4 STRUCTURAL EVALUATION

4.1 Review Objective

The objective of the U.S. Nuclear Regulatory Commission's (NRC's) structural review is to ensure that the structural integrity of structures, systems, and components (SSCs) of the dry storage facility (DSF), which includes independent spent fuel storage installations (ISFSIs) and monitored retrievable storage installations (MRSs), or of a dry storage system (DSS), emphasizing SSCs important to safety (identified in Chapter 3 of the safety analysis report (SAR)). These SSCs may provide confinement, subcriticality, radiation shielding, support, and retrievability safety functions of the stored materials, and therefore, should be appropriately maintained under all credible loads and their combinations for normal, off-normal, and accident conditions and natural phenomena effects. These SSCs include pool and pool confinement facilities. Because the pool and pool confinement facilities are not routinely part of a storage facility application, they are not included in the standard review, but are presented in Appendix 4B. The evaluation should result in a reasonable assurance that storage systems and associated facilities will maintain their intended function.

4.2 Applicability

This chapter applies to the review of applications for specific licenses for an ISFSI or a MRS facility, categorized as a DSF. It also applies to the review of applications for a certificate of compliance (CoC) of a DSS for use at a general license facility. Sections that apply only to specific license applications have "**(SL)**" in the heading. Sections that apply only to CoC applications have "**(CoC)**" in the heading. In this chapter, these designations only appear in Table 4-1b and Section 4.6, "Evaluation Findings." All other sections apply to both types of applications, as specified in the text.

4.3 Areas of Review

This chapter applies to the evaluation of structural integrity for SSCs important to safety and other SSCs. It broadly categorizes the applicable regulatory requirements, acceptance criteria, and review procedures into features common to all SSCs, followed by areas of review for site-specific SSCs, outlined as follows:

4.3.1 Structures, Systems, and Components Important to Safety

- confinement canister (shell and associated welds and bolts)
  - fuel basket
  - fuel and cladding
  - racks for positioning stored fuel or waste material within the canister or cask (including lifting components)
  - closure lids
  - closure welds
- transfer cask
- storage overpack (horizontal, vertical, or underground)
- storage cask

4.3.2 Other Structures, Systems, and Components Subject to NRC Approval

- concrete pads for placement of storage systems. Concrete storage pads may be classified important to safety depending on the application
- SSCs associated with the transfer of confinement and transfer casks on site, including cask loading and extraction equipment, trailers, prime movers, crane, and equipment unique to the cask system whose failure would not jeopardize the basic safety requirements of the confinement system
- SSCs including cranes and other equipment for intermodal transfer of containers holding nuclear materials, such as truck, rail, and barge and ship docks whose failure would not jeopardize the basic safety criteria
- onsite SSCs associated with facilities other than for the ISFSI or MRS but which are shared by the ISFSI and MRS, or that are physically connected to SSCs supporting the ISFSI or MRS, or both, and that have safety or safeguards and security-related functions
- onsite radioactive material transfer route structures, such as bridges, roads, rail crossings and heavy-haul paths
- structures and earthworks to prevent facility flooding on site
- SSCs, including equipment, that provide fire protection or that may be required to mitigate the effects of accident events
- other SSCs required for compliance with code safety requirements, such as for lightning protection

4.4 Regulatory Requirements and Acceptance Criteria

This section summarizes those parts of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste and Reactor-Related Greater Than Class C Waste," that are relevant review areas. Tables 4-1a and 4-1b match the relevant regulatory requirements to the areas of review this chapter covers. Table 4-1a matches the relevant regulatory requirements to the areas of review for specific license applications. Table 4-1b matches the relevant regulatory requirements to the areas of review for a CoC. Refer to the language in the regulations and verify the association of the regulatory requirements with the areas of review presented in the table to ensure that no requirements are overlooked as a result of unique applicant design features.

Table 4-1a Relationship of Regulations and Areas of Review for a DSF (SL)

Areas of Review	10 CFR Part 72 Regulations					
	Subpart B	Subpart C	Subpart F			
	72.24	72.40	72.120	72.122	72.124	72.128
SSCs Important to Safety	(b)(c)(d)(i)	(a)(1)	(a)	(a)(b)(c)(d)(l)	(a)(b)	(a)(2), (a)(3)
Other SSCs	(b)(c)	(a)(1)		(b)(2)(ii), (d)	(a)	
Pool and Facilities (see Appendix 4B)	(b)(c)(d)(i)	(a)(1)	(a), (b)(3)	(a)(b)(c)(d)(l)	(a)(b)	(a)(2), (a)(3)

Table 4-1b Relationship of Regulations and Areas of Review for a DSS (CoC)

Areas of Review	10 CFR Part 72 Regulations		
	Subpart F	Subpart L	
	72.124	72.234	72.236
SSCs Important to Safety	(a)(b)	(a)	(b)(c)(d)(e)(g)(h)(l)(m)
Other SSCs	(a)(b)		

Acceptability of the design of the SSCs as described in the SAR is based on compliance with the requirements in 10 CFR Part 72 and regulatory guidance as determined by independent calculations and staff judgment. The designs of the SSCs are acceptable if they meet general or specific design criteria discussed in this Standard Review Plan (SRP).

DSS or DSF applications have a one-step license approval process. Thus, the evaluation of the SAR and the supporting materials is the sole occasion during which the NRC staff comprehensively reviews the design and proposed construction.

SSCs important to safety are required to have sufficient structural capacity so that the structure can withstand the postulated worst-case loads under normal, off-normal, and accident conditions described in Section 4.5, “Review Procedures,” of this SRP, while performing their required function (confinement, shielding, subcriticality). The NRC does not accept breach of the storage confinement.

SSCs important to safety are expected to withstand the postulated worst-case loads under postulated accident conditions to successfully prevent preclude the following events:

- unacceptable risk of criticality

- unacceptable release of radioactive materials to the environment
- unacceptable radiation dose to the public or workers
- significant impairment of retrievability or recovery, as applicable, of stored nuclear materials for postulated normal and off-normal conditions.

This position does not necessarily require that the confinement system and other structures important to safety survive every postulated design-basis accident condition without any permanent deformation or other damage. Some load combination expressions for the design-basis conditions for structures important to safety permit stress levels that exceed the yield strength of the material. The SAR should include computations of the maximum extent of potentially significant accident deformations and any permanent deformations, degradation, or other damage that may occur.

Similarly, the review of the other SSCs should ensure their structural integrity under the loading resulting from postulated normal, off-normal, and accident conditions, as defined in the glossary to this SRP. Section 4.5.2 of this SRP provides a more detailed discussion for the review requirements and acceptance criteria for the SSCs.

4.5 Review Procedures

Review the entire SAR, particularly the sections that describe the overall design and operations, the design criteria including the site characterization and bases, the structural evaluation information, the accident analysis, and the operating controls and limits. Coordinate with the materials reviewer to ensure that the materials and their associated structural properties are consistent with those used in the structural evaluations. Review any drawings and calculation packages submitted with the SAR for the particular SSC being evaluated. Figure 4-1 shows the interrelationship between the structural evaluation and the other areas of review described in this SRP.

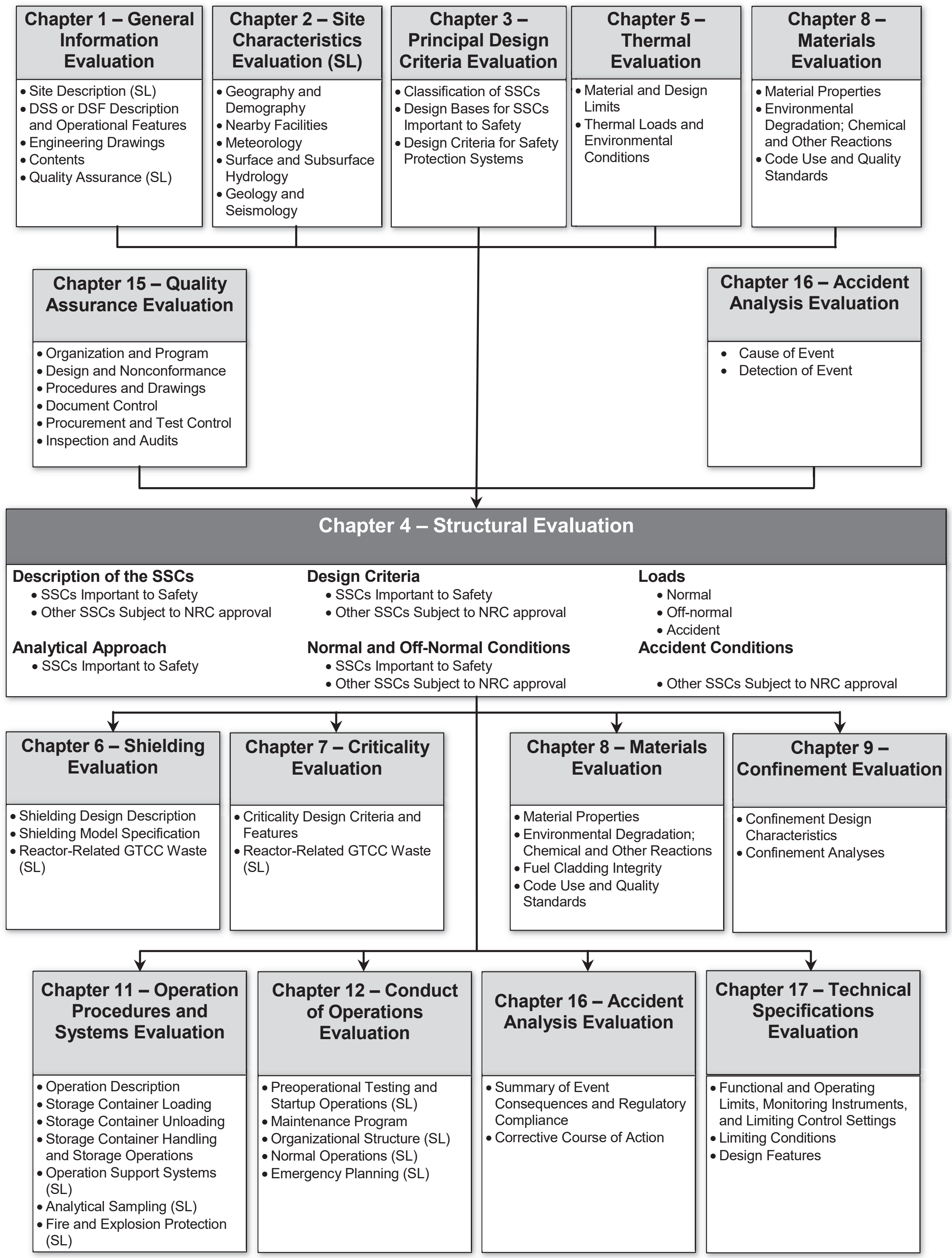

Figure 4-1 Overview of Structural Evaluation

Ensure that the application includes descriptions, design criteria, and safety analyses for site facilities and infrastructure of concern to the NRC, as appropriate to safety. These could include the waste facilities and other elements of the same infrastructure.

