supplemental guidance primarily related to steel structures, other than the confinement cask and its contents and integral components, which are typically designed to Section III of the ASME B&PV Code

i. Load Conditions

The load definitions and combinations shown in Table 3-1 have been accepted by the NRC for analysis of steel and reinforced concrete ISFSI structures that are important to safety. These load combinations are included in or derived from ANSI/ANS 57.9 and ACI 349.

Structures that are important to safety should have sufficient capability for every section to withstand the worst-case loads under normal and off-normal conditions. Such capability ensures that these structures will not experience permanent deformation or degradation of the capability to withstand any future loadings.

The NRC accepts the load combinations in Table 3-1, which implement and supplement those of ANSI/ANS-57.9.

ii. Structural Analysis Methods

The applicant should select and use analytical methods that are appropriate for the proposed type of materials and construction. In certain instances, however, the applicant may have to adapt existing analytical methods, codes, and models for highly specialized cask system equipment designs. Such instances require special review attention. In particular, ensure that the adapted approach is fully documented, supported, and acceptable. In addition, consider the potential for safety-related risk associated with a possible error in the design of special cask system equipment. The degree of risk indicates the suitability and acceptability of the adapted approach.

iii. Structural Evaluation

In evaluating the variety of cask system equipment and structures that may be important to safety, ensure compliance with the basic safety criteria in Subsection V.3.b(i)(1), above.

4. Other Components Subject to NRC Approval

a. Scope

The cask system description provided in the SAR may include a variety of structures that are not important to safety, such as transporters, ram systems vacuum drying systems, and drain and fill quick disconnects. Review these structures to ensure proper functioning to the extent that the structures represent required elements of the total cask system. In particular, evaluate all structures that are proposed for approval in a design acceptable to the NRC. This evaluation should ensure that the SAR provides sufficient information to confirm the proper functioning of the structures and the overall system. For each system element that is not important to safety, address the potential response to accidents and natural phenomenon events, in order to ensure that the given element will not jeopardize the safety provided by other system elements.

In addition, to the extent that physical protection is incorporated in the cask system design subject to approval, reviewed the design for compliance with 10 CFR 72.182.

b. Structural Design Criteria and Design Features

i. Design Criteria

(1) General Structural Requirements

Structures subject to approval but not important to safety should be reviewed on the based of determining whether the structures can properly perform their intended function(s). In addition, the NRC review should ensure that the response of the structures to credible off-normal and accidents and conditions will not create secondary hazards for cask system components or the stored nuclear materials.

(2) Applicable Codes and Standards

Review the suitability of the applicant's identification of codes and standards to be met by the structural design and construction of other components subject to NRC approval. The principal codes and standards include the following references:

- ASCE 7
- Uniform Building Code (UBC)
- AISC, "Specification for Structural Steel Buildings—Allowable Stress Design and Plastic Design"
- AISC "Code of Standard Practice for Steel Buildings and Bridges"
- ASME B&PV Code, Section VIII

ii. Structural Design Features

Review the adequacy of the applicant's descriptions of cask system components that are not important to safety, but are subject to NRC approval. These descriptions should adequately identify the intended function(s) of each component.

Although the components evaluated in this portion of the DCSS review are not directly important to safety, a credible possibility may exist that the structural response or failure of these components may cause a secondary risk to other components that *are* important to safety or to the subject nuclear material. For example, under tornado or seismic event conditions, the components may impact other components that are important to safety. When such a possibility exists, the applicant must provide more extensive structural information and greater assurance of acceptable fabrication and construction.

c. Structural Materials

Review the identification of structural materials to the extent appropriate to determine if they are adequate for their intended function(s). Determine the required level of review and extent of information in relation to the possibility and consequences of secondary effects on components that are important to safety (see b(ii), above). Materials should be as permitted or specified in the applicable code(s) (see V.3 b(i), above).

d. Structural Analysis

i. Load Conditions

The load definitions and combinations shown in Table 3-1 have been accepted by the NRC for analysis of steel and reinforced concrete ISFSI structures that are important to safety. These load combinations may also be used for structures not important to safety.

In addition, for structures not important to safety, the NRC accepts the use of load combinations given in the Uniform Building Code, as well as ACI 349, ANSI/ANS 57.9, and ASCE 7.

