2 STRUCTURAL EVALUATION

2.1 Review Objective

The objective of this U.S. Nuclear Regulatory Commission (NRC) structural evaluation is to verify that the applicant has adequately evaluated the structural performance of the package (packaging together with contents) so that it meets the regulations in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 71, "Packaging and Transportation of Radioactive Material."

2.2 Areas of Review

The NRC staff should review the application to verify that it adequately describes the package and includes adequately detailed drawings. In general, the staff should review the following information to determine the adequacy of the package description:

- description of structural design
  - descriptive information including weights and centers of gravity
  - identification of codes and standards
- general requirements for ALL packages
  - minimum package size
  - tamper-indicating feature
  - positive closure
  - package valve
- lifting and tie-down standards for all packages
  - lifting devices
  - tie-down devices
- general considerations for structural evaluation of packaging
  - evaluation by analysis
  - evaluation by test
- normal conditions of transport
  - heat
  - cold
  - reduced external pressure
  - increased external pressure
  - vibration
  - water spray
  - free drop
  - corner drop
  - compression
  - penetration

- hypothetical accident conditions
  - — free drop
  - — crush
  - — puncture
  - — thermal
  - — immersion—fissile material
  - — immersion—all material

- air transport accident conditions for fissile material
  - — free drop test
  - — crush test
  - — puncture test
  - — thermal test
  - — 90-meter-per-second (m/s) impact test

- special requirements for Type B packages containing more than 10^5 A_2
- air transport of plutonium
- appendix

2.3 Regulatory Requirements and Acceptance Criteria

This section provides a summary of those sections of 10 CFR Part 71 relevant to the structural review areas addressed in this standard review plan (SRP) chapter. Table 2-1 identifies the relevant regulatory requirements and the areas of review covered by this chapter. The reviewer should verify the association of regulatory requirements with the areas of review presented in these tables to ensure that no requirements are overlooked as a result of unique applicant design features.

The structural evaluation seeks to ensure that the transportation package design under review meets the applicable regulatory requirements and fulfills the acceptance criteria. Section 2.4 of this SRP chapter describes the application of the regulations and the acceptance criteria for each of the review areas listed in Table 2-1.

Acceptability of the design of the packages used for the transport of radioactive materials, as described in the application, is based on compliance with the requirements of 10 CFR Part 71 and regulatory guidance.

The package must have adequate structural performance to meet the containment, shielding, subcriticality, and temperature requirements of 10 CFR Part 71 under normal conditions of transport, hypothetical accident conditions, and air transport conditions, as applicable.

2.4 Review Procedures

For the structural evaluation, the NRC staff should ensure that the application adequately describes and evaluates the package design under the normal conditions of transport, the hypothetical accident conditions, and air transport conditions to demonstrate sufficient structural integrity to meet the requirements of 10 CFR Part 71.

Table 2-1 Relationship of Regulations and Areas of Review for Transportation Packages

Areas of Review	Applicable 10 CFR Part 71 Structural Regulations												
	71.31	**71.33**	**71.35**	**71.41**	**71.43**	**71.45**	**71.51**	**71.55**	**71.61**	**71.64**	**71.71**	**71.73**	**71.74**
Description of structural design	(a)(1) (c)	(a),(b)	(a)										
Lifting and tie-down standards for packages						(a),(b)							
General considerations	(a)(2)		(a)		(a) (b),(c) (e)								
Normal condition of transport				(a)	(f)		(a)(1)	(d)(2)			●		
Hypothetical accident conditions				(a)			(a)(2)	(e)				●	
Air transport accident conditions for fissile material								(f)					
Special requirements for Type B packages containing more than 10^5 A_2.									●				
Air transport of plutonium										●			●

Note: The bullet (●) indicates the entire regulation as listed in the column heading applies.

The structural evaluation is based in part on the descriptions and evaluations presented in the General Information, Thermal, and Materials sections of the application. The results of the structural review are considered in the reviews of thermal, containment, shielding, criticality, operating procedures, and acceptance tests and maintenance program technical areas. Thus, reviews of all the sections of the application take into account the results of the structural evaluation. An example of this information flow for the structural evaluation is shown in Figure 2-1.

2.4.1 Description of Structural Design

2.4.1.1 General

Review drawings and other descriptions of the structural design in the General Information and Structure Evaluation sections of the application. Ensure that the information describes the function, geometry, and material of construction of all structural components of the packaging and its lifting and tie-down devices. The information should be sufficient for evaluating the structural performance of the packaging to meet the regulatory requirements, which include containment, shielding, and maintaining subcriticality of the radioactive contents under the normal conditions of transport and the hypothetical accident conditions. Verify that the data used in the structural evaluation are consistent with those on the drawings and descriptions of the structural design in the application.

Verify that packaging drawings provided in the General Information and Structural Evaluation sections of the application specify the materials of construction, dimensions, tolerances, and fabrication methods of the packaging and subassemblies, receptacles, internal or external