SSCs important to safety are not required to survive accidents to the extent that they remain suited for use for the life of the storage system without inspection, repair, or replacement. Ensure the SAR includes procedures for determining and correcting degradation and performing other acceptable remediation of SSCs if the service life of SSCs important to safety become degraded by accident conditions. The accident analysis evaluation chapter of the SAR addresses this.

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. Both the SAR and the NRC's safety evaluation report (SER) should include the operating controls and limits of the technical specifications. The SAR and SER should describe actions to be taken and inspections to be conducted upon the occurrence of events that may cause such damage.

Verify that the SAR clearly identifies the proposed structural design and construction of SSCs necessary for effective functional performance and safety. Review the SAR and supplemental material the applicant submitted to assess compliance with the applicable scope and content requirements defined in 10 CFR Part 72. Focus in particular on requirements and conditions of use related to design, construction, implementation, operation, and maintenance of SSCs.

Ensure the SAR identifies the design codes and standards used for all SSCs and their components. The structural design, fabrication, and testing of the SSCs should comply with an acceptable code or standard. Using codes and standards that have been accepted by the NRC may expedite the evaluation process.

Verify that the SAR defines the loads and load combinations. 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. If components associated with or integral to the fuel assembly are to be stored in the cask, ensure that the applicant's structural analysis has considered these components.

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

Determine whether 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, and assess compliance with the acceptance criteria defined in this chapter of the SRP.

Evaluate the proposed limitations on allowable stresses and strains in the canister and steel parts important to safety and subject to review by comparison with those specified in applicable codes and standards. Where certain proposed load combinations will produce values that exceed the accepted limits for localized points on the structure, ensure the application provides adequate justification to show that a deviation will not affect the functional integrity of the SSC. Under certain conditions, limiting strains and limiting deformations may form part of the acceptance criteria.

Review the structural evaluation to determine whether conditions of use or technical specifications should be associated with the structural design. Determine 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. 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).

4.5.1 Description of the Structures, Systems, and Components

4.5.1.1 *Structures, Systems, and Components Important to Safety*

The SSCs that are important to safety are those whose function provides for the general design criteria of confinement, subcriticality, shielding, and retrievability. Ensure that the SAR provides drawings, plans, sections, supporting computations, and specifications for those structural components important to safety in sufficient detail to allow meaningful reviews, as required by 10 CFR Part 72. Ensure that the application includes the year of all codes or standards that are referenced on the drawings.

Ensure the applicant describes the SSCs important to safety in sufficient detail to allow evaluation of their structural behavior and effectiveness under the imposed design conditions. In addition, ensure the SAR identifies all codes and standards applicable to the components.

4.5.1.1.1 Canister or Storage Cask and Metallic Internals

Review the canister or storage cask descriptive information presented in the SAR chapter on general information, as well as any related information provided in the SAR chapter on structural evaluation. These may include the canister or metal storage cask system that could include a shell, inner and outer lids, and welds or bolts; port covers and bolts; vent port covers to be welded in place; and fuel basket.

Coordinate with the confinement reviewer (SRP Chapter 9, “Confinement Evaluation”) 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 as provided by the system.

Ensure that the canister or cask assembly drawing, figures, tables, and specification in the SAR fully show geometry and material used for analysis and fabrication. Canister and cask shells are normally constructed from stainless steel. Appropriate numbers of plugs are provided to drain and vent the shell assembly. Ensure the canister or cask is designed to provide confinement in an inert environment, structural support, and criticality control for the fuel assemblies. The canister or cask is equipped with design features for shielding and heat rejection capabilities. Verify that the application reflects that the spent nuclear fuel (SNF) storage cask provides redundant sealing of the confinement system.

Review the SAR to verify that the canister top and bottom cover plates are properly located and welded with full or partial penetration welds. With the exception of the top cover plates, ensure that the canister is fabricated with full penetration welds. Ensure that the closure system consists of redundant lids that are attached with partial penetration welds.

Review the SAR for any details on lifting attachments used to handle the canister or cask loaded with SNF into and out of the storage overpack and transfer cask respectively.

4.5.1.1.2 Fuel Basket

Review the SAR for the fuel basket design to ensure that it locates and confines the fuel assemblies inside the canister. Ensure the SAR describes the type and number of fuel assemblies (pressurized-water reactor or boiling-water reactor) to be stored in the fuel basket. Ensure the basket design is adequate to withstand the combined effects of weight, thermal stresses, and cask-drop impact forces that could arise during SNF transfer and storage operations. The weight supported by the basket should be the maximum or design weight of the SNF to be stored. In addition, ensure the applicant evaluates all credible potential orientations of the cask and basket during cask transfer and handling drops while transferring the SNF into storage.

4.5.1.1.3 Fuel and Cladding

Review the SAR for the design, specifications, and geometry of the fuel rod and cladding. While the fuel assembly is not necessarily an SSC, the cladding does provide defense in depth by containing fission products within its boundary.

4.5.1.1.4 Transfer cask

Review the transfer cask descriptive information presented in the SAR chapter on general information, as well as any related information provided in the SAR chapter on structural evaluation. Ensure the transfer cask is examined for normal, off-normal, handling, and accident conditions. The geometry of the transfer cask design should be such as to provide shielding and protection from potential hazards during canister loading and closure operations as well as during transfer to the storage overpack. The transfer cask is not required to be a pressure-retaining vessel. Ensure the design incorporates features to provide circulation of cooling air in the annular space between the canister and transfer cask inner diameter.

The transfer cask is usually manufactured from steel with welded bottom assemblies and a bolted top cover plate. Verify that the neutron and gamma shields are fabricated from appropriate materials. For ease of handling and transportation, lifting trunnions are usually provided on the transfer cask. The transfer cask for the vertical cask system may also have doors and associated rail or attachments on the bottom to facilitate the transfer of the canister into the storage overpack.

If impact limiters are used during the transfer and storage operations, ensure the applicant thoroughly evaluates and verifies the nonlinear impact characteristics of the limiters. In addition, ensure that the applicant tabulates and describes the crush characteristics and properties of the limiters (if any) in the directions that are to be used.

4.5.1.1.5 Storage Overpack (horizontal, vertical, or underground)

Ensure that the SAR provides a detailed description, specification, materials of construction, and drawings showing the geometry and structure arrangement of the storage overpacks. The storage overpack should be designed as a freestanding or underground structure (normally of concrete, steel, or both), designed to provide environmental protection and radiological shielding for the canister. Ensure the drawings in the SAR clearly show how the canister will be inserted and stored inside the cask. In addition, ensure the drawings show the location of reinforcing steel and embedment required to attach other components, such as heat shields and shield walls.

The concrete may be cast in place, on site, or elsewhere. Concrete overpacks may also be combinations of cast-in-place and precast sections that are integrated by bolting, welding, fitting, grouting, or placing additional concrete at the site.

4.5.1.1.6 Independent Spent Fuel Storage Installations Concrete Pad (as applicable)

If the concrete storage pad is classified as important to safety, ensure that the SAR provides a detailed description, specification, and materials of construction to be used for the ISFSI concrete pad. In addition, ensure that the drawings show the layout and cask transportation route on the pad. Verify that the SAR describes how the casks will be arranged on top of the ISFSI concrete pad.

4.5.1.2 *Other Structures, Systems, and Components Subject to NRC Approval*

Ensure that the SAR text descriptions, drawings, figures, tables, and specifications fully define the other SSCs subject to NRC approval. Ensure that the specifications reference the codes that govern the design details. Verify that the combinations of drawings, specifications, appropriate codes and standards, and supporting calculations are sufficient.

Confirm that, at a minimum, the SAR documentation provides (1) the dimensions of all sections that have a structural role including locations, sizes, configuration, and spacing; (2) structural materials with defining standards or specifications; (3) location and specifications for assembly and weld joints; (4) location of all reinforcing steel; and (5) fabrication codes and standards.

Verify that these SSCs are described sufficiently to provide an adequate basis for their approval. Typically, this would include descriptive information about the function, applicable codes, and standards for design and manufacture or procurement.

4.5.2 Design Criteria

Review the design criteria that the applicant is using to qualify the structural performance of each of the SSCs. This review should include the codes and standards and applicable loading conditions (i.e., normal, off-normal, and accident). Ensure the SAR identifies the design criteria (code, code case, or standard) used for the design, fabrication, and testing of each SSC component and any alternatives to those design criteria. Ensure the year of the code or standard is included for all codes and standards referenced in the application.