The NRC also accepts the load descriptions, combinations, and analytical approaches given in the ASME B&PV Code, Section VIII, for pressure systems, vessels, and casks that do not form elements of the confinement cask.

ii. Structural Analysis Methods

The reviewer shall evaluate the applicant's selection and use of structural analysis methods, codes, and models and ensure that these are consistent with and appropriate for the design code applicable to the component (as discussed above).

iii. Structural Evaluation

The reviewer may determine that an NRC structural evaluation of certain other components is not necessary for approval of the cask system. Similarly, the NRC may determine that approval of the cask system does not need to include specific components that are not important to safety, even though the applicant seeks approval of those components as part of the application.

The SER should identify the system components that are excluded from the approval, stating the rationale for exclusion of each. As a corollary, the SER should also identify the components that are included, stating any limitations on the scope of the NRC review (e.g., "reviewed for functionality only").

VI. Evaluation Findings

The structural evaluation must provide reasonable assurance that the cask system will allow safe storage of spent fuel. This finding should be reached on the basis of a review that considered the regulation, appropriate Regulatory Guides, applicable codes and standards, and accepted engineering practices. Acceptance of the structural design of a storage cask system therefore implies that the design meets the relevant requirements of the following regulations:

- The SAR adequately describes all structures, systems, and components (SSC) that are important to safety, providing drawings and text in sufficient detail to allow evaluation of their structural effectiveness.

- The applicant has met the requirements of 10 CFR 72.24, "Contents of Application: Technical Information," with regard to information pertinent to structural evaluation.

- The applicant has met the requirements of 10 CFR 72.26, "Contents of Application," and 10 CFR 72.44(c), "License Conditions," with regard to technical specifications pertaining to the structures of the proposed cask system.

- The applicant has met the requirements of 10 CFR Part 72.122(b) and (c) and 10 CFR Part 72.24(c)(3). The structures, systems, and components important to safety are designed to accommodate the combined loads of normal, off-normal, accident, and natural phenomena events with an adequate margin of safety. Stresses at various locations of the cask for various design loads are determined by analysis. Total stresses for the combined loads of normal, off normal, accident, and natural phenomena events are acceptable and are found to be within limits of applicable codes, standards, and specifications.

- The applicant has met the requirements of 10 CFR Part 72.124(a), "Criteria for Nuclear Criticality Safety", and 10 CFR Part 72.236 (b), "Specific requirements for spent fuel storage cask approval." The structural design and fabrication of the DCSS includes structural margins of safety for those SSC important to nuclear criticality safety. The applicant has demonstrated adequate structural safety for the handling, packaging, transfer, and storage under normal, off-normal, and accident conditions.

- The applicant has met the requirements of 10 CFR 72.236(l), "Specific Requirements for Spent Fuel Storage Cask Approval." The design analysis and submitted bases for evaluation acceptably demonstrate that the cask and other systems important to safety will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.

- The applicant has met the requirements of 10 CFR 72.120, "General Considerations," and 10 CFR 72.122, "Overall Requirements," with regard to inclusion of the following provisions in the structural design:
    - design, fabrication, erection, and testing to acceptable quality standards
    - adequate structural protection against environmental conditions and natural phenomena, fires, and explosions
    - appropriate inspection, maintenance, and testing
    - adequate accessibility in emergencies
    - a confinement barrier that acceptably protects the spent fuel cladding during storage
    - structures that are compatible with appropriate monitoring systems
    - structural designs that are compatible with ready retrievability of spent fuel
- The applicant has met the specific requirements of 10 CFR 72.236(e)(f) (g)(h)(i)(j)(k) and (m), as they apply to the structural design for spent fuel storage cask approval. The cask system structural design acceptably provides for the following required provisions:
    - redundant sealing of confinement systems
    - adequate heat removal without active cooling systems
    - storage of the spent fuel for a minimum of 20 years
    - compatibility with wet or dry spent fuel loading and unloading facilities
    - acceptable ease of decontamination
    - inspections for defects that might reduce confinement effectiveness
    - conspicuous and durable marking
    - compatibility with removal of the stored fuel from the site, transportation, and ultimate disposition by the U.S. Department of Energy

Table 3-1 Loads and load combinations

Designations and Descriptions of Loads

Definitions of terms used in the following table are as accepted by the NRC. Many definitions are expanded, with their intended applications more fully described and implemented than in the referenced sources.