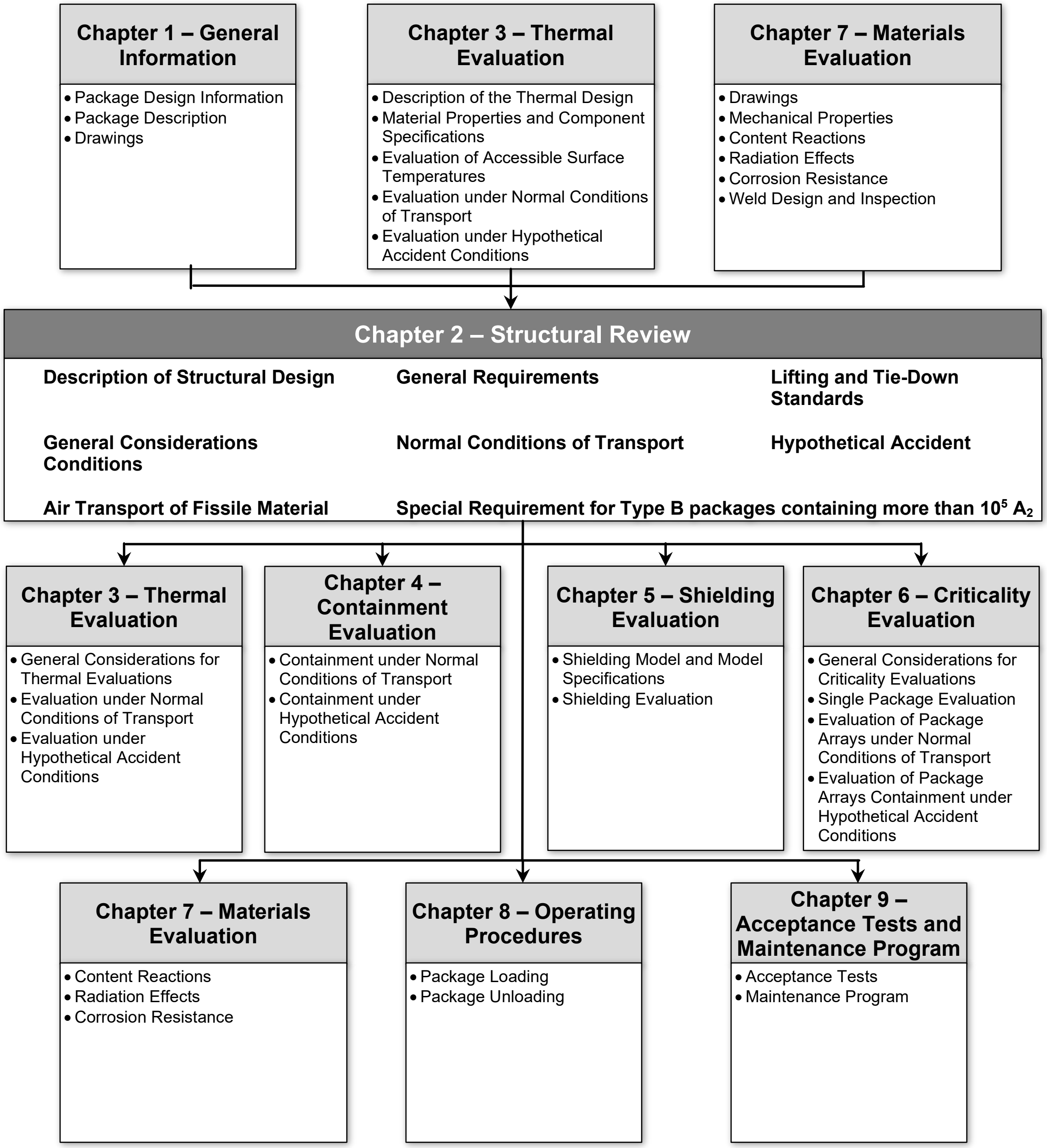

Figure 2-1 Information Flow for the Structural Evaluation

support structures, valves and ports, lifting devices, tie-down devices, and other design features relevant to the structural evaluation. Ensure that the application includes descriptive information, such as the maximum and minimum weight of the package, the maximum weight of the contents, the center of gravity (c.g.) of the package, and the maximum normal operating pressure.

Review the package description presented in the General Information and Structural Evaluation sections of the application. Descriptive information important to structures includes the following:

- dimensions, tolerances, and materials
- code of record and alternatives to specify the American Society of Mechanical Engineers (ASME) Boiler and Pressure Valve (B&PV) Code requirements
- maximum and minimum weights and centers of gravity of packaging and major subassemblies
- maximum and minimum weight of contents, if appropriate
- maximum normal operating pressure
- description of closure system
- description of handling requirements
- fabrication methods, as appropriate

Confirm that the text and sketches describing the structural design features are consistent with the engineering drawings and the models used in the structural evaluation. In accordance with 10 CFR 71.31(a)(1), the structural description must meet the applicable requirements of 10 CFR 71.33(a) and (b).

2.4.1.2 Identification of codes and standards for package design

Verify that the codes and standards are appropriate for the intended purpose and are properly applied. In accordance with 10 CFR 71.31(c), ensure that the application identifies established codes and standards or justifies the basis used for the package design and fabrication. Use the following criteria to verify that the code or standard applies:

- The code or standard was developed for structures of similar design and material, if not specifically for shipping packages.
- The code or standard was developed for structures with similar loading conditions.
- The code or standard was developed for structures that have similar consequences of failure.
- The code or standard adequately addresses potential failure modes.
- The code or standard adequately addresses margins of safety.

NUREG/CR-3854, “Fabrication Criteria for Shipping Containers,” issued March 1985, identifies codes and standards that may be used for fabricating components of spent nuclear fuel (SNF) transportation packaging based on the container contents.

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Division 3 was developed specifically for the design and construction of the containment systems of a SNF or radioactive waste transportation packaging. The NRC may accept the material, design, fabrication, welding, examination, testing, inspection, and certification of containment systems for SNF transportation packages, in accordance with the B&PV Division 3 Code.

In general, the NRC accepts the use of the most recent code year for the design of shipping packages for new applications. ASME B&PV Code, Section III, Division 1, Subsection NCA-1140 has provisions for the use of ASME B&PV Division 1 code editions, addenda, and cases that apply to both new applications and amendments. ASME B&PV Code, Section III, Division 3, Subsection WA-1140 has provisions for the use of ASME B&PV Division 3 code editions, addenda, and cases for all submissions. The NRC may consider alternatives to this guidance on a case-by-case basis.

If there are any deviations from the ASME B&PV Code, ensure that the application explicitly states the justification for the deviation.

The following NRC regulatory guides (RG) and NUREGs provide guidance for structural design evaluation of packages using information from existing codes and practices:

- RG 7.6, “Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels,” provides design stress criteria for the containment system of Type B packages.

- RG 7.8, “Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material,” identifies the load combinations to be used in package design evaluation.

- RG 7.9, “Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material,” provides the standard format for the safety analysis report (SAR).

- RG 7.11, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m),” and RG 7.12, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1 m) But Not Exceeding 12 Inches (0.3 m),” describe criteria for precluding brittle fracture in package containers made of ferritic steels.

- NUREG/CR-6322, “Buckling Analysis of Spent Fuel Basket,” issued May 1995, provides guidance for buckling analysis of SNF baskets.

- NUREG/CR-6007, “Stress Analysis of Closure Bolts for Shipping Casks,” issued April 1992, provides guidance and criteria for design analysis of closure bolts for packages.

- NUREG/CR-3019, “Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials,” issued March 1984, presents criteria for transportation package welds.