Applicants should propose a condition to the CoC or technical specification in a site license, either directly or by reference, describing the alternatives to the referenced codes. Ensure the condition or technical specification also describes a process to address one-time alternatives from the code that may occur during fabrication. Verify that the application identifies the component, references the code (code edition, addenda, section, or article), describes the code requirement, and describes the alternative. In addition, ensure the applicant justifies the alternative, including a description of how the alternative would provide an acceptable level of quality and safety. Confirm that the application describes how compliance with the code provisions would result in hardship or difficulty without a compensating increase in the level of quality or safety.

An applicant should justify the use of new criteria if no staff position has been established. However, 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 may require a more detailed review.

Review the identification of structural materials in coordination with the materials discipline as described in Chapter 8, “Materials Evaluation,” of this SRP to the extent appropriate to determine if the materials 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. Ensure the materials are permitted or specified in the applicable code(s).

Radiation shielding in the cask system is required to protect the public and workers involved with SNF handling and storage. Ensure such shielding will not degrade under normal or off-normal conditions or events. The shielding function may degrade as a result of an accident (e.g., displacement of source or shielding, reduction in shielding). However, the loss of function should be readily visible, apparent, or detectable. Ensure that the application shows that any permissible degradation in shielding will result in dose rates sufficiently low to permit recovery of the damaged cask including unloading, if necessary. Further, ensure that the applicant clearly identified the necessary structural criteria to assure adequate shielding remains in place.

The NRC has accepted the American Society of Mechanical Engineers (ASME) Boiler and Pressure Valve (B&PV) Code, Section III, “Rules for Construction of Nuclear Facility Components,” Division 1, “Metallic Components,” as the basic reference for metallic SSCs and has equated normal conditions of loading with Service Level A, off-normal loading with Service Level B, and accident condition loading with Service Level D. The ASME B&PV Code defines the requirements for categorizing stresses and determining allowable stress limits for the SSC or component in question. The NRC has also accepted the analytical approaches given in the ASME B&PV Code, Section VIII, “Rules for Construction of Pressure Vessels,” for pressure systems, vessels, and casks that do not form elements of the confinement cask. 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, verify that the octahedral shear stresses are not compared with the stress intensity limits. Appendices I and III to the ASME B&PV Code define values for the stress intensity limits. Verify that the applicant considers stresses resulting from inertial and pressure loads as primary stresses and that thermal stresses resulting from temperature gradients are considered secondary stresses if they are self-limiting and do not cause structural failure. Stresses caused by thermal gradients in fuel baskets may not be self-limiting; ensure the applicant considers these stresses because of the possibility of uneven heat loadings of adjacent assemblies as well as the effects of asymmetry in the basket structure. The NRC has accepted the use of American Concrete Institute (ACI) 349, “Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary,” as the basic reference for concrete structures important to safety that are not designed in accordance with ASME B&PV Code Section III, Division 1 or Division 2, “Code for Concrete Containments.”

In general, the NRC accepts the use of the most recent code year for the design of SSCs for new applications. ASME B&PV Code Section III, Division 1, Subsection NCA-1140 has provisions for the use of ASME code editions, addenda and cases that applies to both new applications and amendments. The NRC may consider alternatives to this guidance on a case-by-case basis.

4.5.2.1 *Structures, Systems, and Components Important to Safety*

Ensure that the SAR indicates that the SSCs will not experience any permanent deformation or loss of safety function capability (i.e., confinement, subcriticality, shielding, and retrievability) during normal or off-normal operating conditions. However, the system may experience some permanent deformation, but no loss of safety function capability, in response to an accident.

4.5.2.1.1 Canister and Storage Cask Confinement Shell

A canister serves to confine and maintain safe storage conditions throughout its service life. Ensure that the SAR reflects that the confinement structures have sufficient structural capability so that every cross section of the structure can withstand the worst-case loads and successfully preclude the unacceptable risk of criticality, unacceptable release of radioactive materials to the environment, unacceptable radiation dose to the public or workers, and significant impairment of ready retrievability of the stored nuclear material. Ensure the SAR indicates that confinement of radioactive material is maintained under normal, off-normal, and accident conditions.

Design and construction codes (e.g., ASME B&PV Code, Section III) give reasonable assurance that the as-fabricated material will provide the necessary integrity. ASME B&PV Code Section III, Division 1 applies specifically to maintaining pressure boundaries and supporting structures in nuclear power plants and may not necessarily be totally applicable to all confinement SSCs. 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 Code are not likely to address all the potential performance conditions (e.g., cracking, creep, corrosion) that may arise from environmental, electrochemical, or dynamic loading. Ensure the SAR addresses these and other effects specific to the individual application in order to meet the guidance in Chapter 8 of this SRP.

For the canister and associated welds, the NRC has accepted the use of ASME B&PV Code Section III, Division 1, Subsection NB or Subsection NC as the design criteria for normal and off-normal loading (Service Levels A and B, respectively) and Appendix F to ASME B&PV Code Section III, Division 1 for accident or natural phenomenon loading (Service Level D).

ASME B&PV Code Section III, Division 1 does not allow partial penetration welds for containment (confinement) boundaries. Because of fabrication considerations for the final canister closure weld, a full penetration weld is not always feasible. The NRC has accepted a partial penetration weld as an alternative to a full penetration weld for the closure weld, provided a stress reduction factor of 0.8 is applied to the strength of the weld to account for imperfections or flaws that may be missed by the allowed progressive surface examinations. Verify that the applicant applied a stress reduction factor of 0.8 to the allowable stress values for the design criteria. See Chapter 8 of this SRP for more information on weld design and examination.

4.5.2.1.2 Fuel Basket

For the fuel basket, the NRC staff has accepted the use of ASME B&PV Code Section III, Division 1, Subsection NG for the design criteria for normal and off-normal loading (Service Levels A and B, respectively) and Appendix F to ASME B&PV Code Section III, Division 1, for accident and natural phenomenon loading (Service Level D).

Ensure that the SAR includes an evaluation of 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, “Buckling Analysis of Spent Fuel Basket,” issued May 1995. Ensure the applicant selects the appropriate end conditions used in the buckling capacity equations on the basis of sensitivity studies. These studies can bound the range of conditions that typically are either fixed for a welded connection or free if there is no rigid connection.

4.5.2.1.3 Fuel and Cladding

Review the design fuel cladding to ensure that it is adequately protected against gross rupture caused by degradation resulting from design or accident conditions. The combined stresses in cladding should remain below the yield strength of the material or justified otherwise. Confirm that the design ensures that the SSCs will not experience accelerations or decelerations, or both, that would damage their structural integrity or jeopardize their subcritical condition or retrievability under normal and off-normal design conditions.

Ensure that the applicant has evaluated fuel rod integrity by demonstrating that it will not buckle under the effects of the canister bottom-end drop condition.

4.5.2.1.4 Transfer Cask

For the transfer cask, the NRC has accepted the use of ASME B&PV Code Section III, Division 1, Subsection NF for the design criteria for normal and off-normal loading (Service Levels A and B respectively) and ASME B&PV Code Section III, Division 1, Appendix F for accident and natural phenomenon loading (Service Level D). For the neutron shield tank design, the NRC has accepted the use of ASME B&PV Code Section III, Division 1, Subsection ND for the design criteria for normal and off-normal loading (Service Levels A and B, respectively) and Appendix F to ASME B&PV Code Section III, Division 1 for accident and natural phenomenon loading (Service Level D).

Ensure the lid bolts that attach the lid to the body of the transfer cask are designed to the same standard as the transfer cask itself or to NUREG/CR-6007, “Stress Analysis of Closure Bolts for Shipping Casks,” issued April 1992. The NRC has accepted both standards.

The NRC has typically accepted American National Standards Institute (ANSI) N14.6 (1978), “Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More,” for governing transfer cask lifting device design and inspection requirements. This applies to lifting trunnions, their connections with the cask body, and the cask body localized around the trunnions, as modified by NUREG-0612, “Control of Heavy Loads at Power Plants: Resolution of Generic Technical Activity A-36.” NUREG-0612 stipulates that the weight of the lifting device consider a dynamic load factor. In addition, these design criteria may also apply to any doors and associated rails and attachments on the bottom of the transfer cask that facilitate the transfer of the canister into the storage overpack. Ensure the SAR reflects that the trunnions are tested to 300 percent of the design load during fabrication.

4.5.2.1.5 Storage Overpack (horizontal, vertical, underground)

The overpack should withstand the effects of credible accident conditions without impairing their ability to perform safety functions. The principle safety functions include maintaining subcriticality, containing radioactive material, providing radiation shielding for the public and workers, and maintaining retrievability of the stored material.

Concrete Storage Overpacks

For a concrete storage overpack, the NRC has accepted the use of the latest edition of ACI 349, supplemented with ACI 318, "Building Code Requirements for Structural Plain Concrete and Commentary," for normal, off-normal, and accident loading combinations. In addition, for any structural steel elements that are part of the concrete overpack, the NRC has accepted the use of the latest edition of ANSI/American Institute of Steel Construction (AISC) 360, "Specification for Structural Steel Buildings," or ASME B&PV Code Section III, Division 1, Subsection NF.

For welding of structural steel, the NRC has accepted American Welding Society (AWS) D1.1, "Structural Welding Code–Steel'" or ASME B&PV Code, Section IX, "Welding, Brazing, and Fusing Qualifications."

Ensure steel embedments in the storage cask satisfy the requirements of the design code applicable to the reinforced concrete structure. Similarly, ensure structural steel satisfies the requirements of the applicable steel design code (e.g., ASME B&PV Code, AISC standard, or other identified code).

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 the pertinent provisions in ACI 349. Seismic loads are considered to be "impulsive" and, therefore, are subject to the additional design constraints of Appendix F to ACI 349. Other accident conditions may also produce impulse or impact loading, necessitating the additional requirements of Appendix F to ACI 349.