Table 3-1 does not apply to the analysis of confinement casks and other components designed in accordance with Section III of the ASME B&PV Code.

Capacities ("S" and "U" terms) and demands (factored or unfactored loads) may be loads, forces, moments, or stresses caused by such loads. Usage must be consistent among the terms used in the load combination. Units of force, rather than mass, are to be used for loads.

Definitions of terms used in the load combination expressions for reinforced concrete and steel are derived from ANSI 57.9, ACI 349, AISC specifications, or another source. Where used in an expression related to steel analysis, definitions derived from ACI 349 are not limited in application to reinforced concrete analyses.

The load combinations defined on the basis of allowable stress apply to total stresses (that is, combined primary and secondary stresses). The load and stress factors do not change if secondary stresses are included.

Symbol	Capacity or Load Term	Source	Capacity or Load (or Demand) Description
S	Steel ASD strength	ANSI 57.9	Strength of a steel section, member, or connection computed in accordance with the "allowable stress method" of the AISC "Specification for Structural Steel Buildings." Note exception for shear strength (see $S_{v)}$.
S_v	Steel ASD shear strength	ANSI 57.9	Shear strength of a section, member, or connection computed in accordance with the "allowable stress method" of the AISC "Specification for Structural Steel Buildings."
Us	Steel plastic strength	ANSI 57.9	Strength (capacity) of a steel section, member, or connection computed in accordance with the "plastic strength method" of the AISC "Specification for Structural Steel Buildings."
U_c	reinforced concrete available strength	ANSI 57.9, ACI 349	Minimum available strength (capacity) of reinforced concrete section, member, or embedment to meet the load combination, calculated in accordance with the requirements and assumptions of ACI 349 and, after application of the strength reduction factor, Ø, as defined and prescribed at §9.2, "Design Strength," of ACI 349. If strength may be reduced during the design life by differential settlement, creep, or shrinkage, those effects shall be incorporated in the dead load, D (instead of by subtraction from minimum available strength). reinforced concrete footing and foundation sections whose demand loads are dominated by the maximum soil reaction may be designed and evaluated using U_f.

Symbol	Capacity or Load Term	Source	Capacity or Load (or Demand) Description
U_f	Strength of foundation sections	ANSI 57.9	Minimum available strength of reinforced concrete footing and foundation sections whose demand loads are dominated by the maximum soil reaction, and after the strength reduction factor, Ø, as defined and prescribed at §9.2, "Design Strength," of ACI 349 is applied. Structural elements interface with columns, walls, grade beams, or footings and foundations should be evaluated by using load factors and load combinations for U_c. These interface elements include anchor bolts and other embedments, dowels, lugs, keys, and reinforcing extended into the footing or foundation.
U_g	Soil reaction or pile capacity	ANSI 57.9	Minimum available soil reaction or pile capacity is determined by foundation analysis (included with a license application SAR, or expressed in a SAR for approval of a cask system as a required minimum for the cask system design). U_g is derived using the same load factors and load combinations as shown for determination of Uc.
O/S	Overturning/ sliding resistance	ANSI 57.9	Required minimum available resistance capacity of structural unit against both overturning or sliding. Capacities for resistance of overturning and sliding are checked against the factored load combination separately, although the minimum margins of safety may occur concurrently. O/S is not determined by strength capacities of structural elements. Stress or strength demands resulting from an overturning or sliding situation are evaluated in load combinations involving S, S_v, U_s, U_c, and U_f.
	All loads used in combination	ANSI 57.9 ACI 349	If any load reduces the effects of the combination of the other loads, and that load would always be present in the condition of the specific load combination, the net coefficient (factor) for that load shall be taken as 0.90. If the load may not always be present, the coefficient for that load shall be taken as zero. Each load that may not always be present in the load combinations is to be varied from 0 to 100% to simulate the most adverse loading conditions (to the extent of proving that the lowest margins of safety have been determined).