- Guidance applicable for trunnions is provided in NUREG-0612, “Control of Heavy Loads at Nuclear Power Plants,” issued July 1980, and American National Standards Institute N14.6, “Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (45,000 kg) or More for Nuclear Materials.”

Attachment 2A to this SRP chapter provides guidance for the review of computational modeling software.

Ensure that the application clearly describes the methodology, approach, and the assumptions used in the buckling analysis of irradiated fuel elements, including Tritium-Producing Burnable Absorber Rods (see Appendix E, “Description and Review Procedures for Irradiated Tritium-Producing Burnable Absorber Rods Packages” to this SRP), under bottom-end package-drop conditions. If the application uses the simplified approach, as described in the Lawrence Livermore National Laboratory report UCID-21246, “Dynamic Impact Effects on Spent Fuel Assemblies,” dated October 20, 1987, ensure that the analysis uses the irradiated fuel properties and the weight of the fuel pellets, in addition to cladding weight, for more realistic results.

Alternatively, an analysis of fuel element integrity, which considers the dynamic nature of the drop accident and any restraints on fuel movement resulting from the package design, is acceptable if it demonstrates that the cladding stress remains below the yield strength. If a finite element analysis is performed, the analysis model may consider the entire fuel element length with intermediate supports at each grid support (spacers). Ensure that the analysis considers irradiated material properties and the weight of fuel pellets.

2.4.2 General Requirements for All Packages

2.4.2.1 Minimum package size

Review the drawings in the application to determine whether the package meets the minimum package size of 10 CFR 71.43(a).

2.4.2.2 Tamper-indicating feature

In accordance with 10 CFR 71.43(b), ensure that the application describes the package closure system in sufficient detail to show that it incorporates a protective feature that, while intact, is evidence that unauthorized persons have not tampered with the package. This description should include covers, ports, or other access that must be closed during normal transportation. Ensure that the description also includes tamper indicators and their location.

2.4.2.3 Positive closure

In accordance with 10 CFR 71.43(c), ensure that the application describes the package closure system in sufficient detail to show that it cannot be inadvertently opened. This description should include covers, valves, or any other access that must be closed during normal transportation.

2.4.2.4 Package valve

In accordance with 10 CFR 71.43(e), ensure that the application describes any valve or other device, the failure of which would allow radioactive contents to escape, in sufficient detail to determine whether it is protected against unauthorized operation. Ensure that the description includes any enclosure to retain any leakage. This enclosure does not apply to pressure-relief valves.

2.4.3 Lifting and Tie-Down Standards for All Packages

2.4.3.1 Lifting devices

Review the design and evaluation of those lifting devices that are a structural part of the package, their connection with the package body, and the package body in the local area around the lifting devices. Verify that the design, testing, and analyses demonstrate that these devices comply with the following requirements of 10 CFR 71.45(a):

- Any lifting attachment that is a structural part of the package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner.

- Any lifting attachment that is a structural part of the package must be designed so that its failure under excessive load would not impair the ability of the package to meet other requirements.

Verify that the packaging drawings show the location and construction of the lifting devices. Any other structural part of the package that could be used to lift the package must be rendered inoperable for lifting during transport or be designed with strength equivalent to that required for lifting attachments.

2.4.3.2 Tie-down devices

Review the design and evaluation of the tie-down devices that are a structural part of the package, their connection with the package body, and the package body in the local area around the tie-down devices. Verify that the design, testing, and analyses demonstrate that these devices comply with the following requirements of 10 CFR 71.45(b):

- Any tie-down device that is a structural part of the package must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the c.g. of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents.

- A tie-down device that is a structural part of the package must be designed so that its failure under excessive load would not impair the ability of the package to meet other requirements.

Verify that the packaging drawings show the location and construction of the tie-down devices. Any other structural part of the package that could be used to tie down the package must be rendered inoperable for tying down the package during transport or be designed with strength equivalent to that required for tie-down devices.

2.4.4 General Considerations for Structural Evaluation of Packaging

Review the evaluations in the application to ensure that they demonstrate that the analyses or tests used to evaluate the package under the normal conditions of transport and the hypothetical accident conditions have been adequately performed, and that the structural performance of the package meets the following requirements of 10 CFR 71.41(a):

- The initial conditions (e.g., temperature, pressure, and residue heat) used are the most limiting for test or loading conditions of the packaging (see RG 7.8 for further guidance).
- The evaluation methods employed are appropriate for loading conditions considered and follow accepted practices and precepts.
- Interpretations of evaluation results are correct.
- The drop orientations considered in the evaluation are the most damaging. Note that the most damaging orientation for one component may not be the worst case for another component.
- Design criteria have been properly applied (see RG 7.6 for further guidance).

2.4.4.1 Evaluation by analysis

If the structural evaluation is by analysis, include the following elements, at a minimum, in the review of the application:

- Verify that the application clearly describes the analysis models, methods, and results including all assumptions and input data used. The analysis model should adequately represent the geometry, boundary conditions, loading, material properties, and structural behavior of the packaging analyzed.
- Verify that the applicant provided information on any computer-based modeling, as described in Attachment 2A to this SRP chapter, and review the structural analysis the applicant submitted, in accordance with the attachment.
- Verify that for each structural analysis, the application includes information on any computer-based modeling, as described in Attachment 2A to this SRP chapter, and review the structural analysis the applicant submitted in accordance with the attachment.
- Verify that the material model and properties are appropriate for the analyses. If the analysis is an elastic analysis, ensure that the material also is modeled as an elastic material. If the analysis is inelastic, ensure that the application reflects use of the actual material behavior or a conservative elastic-plastic material model representing the actual material. The application should describe how the material properties were obtained and why the material model is appropriate for the loading conditions considered. For analyses involving large strains, verify that the application reflects use of a stress-strain curve for that material. Wood properties can vary greatly depending on species, orientation (direction of loading with respect to the grain direction), temperature, and moisture content. Refer to Section 7.4.4.4 of this SRP for further information on wood material.