Check the location and size of the steel reinforcement in the drawings to ensure that they are consistent with the design analysis.

Consider the following aspects of the design:

- 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

- reinforcement embedment designed for ductile failure where steel fails before pulling out from the concrete

Review the design to ensure that substitution of materials, use of larger sizes, or placement of larger quantities of steel will be precluded (to avoid changes in structural response), and that provisions for splicing or development of reinforcing steel will not reduce ductility of the members.

Metallic Storage Overpacks

For metal overpacks, or composite concrete structure overpack liners, the NRC has accepted the use of ASME B&PV Code Section III, Division 1, Subsection NF for the steel components.

If the overpack will be handled while loaded with fuel (i.e., transported to the storage pad while loaded with SNF), it should be considered a special lifting device. As such, ensure any trunnions or lifting attachments are also designed in accordance with the provisions of the lifting devices for a transfer cask in Section 4.5.2.1.4 of this SRP.

4.5.2.1.6 Independent Spent Fuel Storage Installation Concrete Storage Pad

Unless otherwise classified, the concrete storage pad is not generally classified as important to safety. In cases where the concrete pad serves a safety function (i.e., the storage cask is attached to the pad, or the pad has bollards around the cask), ensure it is classified as important to safety.

Verify that the ISFSI is designed to adequately support the static and dynamic loads of the stored casks, considering the potential amplification of earthquakes through soil structure interaction and soil liquefaction potential or soil instability due to vibratory motion. See NUREG/CR-6865, “Parametric Evaluation of Free Standing Spent Fuel Dry Cask Storage Systems,” issued February 2005 for further guidance.

Concrete storage pads that support the storage casks are not “pavements.” They should be designed and constructed as foundations under the applicable code. If the pad is classified as important to safety, the NRC has accepted ACI 349 for design and ACI 318 for construction. If the pad is not classified as important to safety, the NRC has accepted ACI 318 or the International Building Code (IBC) for design and construction.

Ensure the ISFSI concrete storage pad has sufficient capacity to withstand the worst-case loads under normal, off-normal, and accident loading combinations. Such capacity ensures that these structures will not experience permanent deformation or degradation of the ability to withstand any future loadings.

Vertical cask storage systems are evaluated against tipover during initial licensing, and all cask storage systems are evaluated against credible handling accidents during licensing. Although there is not a regulatory requirement of evaluating the system against a non-mechanistic event (i.e., non-credible tipover), performing the tipover and handling accident analysis, as documented in the SAR accident analyses chapter, provides additional assurance that the design will maintain confinement, criticality, and shielding during storage. The tipover analysis is performed by using a concrete compressive strength f_c' achieved at 28 days (see Tripathi 2007).

4.5.2.2 *Other Structures, Systems, and Components Subject to NRC Approval*

Details specific to certain codes and standards that may apply to other SSCs are listed below:

- ANSI/AISC 360–If the NRC receives an application using Load and Resistance Factor Design, or LRFD, the staff would evaluate the proposal for compliance with the loads and load combinations summarized in Tables 4-2 and 4-3, respectively, and for consistent application of the load and resistance factor design methodology.
- To date, the NRC has not required applicants to design or build structural steel components of a cask system important to safety in compliance with ANSI/ANS N690, "Nuclear Facilities–Steel Safety-Related Structures for Design Fabrication and Erection."
- AWS D1.1
- ASCE 7, "Minimum Design Loads for Buildings and Other Structures"
- IBC
- ASME B&PV Code, Section VIII
- ACI 318

4.5.3 Loads

Review the loads that the applicant is considering for each SSC. In some cases, the loads may change based on the orientation of the SSC, such as the canister in the vertical position, down-ending into a horizontal position, in a horizontal position. Not all of the loads may apply to each SSC. For instance, a confinement canister inside a horizontal overpack may not be subject to tornado winds or tornado-generated missiles because it is protected by the overpack. It is, however, subject to seismic accelerations that may be amplified because of the dynamic response of the overpack to the seismic accelerations. Ensure that the applicant indicates all loads that are applied to each component and the manner in which they are applied.

Ensure that the design of the SSCs accommodates the full spectrum of load conditions, including all anticipated normal, off-normal, and accident or natural phenomena conditions. Coordinate with the appropriate NRC reviewer associated with Chapter 16, "Accident Analysis Evaluation," of this SRP to verify that the accidents identified in that chapter correspond to the accident conditions evaluated in this chapter.

4.5.3.1 *Normal Conditions*

Normal conditions and events are those associated with canister system operations, including storage of nuclear material, under the normal range of environments. Ensure that the SAR states the assumed limits of normal-use environments to support an evaluation by a user of the certified cask system of its suitability for use at a licensed specific site under a general license or at a site with a specific license.

Loads normally applicable to the SSCs 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 in storage and loaded with SNF. However, depending on the operation and procedures, the weight should also include water fill. Confirm that the applicant evaluated all orientations of the cask body and closure lids during normal operations and storage conditions, including loads associated with loading, transferring, positioning, and retrieving the confinement cask.

Internal pressures result from hydrostatic pressure, cask drying and purging operations, filling with nonreactive 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 canister, closure lids, and associated welds. Coordinate with the thermal reviewer (SRP Chapter 5, "Thermal Evaluation") to determine the enveloping values and combinations of the cask internal pressures and temperatures for both hot and cold conditions. Use the temperature gradients calculated in the SAR chapter on thermal evaluation to determine thermal stresses. If the confinement system has several enclosed areas, all areas may not have the same internal pressures. In some canisters, enclosed areas consist of the canister 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.

For lifting and handling operations, ensure that the applicant applies an appropriate dynamic load factor to the load. See NUREG-0612, Section 5.1.1(4) for the appropriate application of the dynamic load factor for lifting operations.

For handling conditions, verify that the SAR reflects application of appropriate additional loads in vertical, transverse, and axial to fuel assemblies in normal conditions. As a minimum, the NRC considers loads of 1 g (in addition to self-weight) in all directions to be acceptable unless detailed analysis is performed otherwise.

Other loads during normal conditions may include the following:

- hydrostatic pressure in the neutron shield tank from the weight of the water and any applied pressure
- live and dynamic loads associated with the transfer of the confinement cask to and from its storage position and in its storage location for its service lifetime
- load or support conditions associated with potential differential settlement of foundations supporting the ISFSI pad over the life of the cask system
- thermal gradients associated with the normal range of operations and ranges of ambient temperature
- dead, live, and lateral soil loads defined in Table 4-3 of this SRP and ASCE 7 or the IBC for facilities

4.5.3.2 *Off-Normal Conditions*

Identify and evaluate all off-normal events and conditions described in Chapter 16 of this SRP. Review the off-normal conditions and events for those that affect the SSC. The SSCs should satisfy the same structural criteria required for normal conditions, as discussed above.

Ensure that the SAR clearly identifies anticipated off-normal conditions and events that may reasonably be expected to occur during the life of the SSC at the proposed site. In addition, verify that the SAR states the environmental limits to support comparison of the DSS 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).

Other off-normal loads may include the following:

- 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 or steel structure
- the impact to reinforced concrete structures by a suspended transfer, confinement, or storage cask
- off-normal ambient temperature conditions; while 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 elevated concrete temperatures above those allowable by the code may be allowed for accident conditions in accordance with ACI 349, Section A.4. Consult Chapter 8 of this SRP for more information on elevated concrete temperatures
- dead, live, lateral soil pressure and wind loads defined in Table 4-3 of this SRP and ASCE 7 or the IBC for facilities

4.5.3.3 *Accident Conditions*

Ensure the SAR addresses, at a minimum, each of the following accidents or states why they are not credible. SRP Chapter 16 addresses the identification of credible accident conditions and any postevent inspection and remedial actions that may be necessary.

Ensure that the SAR considers the following accident scenarios:

4.5.3.3.1 Cask Drop and Tipover

A cask drop (including the transfer cask) or tipover scenario could result from cask handling during the loading and transfer process, an earthquake, flood, and wind effects. Ensure that the SAR includes a drop and tipover analysis. Ensure the SAR identifies the operating environment experienced by the SSC and the drop events (end, side, tipover) that could result. Generally, applicants establish the design basis in terms of the maximum height to which the cask is lifted 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.

Although cask system supporting structures may be identified and constructed as important to safety (i.e., designed to preclude cask tipovers), the NRC considers that cask tipover events should be analyzed. For such analysis, the NRC has accepted cask tipover about a lower corner onto a 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 (side drop), together with a drop with the longitudinal axis vertical (top or bottom-end drop), if this combination bounds a non-mechanistic tipover analysis.

The applicant may use prototype or scale-model testing to obtain more realistic SSC deceleration or equivalent load for quasi-static analyses when applicable. 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. In general, using an unyielding surface will produce higher decelerations in a drop or tipover since the storage pad will, in reality, bend and deform. If the pad is treated as being other than an unyielding surface, the applicant should consider concrete hardening with time. Specifically, NUREG/CR-6424, "Report on Aging of Nuclear Power Plant Reinforced Concrete Structures," issued March 1996, states that the majority of concrete hardening occurs within the first 10 years of service life. Compressive strength (f_c') can be assumed to have increased on average by 65 percent, while Young's Modulus (E) can be calculated with this value using ACI-318 for normal weight concrete.

Ensure that the applicant evaluated all credible potential orientations of the cask during cask transfer and handling drops while transferring the SNF into storage. End or side drops typically produce the greatest structural demand on various basket components. Often in an end drop, the basket is supported by the bottom of the confinement cask cavity upon impact. In the side drop, ensure the basket structure and points of contact with the confinement cask support the mass of the basket and loaded fuel.

4.5.3.3.2 Earthquake

Review the applicant's evaluation of the cask design with regard to the structural consequences of the earthquake event. Ensure that the cask designs satisfy the load combinations that encompass earthquake, including those for sliding and overturning. Ensure that the applicant demonstrated 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 is shown to be structurally adequate. In most cases, impacts between casks are bounded by the non-mechanistic tipover analysis.