Symbol	Capacity or Load Term	Source	Capacity or Load (or Demand) Description
D	Dead load	ANSI 57.9	Dead load of the structure and attachments including permanently installed equipment and piping. The weight and static pressure of stored fluids may be included as dead loads when these are accurately known or enveloped by conservative estimates. Loads resulting from differential settlement, creep, and/or shrinkage, if they produce the most adverse loading conditions, are included in dead load. If differential settlement, creep, or shrinkage would reduce the combined loads, it shall be neglected. D includes the weight of soil vertically over a footing or foundation for the purposes of determining U_g, U_f. and O/S. Regardless of the load combination factor applied, D is to be varied by +5% if that produces the most adverse loading condition.
L	Live loads	ANSI 57.9 ACI 349	Live loads, including equipment (such as a loaded storage cask) and piping not permanently installed, and all loads other than dead loads that might be experienced that are not separately identified and used in the load combination, and that are applicable to the situation addressed by the load combination. Typically includes the gravity and operational loads associated with handling equipment, and routine snow, rain, ice, and wind loads and normal and off-normal impacts of equipment. Loads attributable to piping and equipment reactions are included. Depending on the case being analyzed, may include normal or off-normal events not separately identified, as may be caused by handling (not including drop), equipment or instrument malfunction, negligence, and other man-made or natural causes. Live loads attributable to casks with stored fuel need only be varied by credible increments of loading of an individual cask. Live loads attributable to multiple casks should be varied for the presence and positioning of one or more cask(s), as necessary and varied to determine the lowest margins of safety.

Symbol	Capacity or Load Term	Source	Capacity or Load (or Demand) Description
L	Live load for precast structures before final integration in-place		Live loads for precast structures shall consider all loading and restraint conditions from initial fabrication to completion of the structure, including form removal, storage, transportation, and erection. The NRC is only concerned with analysis of loading of reinforced concrete structures before use for ISFSI functions to the extent that the structures should not risk damage that may not be evident, thereby jeopardizing the capacity of the structures when in use. If the damage would be visibly obvious before installation, analysis of capacity versus pre-completion demands is not required.
DB_	"Design-basis" (accident-level) loads	10 CFR 72	Design-basis loads are controlling bounds for the following external event estimates: (1) extreme credible natural events to be used for deriving design bases that consider historical data or rated parameters, physical data, or analysis of upper limits of the physical processes involved (2) extreme credible external man-induced events used for deriving design bases on the basis of analysis of human activity in the region taking into account the site characteristics and associated risks. Design-basis loads include credible accidents and extreme natural phenomena. Presumption of concurrent independent accidents or severe natural phenomena producing compounding design-basis loads is not required. Capacity to resist design basis loads can be assumed to be that of a structure that has not been degraded by previous design basis loads, unless prior significant degradation in structural capacity may credibly occur and remain undetected.
T	Thermal loads	ANSI 57.9 NUREG-0800, Section 3.8.3)	Thermal loads, including loads associated with "normal" condition temperatures, temperature distributions, and thermal gradients within the structure; expansions and contractions of components; and restraints to expansions and contractions, with the exception of thermal loads that are separately identified and used in the load combination. Thermal loads shall presume that all loaded fuel has the maximum thermal output allowed at time of initial loading in the ISFSI. Thermal loads shall be determined for the most severe of both steady-state and transient conditions. For multiple cask storage facilities, thermal loads shall be determined for the worst-case loadings on potentially critical sections (e.g., all in place, only one cask in place, alternating casks in place).