- Verify that the applied (force and displacement) boundary conditions in the analysis model are appropriate. For free-drop impact analyses of packages with “soft” impact limiters, impact loads for package components are usually derived from a rigid-body dynamic analysis of the package and used in a quasi-static analysis of the components. Verify that the applicant applied a dynamic amplification factor to the equivalent static load to account for all vibration effects that have been ignored in the rigid-body dynamic and quasi-static analyses. A summary of the quasi-static and rigid-body dynamic analyses methods for impact analysis is provided in NUREG/CR-3966, “Methods for Impact Analysis of Shipping Containers,” issued November 1987, and UCRL-ID-121673, “Guidelines for Conducting Impact Tests on Shipping Packages for Radioactive Material,” issued September 1995.

- Verify that the solution method is appropriate for the evaluation. If the applicant used a computer program, verify the validity and reliability of the computer program. Ensure that the application describes the solution method, the benchmarking results, and the quality assurance program for maintaining and using the computer code.

- Verify that applicant evaluated the most critical combinations of environmental and loading conditions. At a minimum, ensure that the evaluation covers all the initial and loading conditions listed in RG 7.8. In addition, verify that the applicant evaluated all critical free-drop orientations, assuming that the impact could be at any angle. In general, the drop orientations that should be evaluated consist of two groups: (i) drops that produce the highest g-loads to be used for impact analysis of the package components, and (ii) drops that attack the most vulnerable orientations and parts of the packaging (i.e., bolts, seals, valves, and ports). The first group includes drops with the package c.g. located directly above the center of the impact area. These drops are the end drops, the side drops, and the c.g.-over-corner drops. This group also includes slap-down drops where the package c.g. is not directly above the impact area. A slap-down drop of a long package can produce a high g-load in the second impact because of a whipping action generated by the force of the first impact. The number of drops in the second group will depend on the vulnerability of the packaging components and their structural failure modes. Components vulnerable to impact loads should be protected from direct impacts by employing special design features such as recessed construction, protective cover plate, and impact limiter. Verify that the applicant evaluated the consequences of all credible drops.

- Verify that the analysis results are correctly interpreted or used to demonstrate adequate margins of safety of the structural design. The maximum stresses or strains should be compared with corresponding design allowances specified in the code. Verify that the application shows the response of the package to loads and load combinations in terms of stress and strain to components and structural members. Verify that the applicant evaluated structural stability of individual members, as applicable.

2.4.4.2 Evaluation by test

If the structural evaluation is by test, include the following elements, at a minimum, in the review of the application:

- Verify that the test procedures, test equipment, and the impact pad are adequate for package impact testing. UCRL-ID-121673 provides recommendations for package drop testing, including the use of reduced-scale models, which are commonly used for testing SNF packages.

- Verify that the test specimen is fabricated using the same materials, methods, quality assurance, and inspection specifications, as stated in the design documents. Ensure that the application identifies any differences and includes an evaluation of the effects. The specimens should include all safety components to be tested as well as components that are expected to significantly affect the test results. Substitutes for the radioactive contents during the tests should have the same structural properties as the actual contents. Verify that the substitutes have the same mass and same interaction with the surrounding packaging component as the actual contents. The same criteria should be used for all other simulated components to ensure that the simulated parts do not alter the test results. Verify that the scale-model test specimen is properly scaled, fabricated, and instrumented (if applicable). In general, scale models do not provide reliable data to determine the leakage rate of the package. Verify that effects related to the size of the scale-model test article are not significant. Verify that the application provides data to show that the size effect can be ignored if a reduced-scale model (smaller than 1/4-scale) is used.

- Review the description of the surface (e.g., material, mass, and dimensions) used for the free-drop and crush test. Confirm that the surface is essentially unyielding, as specified in 10 CFR 71.73(c)(1).

- Review the description of the steel bar (e.g., material, dimensions, orientation, and method of mounting) used for the puncture test. Confirm that the steel bar is securely attached to an essentially unyielding surface, has sufficient length to cause maximum damage to the package, and meets the other specifications of 10 CFR 71.73(c)(3).

- Verify that the selected drop orientations are sufficient for a thorough test of all critical components of the package and the selection is supported by sound analysis or reasoning. Apply the criteria in Section 2.4.4.1 of this SRP for the selection of critical drop orientation for analysis, as appropriate. Verify that the methods and instruments are adequate for the measurements and that the measurements are sufficient for describing the structural response or damage, including both interior and exterior damage of the test specimen.

- Verify that all test results are evaluated and their structural integrity implication interpreted. The test conclusions should be valid and defensible. Discuss with the applicant any unexpected or unexplainable test results, indicating possible testing problems or previously unknown specimen behavior. In each test, ensure the test measurements, damage, and observations are consistent with each other. Identify any inconsistencies and explain their possible causes in the application. Identify any unreliable results and assess the need for additional tests. If the package is permanently deformed or damaged, evaluate the possibility of further damage by subsequent test conditions. In addition, if the final damage is severe, evaluate the margin of safety of the package design against an unacceptable structural failure scenario, such as a sudden or total collapse or rupture. If acceptance tests are performed on the specimen after the structural testing, ensure the acceptance tests are performed according to appropriate codes and standards.

- Review the video and photos of the tests, if available.

- Verify that the tests demonstrate an adequate margin of safety. The test results should clearly show that the effects of the tests can be reliably reproduced. Verify that the description of the test results includes a discussion of the effects of uncertainties in mechanical properties, test conditions, and diagnostics.

- Review the criteria for evaluating pass or fail for the test conditions. Compare the test results with these criteria.

2.4.5 Normal Conditions of Transport

The evaluation of the package under the normal conditions of transport is based on the effects of the tests and conditions specified in 10 CFR 71.71. These tests must not result in a decrease in package effectiveness, as specified in 10 CFR 71.43(f), nor in any of the following conditions:

- loss or dispersal of contents

- structural changes reducing the effectiveness of components required for shielding, for heat transfer, or for maintaining subcriticality or containment

- changes to the package affecting its ability to withstand the hypothetical accident conditions

As required by the initial conditions of 10 CFR 71.71(b), the ambient air temperature before and after the tests must remain near constant, at that value between -29 and +38 degrees Celsius [-20 and +100 degrees Fahrenheit] most unfavorable for the feature under consideration. The initial internal pressure within the containment system must be the maximum normal operating pressure unless a lower internal pressure consistent with the ambient temperature assumed to precede and follow the tests is more unfavorable. Separate specimens may be used for the free-drop test, the compression test, and the penetration test, as long as each specimen is subjected to the water spray test before being subjected to any of the other tests.