The DSS or DSF concrete pad, supported by soil, behaves as a rigid mat and therefore possesses no out-of-plane flexibility. This is valid for the majority of nuclear power plant structures, where relatively thick mats support integral reinforced concrete walls. However, pads are usually relatively thin structures (i.e., small thickness-to-length ratio) and generally do not incorporate integral walls to stiffen the pad. While the cask itself is relatively rigid, the rigid cask resting on a flexible pad has a lateral mode frequency that is generally low enough to fall within the amplified range of most design earthquake spectra. Thus, in determining the inertia forces that act at the center of gravity of the cask for the purpose of evaluating the onset of sliding or tipping, ensure that the applicant has either accounted for the out-of-plane flexibility of the pad in the seismic analysis or demonstrated that it is not an important parameter in determining the response of the cask (see Bjorkman et al. 2001).

Verify that the cask system design meets appropriate guidance in Regulatory Guide (RG) 1.29, “Seismic Design Classification,” RG 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” RG 1.61, “Damping Values for Seismic Design of Nuclear Power Plants,” and RG 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” for protection against seismic events.

Ensure that the SAR includes an analysis of the potential for impacts between components of the cask system. These could include contact between the confinement canister and its inner components or outer shield and the rocking and falling back of a vertically or horizontally oriented confinement cask on its supports.

Cask systems are not required to survive a design earthquake without permanent deformation. However, ensure the SAR includes a prediction of the maximum extent of damage from a design earthquake and shows that the ability to provide the safety functions will not be degraded.

4.5.3.3.3 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. The guidance in RG 1.76, “Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants,” recognizes three regions in the contiguous United States, each with distinct design-basis tornado parameters. Ensure that the applicant for a CoC has clearly defined the boundary conditions of the proposed cask system with respect to these regions or uses Region 1.

Confinement casks may be vulnerable to overturning or translation caused by the direct force of the drag pressure while in storage or during transfer operations. Ensure that the SAR provides 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 windborne missiles or collapse of a weather enclosure, if used. Ensure that the SAR identifies the capability and behavior of the cask system under the collapse of any such external structure.

Tornadoes typically produce the greatest “design-level” wind effects for U.S. sites. However, there are some potential U.S. sites at which high hurricane 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 CoC is to include proven design resistance to tornadoes or extreme winds, ensure that the SAR identifies the wind levels (in miles or kilometers per hour), source (tornado or high hurricane wind), and specific wind-driven missiles (shape, weight, and velocity) against which the design is to be evaluated.

RG 1.76 provides applicable tornado-related parameters. The NRC has accepted the use of ASCE 7 for conversion of wind speed to pressure and for typical building shape factors. In sections that discuss conversion of tornado or other wind speeds to pressure, ensure that the SAR assumes that the cask system is at sea level.

Verify that the cask system design is consistent with guidance in RG 1.76; RG 1.117, "Tornado Design Classification," and NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LRW Edition," Section 3.3.2, "Tornado Loadings," for tornado protection.

Ensure the SAR considers that tornadoes and high winds can produce a significant negative pressure differential between interior spaces and the outside in a storage cask system. 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). The SAR does not need 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 so that operations, such as transfer between the fuel transfer facility and storage site, may never be exposed to tornado effects. The staff considers overturning during onsite transfer to be a design-basis event. The tornado analysis may determine that tornado-induced overturning is bounded by drop and tipover cases. Ensure that the SAR shows that the cask system will continue to perform its intended safety functions (i.e., criticality, radioactive material release, heat removal, radiation exposure, and retrievability).

4.5.3.3.4 Tornado Missiles

Review the applicant's evaluation of the cask system design with regard to the structural consequences of wind-driven missile impact (RG 1.76 and Sections 3.5.1.4, "Missiles Generated by Tornadoes and Extreme Winds," and 3.5.3, "Barrier Design Procedures." of NUREG-0800 describe the effects of tornado missiles). Ensure that the SAR defines the missile parameters against which the cask system is to be evaluated based on the three tornado regions identified in RG 1.76.

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. Ensure that the damage does not result in unacceptable radiation dose or significantly impair criticality control, heat removal, or the retrievability of the fuel.

The NRC has accepted the use of the analytical approaches given in Cottrell and Savolainen (1965) for estimating the potential effects of missile impact on steel sheets, plates, and other structures. Section 3.5.3 of NUREG-0800 provides further guidance on analytical acceptable approaches for use in DSS or DSF design.

Cask systems are not required to survive missile impacts without permanent deformation. However, ensure that the maximum extent of damage from a design-basis event is predicted and sufficiently limited. Moreover, ensure that the ability of the SSCs to perform their safety functions is not impaired.

4.5.3.3.5 Flood

Review the applicant's evaluation of the design of SSCs 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 the potential for flooding. In this case, the cask would have to be placed at an ISFSI or MRS above the maximum probable flood level (the accident analysis in the SAR should state this condition).

If a design flood event is defined for the CoC, verify that the SSCs meet the appropriate guidance in RG 1.59, “Design Basis Floods for Nuclear Power Plants,” and RG 1.102, “Flood Protection for Nuclear Power Plants,” for that level of flood protection.

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. Verify that the application states that the critical water velocity and hydrostatic pressure bound the flood analysis.

The NRC has accepted the evaluation for flooding events when the flood conditions for overturning and sliding of stored confinement casks and other cask system structures have been applied. Ensure that the application states the basis for estimation of lateral pressure on a structure is a result of water velocity.

Confirm that the SAR includes a calculation of 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 and rotates about that outer edge, and 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 typically are bounded by analyses for the drop or tipover accident cases.

Additional flood conditions could lead to such consequences as 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. Confirm that the applicant analyzed the consequences of these conditions and that the CoC or specific license identifies the consequences of these conditions so a licensee will be able to consider these factors when siting a DSS or DSF.

4.5.3.3.6 Fire

Verify that the SAR evaluation includes fire-related structural considerations, such as increased pressures in the confinement cask, changes in material properties, stresses caused by different coefficients of thermal expansion or temperatures in interacting materials (or both), and physical destruction. Chapter 5 of this SRP addresses potential fire conditions. Coordinate with the thermal reviewer to ensure that the criteria used (pressure, temperature) are consistent with accident conditions such as wild fire.

Evaluate the discussion in the SAR concerning the treatment of structural effects associated with the presumed fire and those structural effects for the assumed parameters of the postulated 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. 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 has accepted concrete temperatures that exceed the temperature limits of ACI 349 for accidents, provided the temperatures result from a fire. However, corrective actions may need to be taken for continued safe storage.

4.5.3.3.7 *Explosive Overpressure*

External explosion-induced overpressure and reflected pressure may result from 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 typically are similar to those for facilities subject to reviews under 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities.”

Ensure the SAR states the level of overpressure that the cask system can withstand for this accident condition. This overpressure 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 of a general licensee’s facility, but this needs to be demonstrated in the SAR.

If the SAR includes bounding explosion effects for which the cask system is to be approved, verify that the SAR also includes structural analyses of those effects for cask system structures that may be affected. Ensure that the SAR identifies the maximum determined response. The maximum response includes pressure-induced maximum stresses at critical cask locations and governing structural performance modes for the cask components important to safety.

4.5.4 Analytical Approach

Review the structural analysis of various loading combinations and the calculated resulting stresses, strains, and deformations from different loads. Verify the applicant’s proper use of acceptable analytical approaches and tools. The scope of the staff’s review may include evaluating sensitivity analyses (such as finite element analyses) to validate submitted computations or their results.

Ensure that the SAR reflects analytical methods that are appropriate for the proposed type of materials and construction. In certain instances, however, the applicant may have had to adapt existing analytical methods, codes, and models for highly specialized storage-system equipment designs. Such instances require special review attention. In particular, ensure that the adapted approach is fully documented, supported, and acceptable. Consider the potential for safety-related risk associated with a possible error in the design of special cask system equipment. Appendix 4A, “Computational Modeling Software Technical Review Guidance,” to this SRP chapter addresses the application of computational modeling software.

Ensure that the analysis of loads and load combinations is consistent with the code or criteria requirements used in designing the component. Material properties used in an analysis should be consistent with the approach being used.

4.5.4.1 *Hand Calculations*

This type of calculation can be used for analyses involving principles of conservation of energy and comparisons of overturning moments. Hand calculations can come in the form of spreadsheets or computer software such as Mathcad, where variables and intermediate solutions are stored within the program for later use in the calculation. The applicant has to define the equation and provide the necessary variables for its use.

Ensure that use of a particular equations or formulations for the load conditions is justified. The most important aspect of the calculations to evaluate is the basis for the assumptions used in the calculations. Check that calculations include applicable portions of the cask and appropriate load conditions. NUREG/CR-6007, “Stress Analysis of Closure Bolts for Shipping Casks,” issued January 1993, provides acceptable analytical methods for closure bolts.

4.5.4.2 *Finite Element Analyses*

Because of the complexity of many structural design considerations and load conditions, structural design computations are often performed using finite-element analysis (FEA). Ensure that the applicant performed the FEA using a general-purpose program that is well benchmarked and widely used for many types of structural analyses.

Ensure that the FEA reflects appropriate element types, material properties, boundary conditions, consistent applied loading, and ability to accurately the behavior desired based on meshing and element type. Ensure the potential temperature of the material provides the basis for the elastic modulus and limit used for lead in the elastic analysis. An appropriate plasticity model of lead can be used to account for its inelastic behavior. Often, the applicant will create a partial model because of symmetry. Pay attention to the constraints introduced at the symmetry planes to ensure the proper symmetry conditions are applied to the model.