Symbol	Capacity or Load Term	Source	Capacity or Load (or Demand) Description
T_a	Accident-level thermal loads	ANSI 57.9, ACI 349	Thermal loads produced directly or as a result of *off-normal or design-basis* accidents, fires, or natural phenomena. [Note: Although off-normal and design-basis thermal loads are treated the same in the load combinations, there is a distinction between off-normal and design-basis temperature limits for concrete. Off-normal temperature limits are the same as for "normal" conditions.] For multiple cask storage facilities, thermal loads shall be determined for the worst-case loadings on potentially critical sections.
A	Accident loads	ANSI 57.9	Loads attributable to the direct and secondary effects of an off-normal or design-basis accident, as could result from an explosion, crash, drop, impact, collapse, gross negligence, or other man-induced occurrences; or from severe natural phenomena not separately defined. Loads attributable to direct and secondary effects may be assumed to be non-concurrent unless they might be additive. The capacity for resistance to the demand resulting from secondary effects would be that residual capacity following any degradation caused by the direct effect.
H	Lateral soil pressure	ANSI 57.9	Loads caused by lateral soil pressure as would exist in normal, off-normal, or design-basis conditions corresponding to the load combination in which used. H includes lateral pressure resulting from ground water, the weight of the earth, and loads external to the structure transmitted to the structure by lateral earth pressure (not including earthquake loads, which are included in E, see below). H does not include soil reaction associated with attempted lateral movement of the structure or structural element in contact with the earth.
G	Loads attributable to soil reaction	ANSI 57.9	Used only in load combinations for footing and foundation structural sections for which demand is limited by the soil reactions. G represents loads attributable to the maximum soil reaction (horizontal (passive pressure limit) and vertical (soil or pile bearing limit)) that would exist in normal, off-normal, or design-basis conditions, corresponding to the load combination in which used. G is a function of U_g (i.e., $G = f(U_g)$).
W	Wind loads	ACI349	Winds loads produced by normal and off-normal maximum winds. Pressure resulting from wind and with consideration of wind velocity, structure configuration, location, height above ground, gusting, importance to safety, and elevation may be calculated as provided by ASCE 7.

Symbol	Capacity or Load Term	Source	Capacity or Load (or Demand) Description
W_t	Tornado loads	ACI 349	Loads attributable to wind pressure and wind-generated missiles caused by the design-basis tornado or design-basis wind (for sites where design-basis wind rather than tornado produces the most severe pressure and missile loads). Pressure resulting from wind velocity and elevation may be calculated as provided for these factors in ASCE 7. Tornado wind velocity or pressure does not have to be increased for structure importance, gusting, location, height above ground, or importance to safety (these do apply for design-basis wind).
E	Earthquake loads		Loads attributable to the direct and secondary effects of the design-basis or off-normal flood, including flooding caused by severe and extreme natural phenomena (e.g., seiches, tsunamis, storm surges), dam failure, fire suppression, and other accidents.

Load Combinations for Steel and reinforced Concrete (reinforced concrete) Structures

The reinforced concrete structure load combinations apply to reinforced concrete structures important to safety that are not within the scope of ACI 359 (ASME B&PV Code, Section III, Division 2). The load combinations apply to steel structures important to safety that are not within the scope of the ASME B&PV Code, Section III, Division 1. The NRC accepts, but does not require use of these load combinations for steel and reinforced concrete structures that are not important to safety. The NRC accepts steel analyses that reflect allowable stress design or plastic strength design. Steel load combinations may be determined on the basis of the set of load combination expressions involving either "S" or "U_s."

Load Combination	Derivation (Reference)	Acceptance Criteria
Reinforced Concrete Structures — Normal Events and Conditions		
$U_c > 1.4\ D + 1.7\ L$	ANSI 57.9	Capacity/demand >1.00 for all sections
$U_c > 1.4\ D + 1.7\ (L + H)$	ANSI 57.9	Capacity/demand >1.00 for all sections
Reinforced Concrete Structures — Off-Normal Events and Conditions		
$U_c > 1.05\ D + 1.275\ (L + H + T)$	ANSI 57.9	Capacity/demand >1.00 for all sections
$U_c > 1.05\ D + 1.275\ (L + H + T + W)$	ANSI 57.9	Capacity/demand >1.00 for all sections