Coordinate with the containment reviewer to verify that the applicant demonstrates that there would be no loss or dispersal of radioactive contents, as specified in 10 CFR 71.51(a)(1).

Coordinate with the criticality reviewer, as appropriate, to verify that the applicant demonstrates that the geometric form of the fissile content will not be substantially altered from vibration and a 1-foot drop, as specified by 10 CFR 71.55(d)(2).

See RG 7.8 for the applicability of some of the tests based on the size of the package. The NRC staff has determined that some of the tests from 10 CFR 71.71 may not have any significance for large shipping packages.

2.4.5.1 Heat

Verify that the heat-loading condition, as required by 10 CFR 71.71(c)(1), will not compromise the structural integrity of the package. Confirm that the evaluation of thermal performance and the maximum temperatures under the heat conditions are consistent with the Thermal Evaluation section of the application.

There are two sources of thermal stresses. These stresses can be caused by either spatial temperature gradients in constrained package components or by interference between components from the different thermal expansions of the components.

Review the circumferential and axial deformations and stresses (if any) that result from differential thermal expansion. The evaluation should consider possible interferences resulting from a reduction in gap sizes. Verify that the stresses are within the limits for normal condition loads.

Verify that the evaluations are based on the maximum ambient temperature and the design pressure in combination with the maximum internal heat load. For specified components of the package (e.g., elastomer seal and neutron shield material), coordinate with the appropriate reviewer to evaluate the maximum temperatures and their effect on the operation of the package. In addition, coordinate with the materials reviewer to determine the effect of time and temperature on the structural properties of the materials. The evaluation should demonstrate that repeated cycles of thermal loadings, together with other loadings, will not result in fatigue failure or extensive accumulations of deformations.

2.4.5.2 Cold

Confirm that the evaluation of thermal performance and the maximum temperatures under the cold condition, as required by 10 CFR 71.71(c)(2), are adequate and consistent with the Thermal Evaluation section of the application. Verify that the evaluations consider the minimum internal pressure with the minimum internal heat load (typically assumed to be no decay heat) and any residual fabrication stresses. Verify that the applicant has considered differential thermal expansions that could result in possible geometric interferences. Verify that the applicant also considered possible freezing of liquids.

Verify that the stresses are within the limits for normal condition loads.

2.4.5.3 Reduced external pressure

Confirm that the application adequately evaluates the package design for the effects of reduced external pressure equal to 25 kilopascals (kPa) [3.5 pounds per square inch (psi)] absolute as required by 10 CFR 71.71(c)(3). Verify that the application considers the greatest possible pressure difference between the inside and outside of the package as well as the inside and outside of the containment system.

2.4.5.4 Increased external pressure

Confirm that the application adequately evaluates the package design for the effects of increased external pressure equal to 140 kPa [20 psi] absolute as required by 10 CFR 71.71(c)(4). Verify that the application considers this loading condition in combination with minimum internal pressure. Verify that the application considers the greatest possible pressure difference between the inside and outside of the package as well as the inside and outside of the containment system. Ensure that the applicant has considered the possibility of buckling of the containment boundary.

2.4.5.5 Vibration and fatigue

Confirm that the application adequately evaluates the package design for the effects of vibration normally incident to transport as required by 10 CFR 71.71(c)(5). Verify that the application includes a determination of the acceleration from vibration by test or analysis. The applicant should provide a fatigue analysis for highly stressed systems, considering the combined stresses from vibration, temperature, and pressure loads. If closure bolts are reused, verify that the fatigue evaluation includes the bolt preload. NUREG/CR-6007 provides guidance on bolt evaluation. Verify that a resonant vibration condition, which can cause rapid fatigue damage, is not present in any packaging component. Consider the effect on package internals. Additional guidance for vibration evaluation is provided in NUREG/CR-0128, "Shock and Vibration Environments for a Large Shipping Container during Truck Transport (Part II)," issued May 1978, and NUREG/CR-2146, "Dynamic Analysis to Establish Normal Shock and Vibration of Radioactive Material Shipping Packages," issued October 1983.

2.4.5.6 Water spray

Review the package design for the effects of the water spray test that simulates exposure to rainfall of approximately 5 centimeters [2 inches] for at least 1 hour as required by 10 CFR 71.71(c)(6). Verify that this test does not significantly affect material properties.

2.4.5.7 Free drop

Review the package design for the effects of the free-drop test required by 10 CFR 71.71(c)(7). The application should address factors such as drop orientation; effects of free drop in combination with pressure, heat, and cold temperatures; and other factors discussed in this section.

Review the evaluation of the closure lid bolt design, port cover plates, and other package components for the combined effects of free-drop impact force, internal pressures, thermal stress, and all other concurrently applied forces (e.g., O-ring seal compression force and bolt preload). NUREG/CR-6007 provides guidance on bolt evaluation.

Review the evaluation of other package components, such as port covers, port cover plates, and shield enclosures, for the combined effects of package drop impact force, internal pressures, and thermal stress.

2.4.5.8 Corner drop

Review the package design for the effects of the corner-drop test required by 10 CFR 71.71(c)(8). This test applies only to rectangular fiberboard, wood, or fissile material packages not exceeding 50 kilograms (kg) [110 pounds (lb)] and cylindrical fiberboard, wood, or fissile material packages not exceeding 100 kg [220 lb]. This test is generally not applicable to SNF packages, because of their weight exceedance.

2.4.5.9 Compression

Review the package design for the effects of the compression test required by 10 CFR 71.71(c)(9). This test applies only to packages weighing up to 5,000 kg [11,000 lb]. This test is generally not applicable to SNF packages because their weight exceeds 5,000 kg [11,000 lb].

2.4.5.10 Penetration

Review the evaluation of the package for the penetration condition required by 10 CFR 71.71(c)(10). Verify that the most vulnerable orientation and location of the package have been considered for this test condition.

2.4.6 Hypothetical Accident Conditions

Verify that the evaluation under hypothetical accident conditions is based on a sequential application of the tests specified in 10 CFR 71.73, in the order indicated, to determine their cumulative effect on a package. The evaluation of the ability of a package to withstand any one test must consider the damage that resulted from the previous tests. In addition, as stated above, the tests under normal conditions of transport must not affect the package's ability to withstand the hypothetical accident condition tests.