Finite element models do not generally include nonstructural components of the canister. However, check that the models include any influence these nonstructural components may have on the structural performance of the cask. Possible influences include inertial weight, restraint to motion of the structural components, and localized influence on load applications because of geometrical effects.

The NRC has accepted two approaches for analyses of the cask internal components undergoing cask drop scenarios. The first approach uses a two-step process. In step 1, the applicant performs a dynamic analysis of the cask body and its internal mass and stiffness equivalent impacting a target surface and assesses the performance of the cask body, including determining the time-history response. In step 2, this time-history response is translated into a forcing function and applied to the supporting contact points of an appropriate model of the internal components. This approach recognizes a commonly observed condition of the existence of a substantive stiffness difference between the cask body and its internals so that they can be dynamically uncoupled.

The second NRC-accepted approach uses a quasi-static analysis (assuming the quasi-static response dominates the response) of the basket subjected to the equivalent acceleration inertial load derived from the cask-drop impact analysis. If this analysis is used, ensure that the applicant applies the equivalent acceleration inertial load using an appropriate model of the internal components 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, ensure the applicant conservatively selects 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, ensure the inertial load also accounts for dynamic amplification effects by using a dynamic amplification factor.

Review validation of the analytical model. The staff has completed a series of low-velocity impact tests of a steel billet from which a model validation approach and corresponding acceptance criteria have been developed. These tests and analytical evaluations are summarized in

NUREG/CR-6608, “Summary and Evaluation of Low-Velocity Impact Tests of Solid Steel Billet onto Concrete Pads.” On the basis of that report, the following model validation acceptance criteria apply to a cask-pad-soil analytical model for predicting impact responses of the cask:

When a solid steel billet is used to replace the cask in the cask-pad-soil analytical model, it should predict a pulse amplitude slightly higher than the cask. The calculated pulse duration and shape should be similar, but not necessarily identical, to those recorded from the cask. The validated billet-pad-soil model is considered adaptable to a cask-pad-soil analysis model if relevant attributes of the cask are used to replace those of the billet.

The FEA impact analysis for cask drop may consider the ISFSI concrete pad as rigid or a concrete pad underlain with soil. The material properties of the soil should be consistent with NUREG/CR-6608.

Verify that the applicant has provided information on any computer-based modeling as described in Appendix 4A to this SRP chapter and review the structural analyses the applicant submitted in accordance with Appendix 4A.

Alternatively, the draft guidance documents “Use of Explicit Finite Element Analysis for the Evaluation for Nuclear Transport and Storage Packages in Energy-Limited Impact Events” and the associated Attachment A, “Examples Demonstrating Modeling Principles for Explicit Finite Element Analysis,” may be useful in determining the quality of the applicant’s FEA model. Although the document is still in draft form at the time of publication of this NUREG, the guidance that has been developed by the Special Working Group on Computational Modeling for Explicit Dynamics may be relevant. The guidance document was submitted for ASME review in August 2017 and will be published if approved.

4.5.5 Normal and Off-Normal Conditions

Verify that the load combinations that the applicant considers to be normal and off-normal conditions are acceptable. Review the analysis on how the applicant’s results compare to the design criteria. The applicant may present the results in the form of factors of safety, stress ratios, or margins of safety. Confirm that the comparisons of calculated capacity versus demand for the various applicable loading conditions are presented in the same terms used in the design code (e.g., type of stress, bending moments, strains). Ensure the capacity values are larger than the allowed values for different load combinations. If they are not, ensure the applicant provided a defensible explanation as to how the design provides reasonable assurance against failure.

The NRC has accepted the load combinations and definitions shown in Tables 4-2 and 4-3 for analysis of non-confinement steel and reinforced concrete components. Load combinations are included in or derived from and ANSI/ANS 57.9, “Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type).”

4.5.5.1 *Structures, Systems, and Components Important to Safety*

4.5.5.1.1 Canister and Associated Welds and Bolts

Verify that the calculated stress in the canister and associated welds and bolts for the various normal and off-normal condition load combinations and each stress category are within the limits of allowable stress of the stated ASME B&PV Code that the applicant cited as the design criteria.

Ensure the allowable stresses are based on the temperature of the material in the loading condition considered and determined in accordance with ASME B&PV Code.

Verify that the applicant considered whether fatigue analysis of the canister is required in accordance ASME B&PV Code Section III, Division 1, Subsection NB-3222.4.

Review the design analysis for the canister's 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 preload. Typically, applicants specify the preload 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 preload 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.

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.

4.5.5.1.2 Fuel Basket

Verify that the calculated stress in the Fuel basket and associated welds for the various normal and off-normal condition load combinations and each stress category are within the limits of allowable stress of the stated ASME B&PV Code that the applicant cited as the design criteria. Ensure that the allowable stresses are based on the temperature of the material in the loading condition considered and determined in accordance with ASME B&PV Code.

Ensure that the applicant evaluated 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, "Buckling Analysis of Spent Fuel Basket." issued May 1995. For this evaluation, confirm that the applicant selected the appropriate end conditions used in the buckling capacity equations on the basis of sensitivity studies. These studies can bound the range of conditions that are typically either fixed for a welded connection or free if there is no rigid connection.

Review the fuel basket design to assess the applicant's analysis of the combined effects of weight, thermal stresses, and cask-drop impact forces that could arise during spent fuel transfer and storage operations. Ensure the weight supported by the basket is the maximum or design weight of the SNF to be stored

4.5.5.1.3 Spent Fuel Assemblies and Cladding

Verify that the applicant has considered, at a minimum, dead load and internal pressure during normal condition of loading for spent fuel assemblies (SFA) and cladding and that the calculated stresses are within the allowable limits.

Verify that the SAR includes an analysis of SFA integrity for a cask-drop accident. If the analytical approach described in Chun et al. (1987) for axial buckling is used to assess fuel integrity for the cask drop accident, verify that the analysis uses the irradiated material properties and includes the weight of fuel pellets.

Alternatively, an analysis of fuel integrity that considers the dynamic nature of the drop accident and any restraints on fuel movement resulting from cask design is acceptable if it demonstrates that the cladding stress remains below yield. If a finite element analysis is performed, the analysis model may consider the entire fuel rod length with intermediate supports at each grid support (spacer). Ensure that the analysis includes irradiated material properties and the weight of fuel pellets. Coordinate with the materials reviewer (SRP Chapter 8) to verify the material properties of the irradiated fuel cladding.

4.5.5.1.4 Transfer Cask

Verify that the calculated stresses in the transfer cask components as a result of the load combinations for normal and off-normal conditions are within the limits specified in the ASME B&PV Code, or other design criteria the applicant cited. Ensure that the allowable stresses are based on the temperature of the material in the loading condition considered and determined in accordance with the ASME B&PV Code.

As a part of the transfer cask, ensure the SAR includes an analysis for the neutron shield tanks and lifting trunnions, as applicable. The appropriate factors of safety from NUREG-0612 apply to the trunnions when they are used to lift the transfer cask as a special lifting device.

Review the design of the trunnions of the transfer cask, their connections to the cask body, and the cask body in the local area around the trunnions. The design basis for the trunnions can be either nonredundant or redundant. In either case, ensure the design meets the requirements of NUREG-0612.

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 considered, including ASME B&PV Code Section III stress limits by the finite element design analysis and slight material yielding at localized regions, ensure that the SAR includes adequate justifications.

4.5.5.1.5 Storage Overpack

The NRC has accepted the load combinations shown in Table 4-2 for an analysis of steel and reinforced concrete DSS or DSF structures that are important to safety and not within the jurisdiction of ASME B&PV Code Section III, Division 1.

Definitions of terms used in Tables 4-2 and 4-3 are as accepted by the NRC. 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 other sources. Many definitions are expanded with their intended applications more fully described and implemented than in the referenced sources.

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

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.

Table 4-2 lists two load combinations each for reinforced concrete structures and steel structures acting during normal and off-normal conditions.

Verify that the SAR includes the thermal analysis of the storage cask on the reinforced concrete components that are not designed to permit thermal growth. Friction forces should be at the ISFSI storage pad interface.

4.5.5.2 *Other Structures, Systems, and Components Subject to NRC Review*

The NRC has accepted but does not require use of the normal and off-normal condition load combinations from Table 4-2 for steel and reinforced concrete structures that are not important to safety, including the concrete ISFSI pad that is classified as not important to the safety. If Table 4-2 is not used, the load combinations from the IBC, ASCE 7, or ACI 318, as appropriate, should be used. If load combinations other than those from Table 4-2 are used, it is not necessary to distinguish between normal, off-normal, and accident condition load combinations. The applicant can report the results of the governing load combination for the structural component in question. The NRC has accepted 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" terms. Ensure the demand-to-capacity ratio for shear, axial, and bending moment at all locations in the concrete and steel structures is less than 1.0.

If the concrete ISFSI pad is important to safety, the load combinations for the pad for normal conditions listed in Table 4-2 under "Reinforced Concrete Footings" should be used. Ensure the demand-to-capacity ratio for shear, axial, and bending moment at all locations of the concrete pad is less than 1.0. In addition, ensure the soil reaction is less than the allowable bearing pressure.

Coordinate with the thermal review in Chapter 5 of this SRP to verify that the temperatures and pressures (where applicable) for other SSCs presented in the SAR, and subject to NRC approval, correspond to the same temperatures and pressures given in the thermal loads analysis.

Coordinate with the operation systems review in Chapter 3, "Principal Design Criteria Evaluation," of this SRP to verify that the configuration of the other SSCs corresponds to the same configuration used in the various load combinations.

The information and evaluation required for these SSCs is typically to lesser levels than that required for SSCs important to safety, as described in the respective part of this section. For example, the structural capacities or design and construction codes may be stated and evaluated, but there typically is no review of structural analyses or other analyses supporting selection or assessment of projected performance.