Load Combination	Derivation (Reference)	Acceptance Criteria
Reinforced Concrete Structures —Accidents and Conditions		
$U_c > D + L + H + T +(E \text{ or } F)$	ANSI 57.9	Capacity/demand >1.00 for all sections.
$U_c > D + L + H + T + A$	ANSI 57.9	Capacity/demand >1.00 for all sections. An overturning accident for a cask in transfer or in separate storage on a pad is to be assumed, unless more severe overturning also occurs as a result of a natural phenomenon.
$U_c > D + L + H + T_a$	ANSI 57.9	Capacity/demand >1.00 for all sections.
$U_c > D + L + H + T + W_t$	ANSI 57.9 ACI 349	The load combination (capacity/demand >1.00 for all sections) shall be satisfied without missile loadings. Missile loadings are additive (concurrent) to the loads caused by the wind pressure and other loads; however, local damage may be permitted at the area of impact if there will be no loss of intended function of any structure important to safety.
Reinforced Concrete Footings/Foundations —Normal Events and Conditions		
$U_f > D + (L + G)$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
$U_f > D + (L + H + G)$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
Reinforced Concrete Footings/Foundations —Off-Normal Events and Conditions		
$U_f > D + (L + H + T + G)$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction
$U_f > D + (L + H + T + W + G)$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
Reinforced Concrete Footings/Foundations —Accident-Level Events and Conditions		
$U_f > D + L + H + T + E + G$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.

Load Combination	**Derivation (Reference)**	**Acceptance Criteria**
$U_f > D + L + H + T + A + G$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
$U_f > D + L + H + T_a + G$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
$U_f > D + L + H + T + W_t + G$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
$U_f > D + L + H + T + F + G$	ANSI 57.9 ACI 349	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
Steel Structures Allowable Stress Design — Normal Events and Conditions		
$(S \text{ and } S_v) > D + L$	ANSI 57.9	Factored strength/demand >1.00 for all sections
$(S \text{ and } S_v) > D + L + H$	ANSI 57.9	Factored strength /demand >1.00 for all sections
Steel Structures Allowable Stress Design — Off-Normal Events and Conditions		
$1.3\ (S \text{ and } S_v) > D + L + H + W$	ANSI 57.9	Factored strength /demand >1.00 for all sections
$1.5\ S > D + L + H + T + W$	ANSI 57.9	Factored strength/demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile.
$1.4\ S_v > D + L + H + T + W$	ANSI 57.9	Factored strength/demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile.

Load Combination	Derivation (Reference)	Acceptance Criteria
Steel Structures Allowable Stress Design — accidents and Conditions		
$1.6\ S > D + L + H + T +$ $(E \text{ or } W_t \text{ or } F)$	ANSI 57.9; ACI 349	Factored strength/demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile.
$1.4\ S_v > D + L + H + T +$ $(E \text{ or } W_t \text{ or } F)$	ANSI 57.9; ACI 349	Factored strength (allowable stress design)/demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile.
$1.7\ S > D + L + H + T + A$	ANSI 57.9	Factored strength/demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile..
$1.4\ S_v > D + L + H + T + A$	ANSI 57.9	Factored strength/demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile.
$1.7\ S > D + L + H + T_a$	ANSI 57.9	Factored strength/demand >1.00 for all sections
$1.4\ S_v > D + L + H + T_a$	ANSI 57.9	Factored strength/demand >1.00 for all sections
Steel Structures Plastic Strength Design — Normal Events and Conditions		
$U_s > 1.7\ (D + L)$	ANSI 57.9	Plastic capacity/ demand >1.00 for all sections
$U_s > 1.7\ (D + L + H)$	ANSI 57.9	Plastic capacity/ demand >1.00 for all sections
Steel Structures Plastic Strength Design — Off-Normal Events and Conditions		
$U_s > 1.3\ (D + L + H + W)$	ANSI 57.9	Plastic capacity/ demand >1.00 for all sections.

Load Combination	**Derivation (Reference)**	**Acceptance Criteria**
$U_s > 1.3 (D + L + H + T + W)$	ANSI 57.9	Plastic capacity/ demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile.
Steel Structures Plastic Strength Design — accidents and Conditions		
$U_s > 1.1 (D + L + H + T + (E \text{ or } W_t \text{ or } F))$	ANSI 57.9	Plastic capacity/ demand >1.00 for all sections. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile. The load combination (capacity/demand >1.00 for all sections) shall be satisfied without missile loadings. Missile loadings are additive (concurrent) to the loads caused by the wind pressure and other loads, however local damage may be permitted at the area of impact if there will be no loss of intended function of any structure important to safety.
$U_s > 1.1 (D + L + H + T + A)$	ANSI 57.9	Plastic capacity/ demand >1.00 for all sections. An overturning accident for a cask in transfer or in separate storage on a pad is to be assumed unless more severe overturning also occurs as a result of a natural phenomenon. Thermal loads may be neglected when analysis shows that they are secondary and self-limiting in nature, and when the material is ductile.
$U_s > 1.1 (D + L + H + T_{a)}$	ANSI 57.9	Plastic capacity/ demand >1.00 for all sections
Overturning and Sliding — Normal and Off-Normal Events and Conditions		
$O/S \geq 1.5 (D + H)$	ANSI 57.9	Capacity/demand ≥1.00 for structure, to be satisfied for both overturning and sliding
Overturning and Sliding — accidents and Conditions		
$O/S \geq 1.1 (D + H + E)$	ANSI 57.9	Capacity/demand ≥1.00 for structure, to be satisfied for both overturning and sliding