Coordinate with the containment reviewer to verify that the applicant demonstrated that there would be no loss or dispersal of radioactive contents as specified in 10 CFR 71.51(a)(2).

Coordinate with the criticality reviewer, as appropriate, to verify that the application demonstrates the requirements of 10 CFR 71.55(e).

Confirm that the evaluation demonstrates that the package has adequate structural integrity to satisfy the containment, shielding, and subcriticality requirements of 10 CFR Part 71 under the hypothetical accident conditions, considering the following:

- Inelastic deformation of the containment closure and seal system is generally unacceptable for the containment evaluation.

- Review the deformation of shielding components with respect to the shielding evaluation.

- Review the deformation of components required for heat transfer or insulation, in terms of the thermal evaluation.

- Review the deformation of components required for subcriticality, in terms of the criticality evaluation.

The applicant may use either of two approaches to demonstrate that the package remains subcritical: (i) showing that reconfigured fuel is subcritical even with water inleakage, or (ii) showing that the package excludes water under hypothetical accident conditions. For the first approach, ensure that the applicant developed the reconfigured fuel geometries based on the material properties of the spent fuel cladding and impact loads imposed on the fuel assemblies. For the second approach, ensure that the applicant showed that there would be no inelastic deformation of the containment closure system (e.g., bolt closure or welded region of a canister) under hypothetical accident conditions. Coordinate with the materials and criticality reviewers to determine and evaluate the applicant's approach, in accordance with Chapter 1, "General Information Evaluation," of this SRP.

With respect to the test conditions required by 10 CFR 71.73(b), except for the water immersion tests, verify that the ambient air temperature before and after the tests remains at that value between -29 and +38 degrees Celsius (-20 and +100 degrees Fahrenheit), which is the most unfavorable for the feature under consideration. The initial internal pressure within the containment system must be the maximum normal operating pressure, unless a lower internal pressure consistent with the selected ambient temperature is less favorable.

2.4.6.1 Free drop

Review the evaluation of the package for the free-drop test as required by 10 CFR 71.73(c)(1). Verify that the applicant evaluated structural integrity for the drop orientation that produces the highest g-load and causes the most severe damage, including c.g.-over-corner, oblique orientation with secondary impact (slap down), side drop, and drop onto the closure. The most damaging orientation for one component might not be the most damaging orientation for another component. If a feature such as a tie-down component is a structural part of the package, verify that it is included in the drop-test configurations and the drop orientation.

Evaluate the effects of lead slump for a package with lead shielding. The lead slump determined by the applicant should be consistent with that used in the shielding evaluation.

Review the evaluation of the closure lid bolt design, port cover plates, and other package components for the combined effects of free-drop impact force, internal pressures, thermal stress, and all other concurrently applied forces (e.g., O-ring seal compression force and bolt preload). NUREG/CR-6007 provides guidance on bolt evaluation.

Review the evaluation of other package components, such as port covers, port cover plates, and shield enclosures, for the combined effects of package drop impact force, internal pressures, and thermal stress.

Review the impact pad used for the free-drop test to ensure that the evaluation used an essentially unyielding pad of adequate size.

Ensure that the applicant has considered buckling of package components.

2.4.6.2 Crush

If applicable, review the evaluation of the package for the dynamic crush condition required by 10 CFR 71.73(c)(2). Verify that the applicant justified its choice for the most unfavorable orientation. This test is only specified for packages with a mass not greater than 500 kg [1,100 lb], density not greater than water, and radioactive contents greater than 1,000 A_2, not as special form material.

This test is generally not applicable to SNF packages.

2.4.6.3 Puncture

Review the evaluation of the package for the puncture test required by 10 CFR 71.73(c)(3). Verify that the application has identified and justified the orientation and location for which maximum damage would be expected. Consider any damage resulting from the free-drop and crush conditions when evaluating this test.

Although analytical methods are available for predicting puncture, empirical formulas derived from puncture test results of laminated panels are sometimes used for determining the package surface-layer thickness required for resisting punctures. The Nelm's formula, developed specifically for package design, provides the minimum thickness needed for preventing the puncture of the steel surface layer of a typical steel-lead-steel laminated cask wall. NUREG/CR-4554, “SCANS (Shipping Cask Analysis System): A Microcomputer Based Analysis System for Shipping Cask Design Review,” Volume 7, issued February 1990, provides an empirical formula for puncture evaluation based on empirical and analytical puncture studies. The formula is applicable for puncture at an angle normal to the surface and at a location away from a stiff support under the surface. The formula is conservative for solid packaging walls, but may be nonconservative for punctures at an oblique angle, where the delivery of the puncture energy is more concentrated than in a right-angle impact. Fortunately, there are few oblique punctures that can involve the total impact energy. In general, oblique punctures may be critical for thin-shelled packages that require only a fraction of the total impact energy to penetrate the packaging wall. Additional considerations in puncture testing are identified in NRC Bulletin 97-02, “Puncture Testing of Shipping Packages Under 10 CFR Part 71,” dated September 23, 1997.

Verify that punctures at oblique angles, near a support, at a valve, and at a penetration have been considered in the evaluations, as appropriate.

2.4.6.4 Thermal

Verify that applicant evaluated the structural package design for the effects of a fully engulfing fire, as specified in 10 CFR 71.73(c)(4). Any damage resulting from the free-drop, crush, and puncture conditions must be incorporated into the initial condition of the package for the fire test. Confirm that the determination of the maximum pressure in the package during or after the test considers the temperatures resulting from the fire and any increase in gas inventory caused by combustion or decomposition processes. Verify that the applicant evaluated the maximum thermal stresses, which can occur either during or after the fire, and that the results are consistent with the Thermal Evaluation section of the application.

2.4.6.5 Immersion—fissile material

If the contents include fissile material, subject to the requirements of 10 CFR 71.55, “General Requirements for Fissile Material Packages,” and if water inleakage has not been assumed for the criticality analysis, review the evaluation of the damaged test specimen (i.e., after free-drop, puncture, and fire) immersed under a head of water of at least 0.9 meter [3 feet] in the orientation for which maximum leakage is expected, as required by 10 CFR 71.73(c)(5).