4.5.6 Accident Conditions

Verify that the load combinations that the applicant considers to be accident or natural phenomenon conditions of loading are acceptable. Review the analysis and how the applicant's results compare to the design criteria. The SAR may present factors of safety, stress ratios, or margins of safety. Ensure that the calculated values are less than the allowed values for different load combinations.

4.5.6.1 *Structures, Systems, and Components Important to Safety*

Review the SAR's structural analyses to assess the information regarding margins of safety or compliance with the ASME B&PV Code stress limits, overturning margins, and other design criteria as appropriate. Ensure that the applicant presented the comparisons of capacity versus demand for the various applicable loading conditions in the same manner as presented in the same terms used in the design code (e.g., type of stress). In addition, ensure the margins of safety are included on the basis of comparisons between capacity and demand for each structural component analyzed. Ensure the minimum margin of safety for any structural section of a component is included for the different load conditions.

4.5.6.1.1 Canister and Associated Welds and Bolts

Verify that the calculated stress in the canister and associated welds and bolts for each stress category, the stress allowable, stress intensity, and stress ratios are within the limits specified in the ASME B&PV Code. Ensure that the allowable stresses are based on the temperature of the material in the loading condition considered and determined in accordance with the ASME B&PV Code.

During a load drop, the canister will be subjected to compressive forces; therefore, ensure that the applicant evaluated buckling of the canister in accordance with ASME B&PV Code, Appendix F-1331.5, and NUREG/CR-6322, as applicable.

4.5.6.1.2 Fuel Basket

Verify that the applicant has considered, at a minimum, the following loading combinations on the fuel basket for the following accident conditions of loading:

- axial end drop of the transfer cask
- side drop of the transfer cask
- side drop of canister on rails in storage overpack
- side drop of the canister away from rails

During a load drop, the fuel basket will be subjected to compressive forces; therefore, ensure that the applicant evaluated buckling of the fuel basket plates in accordance with ASME B&PV Code, Appendix F-1331.5, and NUREG/CR-6322, as applicable.

4.5.6.1.3 Spent Fuel Assemblies and Cladding

Verify that the applicant has considered, at a minimum, SFA and cladding buckling during accidental side drop and corner drop of the transfer cask or storage cask. The calculated onset of buckling does not necessarily imply cladding failure. Ensure that the stress in the SFA cladding is less than the yield stress of the material. Ensure also that the maximum principal strain is less than allowable strain.

Confirm that the analytical approach used for buckling to assess fuel rod integrity for the cask drop accident uses irradiated material properties and includes the total weight of the fuel.

Alternately, the NRC accepts an analysis of fuel rod integrity that considers the dynamic nature of the drop accident and any restraints on fuel rod movement resulting from cask design. If a finite element analysis is performed, the analysis model may consider the entire fuel rod length with intermediate supports at each grid spacer. Confirm that the SAR includes the irradiated material properties and total weight of the fuel. For further guidance, see Bjorkman (2004, 2009).

4.5.6.1.4 Transfer cask

Verify that the calculated stress in the transfer cask components, the stress allowable, stress intensity, and stress ratios are within the limits specified in the ASME B&PV Code.

Confirm that the transfer cask shell and cover plates are evaluated for penetration by different missiles specified in RG 1.76. Ensure that the maximum penetration depth is not greater than the shell or cover plate thickness.

Confirm that the transfer cask, while sitting on a trailer, is evaluated for overturning from design-basis wind, seismic, and missile impact loads. Ensure the factor of safety against overturning is greater than 1.1.

4.5.6.1.5 Storage Overpack

Table 4-2 lists four load combinations for reinforced concrete structures, and nine load combinations for steel structures (six for applied stress design and three for strength design) occurring during accident conditions. For storage overpacks, ensure the SAR reflects the accident condition loads as weight of the storage overpack, live load, thermal loads, earthquake or seismic loads, accident loads from load drop, and tornado or hurricane loads.

Ensure that the demand-to-capacity ratio for shear, axial force, and bending moment for different individual components is less than 1.0.

Ensure that the applicant evaluated the transfer overpack or cask for overturning and sliding from seismic loads, tornado wind loads, combined tornado effects (wind force in combination with tornado generated missile force), and flood loads. The load combinations from Table 4-2 should be used for this evaluation.

4.5.6.2 *Other Structures, Systems, and Components*

The NRC has accepted but does not require use of the accident condition load combinations from Table 4-2 for steel and reinforced concrete structures that are not important to safety, including the concrete ISFSI pad that is classified as not important to the safety. If Table 4-2 is not used, ensure the analysis uses load combinations from the IBC, ASCE 7 or ACI 318, as appropriate. If load combinations other than those from Table 4-2 are used, it is not necessary to distinguish between normal, off-normal, or accident condition load combinations. The applicant can report the results of the governing load combination for the structural component in question. The NRC has accepted 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” terms. Ensure that the demand-to-capacity ratio for shear, axial, and bending moment at all locations in the concrete and steel structures is less than 1.0.

If the concrete ISFSI pad is important to safety, ensure the SAR reflects the load combinations for the pad for normal conditions listed in Table 4-2 under the reinforced concrete footings column.

Ensure the demand-to-capacity ratio for shear, axial, and bending moment at all locations of the concrete pad is less than 1.0. In addition, ensure that the modulus of subgrade

Table 4-2 Loads and Their Descriptions

Symbol	Capacity or Load	Capacity or Load (or Demand) Description
S	Steel allowable strength design (ASD)	Strength of a steel section, member, or connection computed in accordance with the "allowable stress method" of ANSI/AISC 360.
S_v	Steel ASD shear	Shear strength of a section, member, or connection computed in accordance with the "allowable stress method" of ANSI/AISC 360.
U_s	Steel plastic strength	Strength (capacity) of a steel section, member, or connection computed in accordance with the "plastic strength method" of ANSI/AISC 360.
U_c	Reinforced concrete available strength	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, Φ, as defined and prescribed in Section 9.2, "Design Strength," of ACI 349. If strength may be reduced during the design life by differential settlement, creep, or shrinkage, those effects should 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.
U_f	Strength of foundation sections	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, Φ, as defined and prescribed in Section 9.3 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	Minimum available soil reaction or pile capacity is determined by foundation analysis (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 U_c.
O/S	Overturning or sliding resistance	Required minimum available resistance capacity of structural unit against both overturning and 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.
D	Dead load	Dead load of the structure and attachments including permanently installed equipment and piping. The weight and

Symbol	Capacity or Load	Capacity or Load (or Demand) Description
		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, 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, they should 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 percent if that produces the most adverse loading condition.
L	Live loads	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 manmade or natural causes. Live loads attributable to casks with stored fuel need only be varied by credible increments of loading 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.
L	Live load for precast structures before final integration is in place	Live loads for precast structures should consider all loading and restraint conditions from initial fabrication to completion of the structure including form removal, storage, transportation, and erection. The NRC is concerned with the analysis of loading of reinforced concrete structures before use to the extent that the structures should not have suffered hidden damage from construction live loads, thereby jeopardizing the capacity of the structures when in use. If the damage would be visibly obvious before installation, analysis of capacity versus precompletion demands is not required.
DB	Design-basis (accident) loads	Design-basis loads are controlling bounds for the following external event estimates: • 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. • 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.

Symbol	Capacity or Load	Capacity or Load (or Demand) Description
		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 significant degradation in structural capacity may credibly occur and remain undetected. The retrievability of individual fuel assemblies is not required for design-basis accident conditions that include natural phenomena hazards effects.
T	Thermal loads	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 should presume that all loaded fuel has the maximum thermal output allowed at the time of initial loading in the cask system. Thermal loads should be determined for the most severe of both steady-state and accident conditions. For multiple cask storage facilities, thermal loads should 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).
T_a	Accident condition thermal loads	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 should be determined for the worst-case loadings on potentially critical sections.
A	Accident condition loads	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	Loads caused by lateral soil pressure, as would exist in normal, off-normal, or design-basis conditions corresponding to the load combination 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). 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	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

Symbol	Capacity or Load	Capacity or Load (or Demand) Description
		pile bearing limit) that would exist in normal, off-normal, or design-basis conditions corresponding to the load combination used. G is a function of U_g (i.e., G = f (U_g)).
W	Wind loads	Wind 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.
W_t	Tornado loads	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 earthquake.
F	Flood loads	Loads attributable to the static and dynamic effects of a flooding event. This includes flooding caused by severe and extreme natural phenomena (e.g., seismic, tsunamis, storm surges), dam failure, fire suppression, and other accidents.

NOTE: 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 should be taken as 0.90. If the load is not always present, the coefficient for that load should be taken as zero. Each load that may not always be present in the load combinations is to be varied from 0 to 100 percent to simulate the most adverse loading conditions (to the extent of proving that the lowest margins of safety have been determined).

Table 4-3 Load Combinations for Steel and Reinforced Concrete Nonconfinement Structures

Load Combination	Acceptance Criteria
Reinforced Concrete Structures—Normal Events and Conditions	
U_c > 1.4 D + 1.7 L	Capacity/demand >1.00 for all sections.
U_c > 1.4 D + 1.7 (L + H)	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)	Capacity/demand >1.00 for all sections.
U_c > 1.05 D + 1.275 (L + H + T + W)	Capacity/demand >1.00 for all sections.
Reinforced Concrete Structures—Accidents and Conditions	
U_c > D + L + H + T + (E or F)	Capacity/demand >1.00 for all sections.
U_c > D + L + H + T + A	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	Capacity/demand >1.00 for all sections.
U_c > D + L + H + T + (W_t or W_h)	The load combination (capacity/demand >1.00 for all sections) should be satisfied without missile loadings. Missile loadings are additive (concurrent) to the loads caused by the wind

Load Combination	Acceptance Criteria
	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)	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
U_f > D + (L + H+ G)	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)	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)	Capacity/demand >1.00 for all sections. For footing and foundation sections with load limited by soil reaction.
Reinforced Concrete Footings/Foundations—Accident Events and Conditions	
U_f > D + L + H + T + E + G	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	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	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 or W_h) + G	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	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 and S_v) > D + L	Factored strength/demand >1.00 for all sections.
(S and S_v) > D + L + H	Factored strength /demand >1.00 for all sections.
Steel Structures Allowable Stress Design—Off-Normal Events and Conditions	
1.3 (S and S_v) > D + L + H + W	Factored strength /demand >1.00 for all sections.
1.5 S > D + L + H + T + W	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	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.
Steel Structures Allowable Stress Design—Accidents and Conditions	
1.6 S > D + L + H + T + (E or W_t or W_h or F)	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 or W_t or W_h or F)	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.