Load Combination	**Derivation (Reference)**	**Acceptance Criteria**
$O/S \geq 1.1 (D + H + W_t)$	ANSI 57.9	Capacity/demand $\geq$1.00 for structure, to be satisfied for both overturning and sliding

VII. References

Except for Federal regulations, the documents listed below are suitable for use as references in SARs relevant to structural design and evaluation to the extent described in this chapter. The citations below refer to the latest version of each document, except where a specific edition is indicated. References noted in the documents cited below are considered incorporated to this list. References to "Parts" of the *U.S. Code of Federal Regulations* shall be presumed to imply the "current Code," which includes all changes effective as of the date of submission of the application for approval.

1. *U.S. Code of Federal Regulations*, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," Title 10, "Energy"

2. *U.S. Code of Federal Regulations*, Part 100, "Reactor Site Criteria’ Title 10, "Energy"

3. U.S. Nuclear Regulatory Commission, "System Evaluation Program", Office of Nuclear Reactor Regulation

4. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, "Rules for Construction of Nuclear Power Plant Components"

5. American National Standards Institute, American Nuclear Society, " Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type)," ANSI/AND-57.9

6. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components,"

7. American Concrete Institute and American Society of Mechanical Engineers (Joint Committee), "Code for Concrete Reactor Vessels and Containments," ACI 359, (also designated as ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," Division 2)

8. American Concrete Institute, "Building Code Requirements for Reinforced Concrete," ACI 318

9. American Concrete Institute, "Code Requirements for Nuclear Safety Related Concrete Structures ACI 349

10. U.S. Nuclear Regulatory Commission, "Design of an Independent Spent Fuel Storage Installation (Dry Storage)," Regulatory Guide 3.60

11. ANSI N14.6. "American National Standards for Radioactive Material Lifting Devices for Sipping Containers Weighing 10,000 lbs (4500 kg) or More"

12. American Institute of Steel Construction, "Specification for Structural Steel Buildings — Allowable Stress Design and Plastic Design," published in the AISC "Manual of Steel Construction"

13. American Institute of Steel Construction, "Load and Resistance Factor Design Specification for Structural Steel Buildings"

14. American Welding Society, "Structural Welding Code Steel," AWS D1.1. [This should be cited as applicable for structures that are subject to certification and are not within the specific scope of the ASME B&PV Code for the confinement cask.]

15. American Society of Civil Engineers, "Minimum Design Loads for Buildings and Other Structures," ASCE 7

16. American Concrete Institute, "Code Requirements for Nuclear Safety Related Concrete Structures," ACI 349-85, Appendix B

17. International Conference of Building Officials (ICBO) "Uniform Building Code", (UBC)

18. American Institute of Steel Construction, "Code of Standard Practice for Steel Buildings and Bridges," published in the AISC "Manual of Steel Construction"

19. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section VIII, "Rules for the Construction of Pressure Vessels"

20. U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 inches (0.1m)," Regulatory Guide 7.11, June 1991

21. U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 inches (0.1m)," Regulatory Guide 7.12, June 1991

22. W.R. Holman, *et al*., "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to 4 Inches Thick," NUREG/CR-1815, Lawrence Livermore National Laboratory, June 1981

23. U.S. Nuclear Regulatory Commission, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," Regulatory Guide 7.6, March 1978