2.4.6.6 Immersion—all packages

Review the evaluation of a separate, undamaged specimen subjected to water pressure equivalent to immersion under a head of water of at least 15 meters [50 feet], as required by 10 CFR 71.73(c)(6). For test purposes, an external pressure of water of 150 kPa [21.7 psi] gauge is considered to meet these conditions.

2.4.7 Air Transport Accident Conditions for Fissile Material

In addition to the regulations that govern fissile materials in general (10 CFR 71.55), verify that the package is designed and constructed and its contents limited so that it would be subcritical for air transport, as applicable. Air transport conditions are based on a sequential application of the tests specified in 10 CFR 71.55(f)(1), in the order indicated, to determine their cumulative effect on a package. Ensure that the evaluation of the ability of a package to withstand any one test considers the damage that resulted from the previous tests.

Review the deformation of components required for subcriticality, in terms of the criticality evaluation. Specifically, the following sections describe the tests to be evaluated.

2.4.7.1 Free drop

Evaluate in accordance with 10 CFR 71.73(c)(1) and as described in Section 2.4.6.1 of this SRP chapter.

2.4.7.2 Crush test

Evaluate in accordance with 10 CFR 71.73(c)(2) and as described in Section 2.4.6.2 of this SRP chapter.

2.4.7.3 Puncture test

Review the evaluation of the package for the puncture test as specified in 10 CFR 71.55(f)(1)(iii). Verify that the application identifies and justifies the orientation and location for maximum damage. Consider any damage resulting from the free-drop and crush conditions when evaluating this test.

2.4.7.4 Thermal Test

Evaluate in accordance with 10 CFR 71.73(c)(4) and as described in Section 2.4.6.4 of this SRP chapter, but with a test duration of 60 minutes rather than 30 minutes.

2.4.7.5 90-meter-per-second Impact

Review the evaluation of the package for the 90 m/s impact test in accordance with 10 CFR 71.55(f)(2). Verify that the applicant has evaluated structural integrity for the drop orientation that produces the highest g-load and causes the most severe damage, including c.g.-over-corner, oblique orientation with secondary impact (slap down), side drop, and drop onto the closure with respect to the criticality evaluation. A separate, undamaged specimen can be used for this evaluation.

2.4.8 Special Requirement for Type B Packages Containing More Than 10^5 A_2

For a package of irradiated nuclear fuel with activity greater than 37 petabecquerel (PBq) [10^6 curies (Ci), 10 CFR 71.61, “Special Requirements for Type B Packages Containing More Than 10^5A_2,” requires that its undamaged containment system withstand an external water pressure of 2 megapascals (MPa) [290 psi] for a period of not less than 1 hour without collapse, buckling, or inleakage of water. Ensure that the application provides analysis or test results to show that the containment structure will not collapse or buckle within 1 hour after the pressure is applied. This test applies only to the containment system. No structural support from other packaging components should be considered unless the component is an integral part of the containment system. The inleakage requirement has not been met if the stresses around the closure seal region exceed the yield stress limits. Additionally, coordinate with the containment reviewer to ensure that the O-ring and groove is designed for both internal and external pressures.

2.4.9 Air Transport of Plutonium

In addition to applicable fissile material requirements for plutonium, verify that the evaluation under accident conditions is based on sequential application of the tests specified in 10 CFR 71.74, "Accident Conditions for Air Transport of Plutonium," considering the following:

- Rupture of the containment closure and seal system is generally unacceptable for the containment evaluation.
- Review the deformation of shielding components, in terms of the shielding evaluation.
- Review the deformation of components required for heat transfer or insulation, in terms of the thermal evaluation.
- Review the deformation of components required for subcriticality, in terms of the criticality evaluation.

Ensure that the applicant evaluated the tests of 10 CRF 71.74(a), in the order indicated, to determine their cumulative effect on a package. The evaluation of the ability of a package to withstand any one test must consider the damage that resulted from the previous tests.

Confirm that water and ambient conditions for applicable tests are in accordance with 10 CFR 71.64(b)(1)(ii).

Ensure that the applicant used an undamaged package for the individual free-fall-impact test and individual deep submersion test, as specified in 10 CFR 71.74(b) and 10 CFR 71.74(c), respectively.

2.4.10 Appendix

Confirm that the appendix, if included, provides a list of references, copies of applicable references if not generally available to the reviewer, computer code descriptions, input and output files, test results, and other appropriate supplemental information.

If the applicant evaluated the package by test and listed the elements of the test in the appendix, review the test description. The description should include the following elements:

- test procedures
- test package description
- test initial and boundary conditions
- test chronologies—planned and actual
- photographs of the package components, including any structural damage, before and after the tests
- test measurements, including, at a minimum, documentation of test package physical changes as a result of the tests

- test results
- methods used to obtain these corrected results

2.5 Evaluation Findings

Prepare evaluation findings on satisfaction of the regulatory requirements in Section 2.3 of this SRP chapter. If the documentation submitted with the application fully supports positive findings for each of the regulatory requirements, the statements of findings should be similar to the following:

F2-1 The staff has reviewed the package structural design description and concludes that the contents of the application satisfies the requirements of 10 CFR 71.31(a)(1) and (a)(2) as well as 10 CFR 71.33(a) and (b).

F2-2 The staff has reviewed the structural codes and standards used in package design and finds that they are acceptable and therefore satisfy the requirements of 10 CFR 71.31(c).

F2-3 The staff has reviewed the lifting and tie-down systems for the package and concludes that they satisfy the standards of 10 CFR 71.45(a) for lifting and 10 CFR 71.45(b) for tie-down.

F2-4 The staff has reviewed the package description and finds that the package satisfies the requirements of 10 CFR 71.43(a) for minimum size.

F2-5 The staff reviewed the package closure description and finds that the package satisfies the requirements of 10 CFR 71.43(b) for a tamper-indicating feature.

F2-6 The staff reviewed the package closure system and the applicant's analysis for normal and accident pressure conditions and concludes that the containment system is securely closed by a positive fastening device and cannot be opened unintentionally or by a pressure that may arise within the package and therefore satisfies the requirements of 10 CFR 71.43(c) for positive closure.

F2-7 The staff reviewed the package description and finds that the package valve, the failure of which would allow radioactive contents to escape, is protected against unauthorized operation and provides an enclosure to retain any leakage and therefore satisfies the requirements of 10 CFR 71.43(e).