Load Combination	Acceptance Criteria
1.7 S > D + L + H + T + A	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	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 + Ta	Factored strength/demand >1.00 for all sections.
1.4 S_v > D + L + H + Ta	Factored strength/demand >1.00 for all sections.
Steel Structures Plastic Strength Design—Normal Events and Conditions	
U_s > 1.7 (D + L)	Plastic capacity/demand >1.00 for all sections.
U_s > 1.7 (D + L + H)	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)	Plastic capacity/demand >1.00 for all sections.
U_s > 1.3 (D + L + H + T + W)	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 or W_t or W_h or F))	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) should 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)	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)	Plastic capacity/demand >1.00 for all sections.
Overturning and Sliding—Normal and Off-Normal Events and Conditions	
O/S ≥ 1.5 (D + H)	Capacity/demand ≥1.00 for structure to be satisfied for both overturning and sliding.
Overturning and Sliding—Accidents and Conditions	
O/S ≥ 1.1 (D + H + E or F)	Capacity/demand ≥1.00 for structure to be satisfied for both overturning and sliding.
O/S ≥ 1.1 (D + H + W_t or W_h)	Capacity/demand ≥1.00 for structure to be satisfied for both overturning and sliding.

4.6 Evaluation Findings

The structural evaluation must provide reasonable assurance that the DSF or DSS will allow safe storage of SNF. The reviewer prepares evaluation findings on satisfaction of the regulatory requirements relating to the design and structural evaluation of the DSF or DSS as identified in Section 4.4 of this SRP. Based on the review of the applicant's description, proposed design criteria, appropriate use of material properties, and adequate structural analysis of the two categories of SSCs (important to safety or not important to safety, as applicable), the staff concludes that the SSCs are in conformance with NRC regulations. Because the regulatory requirements are different for a specific license and a general license, the findings for each of these license types are listed separately. Ensure the SER addresses each acceptance criteria provided in Section 4.4 of this SRP similar to the following (finding numbering is for convenience in referencing within the SRP and SER), and that the SER evaluation provides clear bases for any regulatory conclusions:

Specific License **(SL)**

F4.1 The SAR and docketed materials adequately describe the ISFSI structures, and therefore meet the requirements in 10 CFR 72.24(b) with respect to technical information.

F4.2 The SAR and docketed materials describe the design of the ISFSI structures in sufficient detail to support findings in 10 CFR 72.40, "Issuance of License," for the term requested in the application, including the design criteria pursuant to Subpart F, the design bases, and the relation of the design to the design criteria, utilize applicable codes and standards, and therefore meet the requirements in 10 CFR 72.24(c)(1), 10 CFR 72.24(c)(2), and 10 CFR 72.24(c)(4) with respect to technical information.

F4.3 The SAR and docketed material contain information relative to materials of construction, general arrangement, dimensions of principal structures, and descriptions of all SSCs important to safety in sufficient detail to support a finding that the ISFSI will satisfy the design bases with an adequate margin of safety, and therefore meets the requirements in 10 CFR 72.24(c)(3) with respect to technical information.

F4.4 The SAR and docketed material contain an analysis and evaluation of the design and performance of SSCs important to safety, with the objective of assessing the impact on public health and safety resulting from operation of the ISFSI, and therefore meet the requirements in 10 CFR 72.24(d) with respect to technical information.

F4.5 The SAR identifies the SSCs important to safety whose functional adequacy or reliability had not been demonstrated for that purpose or cannot be demonstrated by reference to performance data in related applications or to widely accepted engineering principles, and the applicant has provided a satisfactory schedule showing how safety questions will be resolved before the initial receipt of SNF, HLW, or reactor-related GTCC waste, as appropriate, for storage at the ISFSI, and therefore meets the requirements in 10 CFR 72.24(i).

F4.6 The SAR and docketed materials adequately describe the design criteria for the SSCs important to safety and other SSCs, and therefore meet the requirements in 10 CFR 72.120(a).

F4.7 Each SSC important to safety is designed to the quality standards commensurate with the importance to safety of the function to be performed, and therefore meets the requirements in 10 CFR 72.122(a).

F4.8 The SSCs important to safety are designed to withstand the normal and off-normal conditions associated with the site and can withstand postulated accidents, and therefore meet the requirements in 10 CFR 72.122(b)(1).

F4.9 The SSCs important to safety are designed to withstand the natural phenomena associated with the site without impairing their ability to perform their intended safety functions (with consideration for the most severe natural phenomena reported for the site and in the appropriate combination of normal and accident conditions), and therefore meet the requirements in 10 CFR 72.122(b)(2)(i).

F4.10 All ISFSI structures are designed to prevent massive collapse or dropping of heavy objects onto an SSC important to safety, and therefore meet the requirements in 10 CFR 122(b)(2)(ii).

F4.11 SSCs important to safety are designed and located to continue to perform their safety functions effectively under credible fire and explosion exposure conditions, and therefore meet the requirements in 10 CFR 72.122(c).

F4.12 SSCs important to safety are not shared between the ISFSI and other facilities, or the SAR indicates that such sharing does not impair the capability of either facility to perform its safety functions, including the ability to return to a safe condition in the event of an accident, and therefore meet the requirements in 10 CFR 72.122(d).

F4.13 Storage systems are designed to allow ready retrieval of SNF, HLW, and reactor-related GTCC waste for further processing or disposal, and therefore meet the requirements in 10 CFR 72.122(l).

F4.14 SNF handling, packaging, transfer, and storage systems are designed to ensure subcriticality, in that at least two unlikely, independent, and concurrent or sequential changes must occur before a nuclear criticality accident ensues. The margins of safety of these systems are adequate for the nature of the immediate environment under accident conditions, and therefore meet the requirements in 10 CFR 72.124(a).

F4.15 SSCs important to safety are designed to provide favorable geometry and permanently fixed neutron-absorbing materials, and therefore meet the requirements in 10 CFR 72.124(b).

F4.16 SSCs important to safety that contain SNF, HLW, reactor-related GTCC waste, and other related radioactive waste are designed to ensure adequate safety with respect to suitable shielding and confinement under normal and accident conditions, and therefore meet the requirements in 10 CFR 72.128(a)(2) and 10 CFR 72.24(a)(3).

Certificate of Compliance **(CoC)**

F4.17 SNF handling, packaging, transfer, and storage systems are designed to ensure subcriticality, in that at least two unlikely, independent, and concurrent or sequential changes must occur before a nuclear criticality accident ensues. The margins of safety of these systems are adequate for the nature of the immediate environment under accident conditions, and therefore meet the requirements in 10 CFR 72.124(a).

F4.18 SSCs important to safety are designed to provide favorable geometry or permanently fixed neutron-absorbing materials, and therefore meet the requirements in 10 CFR 72.124(b).

F4.19 The design bases and design criteria are provided for SSCs important to safety that meet the requirements in 10 CFR 72.236(b).

F4.20 The SNF storage cask is designed so that the SNF is maintained in a subcritical condition under credible conditions, and therefore meets the requirement in 10 CFR 72.236(c).

F4.21 The radiation shielding and confinement features are sufficient to meet the requirements of 10 CFR 72.124(a), 10 CFR 72.124(b), and 10 CFR 72.236(d).

F4.22 The SNF storage cask is designed to provide redundant sealing of confinement systems, and therefore meets the requirements in 10 CFR 72.236(e).

F4.23 The SNF storage cask is designed to store the SNF safely for the term proposed in the application, and therefore meets the requirements in 10 CFR 72.236(g).

F4.24 The SNF storage cask is compatible with wet or dry SNF loading and unloading facilities, and therefore meets the requirements in 10 CFR 72.136(h).

F4.25 The SNF storage cask and its systems important to safety have been evaluated by appropriate test or other acceptable means and have demonstrated that they will reasonably maintain confinement or radioactive material under normal, off-normal, and credible accident conditions, and therefore meet the requirements in 10 CFR 72.236(l).

F4.26 To the extent practicable, the SAR has given consideration to the design of the SNF storage cask for compatibility with the removal of the stored SNF from a reactor site, transportation, and ultimate disposition by the Department of Energy, and therefore meets the requirements in 10 CFR 72.236(m).

Provide a summary statement similar to the following:

> The staff concludes that the structural properties of the SCCs of the [cask designation] are in compliance with 10 CFR Part 72 and the applicable design and acceptance criteria have been satisfied. The evaluation of the structural properties provides reasonable assurance that the [cask designation] will allow safe storage of SNF for a licensed (certified) life of years. This finding is reached on the basis of a review that considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

4.7 References

10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities."

10 CFR Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste."

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American Society of Mechanical Engineers (ASME) Boiler and Pressure (B&PV) Code, 2015.
- Section III, "Rules for Construction of Nuclear Facility Components."
  - Division 1, "Metallic Components"; Subsections NB, NC, ND, NF, and NG
  - Appendix F
  - Division 3, "Containments for Transportation & Storage of Spent Nuclear Fuel and High Level Radioactive Material & Waste" (no NRC position on this has been established)
- Section VIII, "Rules for Construction of Pressure Vessels"
- Appendix I
- Appendix III

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