24. American Welding Society, "Standard Symbols for Welding, Brazing, and Nondestructive Examination," AWS A2.4

25. U.S. Nuclear Regulatory Commission, "A study on Ductile and Brittle Failure Design Criteria for Ductile Cast Iron Spent-Fuel Shipping Containers" NUREG-3760, January, 1986

26. NRC bulletin 96-04 “Chemical, Galvanic, or other Reactions in Spent Fuel Storage and Transportation Casks”, July 1996

27. *U.S. Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities," Title 10, "Energy"

28. *U.S. Code of Federal Regulations*, Part 71, "Packaging and Transportation of Radioactive Materials," Title 10, "Energy"

29. S.F. Hoerner, *Fluid-Dynamics Drag*, Hoerner Fluid Dynamics, P.O. Box 342 Brick Town NJ, 1965

30. U.S. Nuclear Regulatory Commission,"Design-Basis Tornado for Nuclear Power Plants," Regulatory Guide 1.76, April 1974

31. U.S. Nuclear Regulatory Commission, "Standard Review Plan for Power Reactors," NUREG-0800

32. W.B. Cottrell and A.W. Savolainen, Oak Ridge National Laboratory, "U. S. Reactor Containment Technology," ORNL-NSIC-5, Vol. 1, Chapter 6

33. R.P. Kennedy, *Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects*, Holmes and Narver Inc., Sept. 1975

34. R.J. Roark, *Formulas for Stress and Strain*, McGraw Hill, 1965

35. J.R. Stokley and D.H. Williamson, "Structural Integrity of Spent Nuclear Fuel Storage Casks Subjected to Drop," *Nuclear Technology*, Volume 114, Number 1, April, 1996.

36. U.S. Nuclear Regulatory Commission, "Control of Heavy Loads at Power Plants NUREG-0612, July 1980

37. A.S. Lee, S.E. Bumpas, Buckling Analysis if Spent Fuel Basket, NUREG/CR-6322, Lawrence Livermore National Laboratory, May, 1995

38. G.C. Mok, L.E. Fischer, Lawrence Livermore National Laboratory, S.T. Hsu, Kaiser Engineering "Stress Analysis of Closure Bolts for Shipping Casks," NUREG/CR-6007, January 1993

39. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section IX, "Welding and Brazing Qualifications"

40. U.S. Nuclear Regulatory Commission "Design Control for ISFSI Components", Inspection Procedure 60851

41. U.S. Nuclear Regulatory Commission, "Design of an Independent Spent Fuel Storage Installation" Regulatory Guide 3.60, March 1987

42. National Fire Protection Association, "Electric, Life Safety, and Lightning Protection Codes"

43. U.S. Nuclear Regulatory Commission, "Applicability of Existing Regulatory Guides to the Design and Operation of an Independent Spent Fuel Storage Installation," Regulatory Guide 3.53, July 1982

44. American Society of Civil Engineers, "Seismic Analysis of Safety-Related Nuclear Structures," ASCE 4

45. American Society of Mechanical Engineers, "Quality Assurance Program Requirements for Nuclear Facilities" ASME NQA-2

46. American National Standards Institute, American Nuclear Society, "Nuclear Facilities — Steel Safety-Related Structures for Design Fabrication and Erection," ANSI/AND N690

47. Nuclear Regulatory Commission, Regulatory Guide 1.26, U.S., "Quality Group Classification and Standard for Water-,Steam-, and Radioactive-Waste-Container Components of Nuclear Power Plants"

48. U.S. Nuclear Regulatory Commission, "Standard Review Plan For Nuclear Power Plants" NUREG-0800 Section 3.2.2

49. American National Standards Institute, American Society of Mechanical Engineers, "Power Piping," ANSI/ASME B31.1

50. American National Standards Institute, "ANSI B16.34 "Valves", B31.1"Power Piping" 1973

51. American Water Works Association, "Standard for Steel Tanks — Stand pipes, Reservoirs, and Elevated Tanks for Water Storage," AWWA D100

52. American National Standards Institute, American Society of Mechanical Engineers, "Specification for Welded Aluminum-Alloy Field-Erected Storage Tanks," ANSI/ASME B96.1

53. American Petroleum Institute, "Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks," API 620

54. American Concrete Institute, "Building Code Requirements for Masonry Structures," ACI 530