F2-8 The staff reviewed the application and finds that the package was evaluated by subjecting a specimen or scale model to the specific tests, or by another method of demonstration acceptable to the Commission, and therefore satisfies the requirements of 10 CFR 71.41(a).

F2-9 The staff reviewed the structural performance of the packaging under the normal conditions of transport required by 10 CFR 71.71 and concludes that there will be no substantial reduction in the effectiveness of the packaging that would prevent it from satisfying the requirements of 10 CFR 71.51(a)(1) for a Type B package and 10 CFR 71.55(d)(2) for a fissile material package.

F2-10 The staff reviewed the structural performance of the packaging under the hypothetical accident conditions required by 10 CFR 71.73 and concludes that the packaging has adequate structural integrity to satisfy the subcriticality, containment, and shielding requirements of 10 CFR 71.51(a)(2) for a Type B package and 10 CFR 71.55(e) for a fissile material package.

F2-11 The staff reviewed the structural performance of the packaging under the air transport accident conditions for fissile material required by 10 CFR 71.55(f) and concludes that the packaging has adequate structural integrity to satisfy the subcriticality requirements of 10 CFR 71.55(f) for air transport of fissile material.

F2-12 The staff reviewed the packaging structural performance under an external pressure of 2 MPa [290 psi] for a period of not less than 1 hour and finds that the package does not buckle, collapse, or allow the inleakage of water and therefore satisfies the requirements of 10 CFR 71.61.

F2-13 The staff reviewed the packaging structural performance under the accident conditions for air transport of plutonium required by 10 CFR 71.74 and concludes that the packaging has adequate structural integrity to satisfy the subcriticality, containment, and shielding requirements of 10 CFR 71.64, "Special Requirements for Plutonium Air Shipments."

The reviewer should provide a summary statement similar to the following:

> Based on review of the statements and representations in the application, the NRC staff concludes that the package has been adequately described and evaluated to demonstrate that it satisfies the structural integrity requirements of 10 CFR Part 71.

2.6 <u>References</u>

10 CFR Part 71, "Packaging and Transportation of Radioactive Material."

American National Standards Institute, ANSI N14.6–1993, *Institute for Nuclear Materials Management*, "Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (45000 kg) or More for Nuclear Materials," New York, NY.

American Society of Mechanical Engineers (ASME) Boiler and Pressure (B&PV) Code, 2007—Addenda 2008. Section III, "Rules for Construction of Nuclear Facility Components." Division 3, "Containments for Transportation & Storage of Spent Nuclear Fuel and High Level Radioactive Material & Waste" (no NRC position on this has been established). Division 1, "Metallic Components"; Subsection NCA-1140.

Bulletin 97-02, U.S. Nuclear Regulatory Commission, "Puncture Testing of Shipping Packages under 10 CFR Part 71," Bulletin 97-02, September 23, 1997.

NUREG-0612, U.S. Nuclear Regulatory Commission, "Control of Heavy Loads at Nuclear Power Plants," NUREG-0612, July 1980, Agencywide Documents Access and Management System Accession No. ML070250180.

NUREG/CR-0128, U.S. Nuclear Regulatory Commission, "Shock and Vibration Environments for a Large Shipping Container During Truck Transport (Part II)," SAND78-0337, Sandia Laboratories, Albuquerque, NM, May 1978.

NUREG/CR-2146, U.S. Nuclear Regulatory Commission, "Dynamic Analysis to Establish Normal Shock and Vibration of Radioactive Material Shipping Packages, Volume 3: Final Summary Report," HEDL-TME 83-18, Hanford Engineering Development Laboratory, October 1983.

NUREG/CR-3019, U.S. Nuclear Regulatory Commission, "Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials," UCR-L53044, Lawrence Livermore National Laboratory, Livermore, CA, March 1984.

NUREG/CR-3854, U.S. Nuclear Regulatory Commission, "Fabrication Criteria for Shipping Containers," UCRL-53544, Lawrence Livermore National Laboratory, Livermore, CA, March 1985.

NUREG/CR-3966, U.S. Nuclear Regulatory Commission, "Methods for Impact Analysis of Shipping Containers," UCID-20639, Lawrence Livermore National Laboratory, Livermore, CA, November 1987.

NUREG/CR-4554, U.S. Nuclear Regulatory Commission, "SCANS (Shipping Cask Analysis System): A Microcomputer Based Analysis System for Shipping Cask Design Review," UCID-20674, Lawrence Livermore National Laboratory, Livermore, CA, February 1990.

NUREG/CR-5502, U.S. Nuclear Regulatory Commission, "Engineering Drawings for 10 CFR Part 71 Package Approvals," UCRL-10-130438, Lawrence Livermore National Laboratory, May 1998.

NUREG/CR-6007, U.S. Nuclear Regulatory Commission, "Stress Analysis of Closure Bolts for Shipping Casks," UCR-ID-110637, Lawrence Livermore National Laboratory, Livermore, CA, April 1992.

NUREG/CR-6322, U.S. Nuclear Regulatory Commission, "Buckling Analysis of Spent Fuel Basket," UCR-LID-119697, Lawrence Livermore National Laboratory, Livermore, CA, May 1995.

Regulatory Guide 7.6, U.S. Nuclear Regulatory Commission, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," Agencywide Document Access and Management System (ADAMS) Accession No. ML003739418.

Regulatory Guide 7.8, U.S. Nuclear Regulatory Commission, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material," ADAMS Accession No. ML003739501.

Regulatory Guide 7.9, U.S. Nuclear Regulatory Commission, "Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material," ADAMS Accession No. ML050540321.

Regulatory Guide 7.11, U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)," ADAMS Accession No. ML003739413.

Regulatory Guide 7.12, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inch (0.1 m),” ADAMS Accession No. ML003739424.

UCID-21246. “Dynamic Impact Effects on Spent Fuel Assemblies,” Chun, R., M. Witte, and M. Schwartz, Lawrence Livermore National Laboratory, CA, October 20, 1987.

UCRL-ID-121673. “Guidelines for Conducting Impact Tests on Shipping Packages for Radioactive Material,” Mok, G.C., R.W. Carlson, S.C. Lu, and L.E. Fischer, Lawrence Livermore National Laboratory, Livermore, CA, September 1995.