3 THERMAL EVALUATION

3.1 Review Objective

The objective of the U.S. Nuclear Regulatory Commission's (NRC's) thermal evaluation with regard to heat transfer and flow is to ensure that the applicant has adequately evaluated the thermal performance of the transportation package design under review for the thermal tests specified under normal conditions of transport, short-term operations (e.g., drying, backfilling), and hypothetical accident conditions, and that the package design meets the thermal performance requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 71, "Packaging and Transportation of Radioactive Material."

3.2 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 the thermal design
    - packaging design features
    - codes and standards
    - content heat load specification
    - summary tables of temperatures
    - summary tables of pressures in the containment vessel
- material properties and component specifications
    - material thermal properties
    - specifications of components
    - thermal design limits of package materials and components
- general considerations for thermal evaluations
    - evaluation by analyses
    - evaluation by tests
    - confirmatory analyses
    - effects of uncertainties
    - conservatisms
- evaluation of accessible surface temperatures
- thermal evaluation under normal conditions of transport
    - heat and cold
    - maximum normal operating pressure

- thermal evaluation under hypothetical accident conditions

    - initial conditions
    - fire test
    - maximum temperatures and pressures

- appendix

3.3 Regulatory Requirements and Acceptance Criteria

This section provides a summary of those sections of 10 CFR Part 71 relevant to the thermal review areas addressed in this standard review plan (SRP) chapter. The NRC staff reviewer should refer to the exact language in the regulations. Table 3-1 matches the relevant regulatory requirements to the areas of review covered in this chapter. The reviewer should also verify the association of 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.

The thermal evaluation seeks to ensure that the transportation package design under review meets the applicable regulatory requirements and fulfills the acceptance criteria.

The package must have adequate thermal performance to meet the containment, shielding, subcriticality, and temperature requirements of 10 CFR Part 71, under normal conditions of transport, short-term operations (e.g., drying, backfilling), and hypothetical accident conditions.

3.3.1 Description of the Thermal Design

The applicant must describe the package in sufficient detail to provide an adequate basis for its evaluation, as stated in the following regulations:

> 10 CFR 71.31, “Contents of Application,” specifically: 10 CFR 71.31(a)(1) and
> 10 CFR 71.33, “Package Description,” specifically: 10 CFR 71.33(a)(5), 71.33(a)(6), 71.33(b)(1), 71.33(b)(3), 71.33(b)(5), 71.33(b)(7), and 71.33(b)(8)

The safety analysis report (SAR) must identify established codes and standards applicable to the thermal design. [10 CFR 71.31(c)]

The thermal design must not depend on a mechanical cooling system to meet the containment requirements of 10 CFR 71.51(a). [10 CFR 71.51(c)]

3.3.2 Material Properties and Component Specifications

The applicant must describe the package in sufficient detail to provide an adequate basis for its evaluation, as stated in the regulations listed below.

> 10 CFR 71.31(a)(1), 10 CFR 71.33(a)(5), and 10 CFR 71.33(b)(3)

In addition to the regulatory requirements identified in the above paragraph, the temperatures of the materials and components used in the package should not exceed their specified maximum allowable temperatures.

Table 3-1 Relationship of Regulations and Areas of Review for Transportation Packages

Areas of Review	10 CFR Part 71 Regulations											
	71.31 (a)(1)	71.31 (a)(2)	71.31 (c)	71.33 (a)(5)	71.33 (a)(6)	71.33 (b)(1)	71.33 (b)(3)	71.33 (b)(5)	71.33 (b)(7)	71.33 (b)(8)	71.35(a)	71.41(a)
Description of the thermal design	•		•	•	•	•	•	•	•	•		
Material properties and component specifications	•			•			•					
General considerations for thermal evaluations		•									•	•
Evaluation of accessible surface temperatures (for SNF)												
Thermal evaluation under normal conditions of transport												
Thermal evaluation under hypothetical accident conditions												

Areas of Review	10 CFR Part 71 Regulations										
	71.41(a)	71.43(f)	71.43(g)[a]	71.51 (a)(1)	71.51(c)	71.55(f)	71.64	71.71 (c)(1)[b]	71.71 (c)(2)[b]	71.73 (c)(4)[c]	71.74
Description of the thermal design					•						
Material properties and component specifications											
General considerations for thermal evaluations	•										
Thermal evaluation of accessible surface temperatures (for SNF)			•								
Thermal evaluation under normal conditions of transport		•		•				•	•		
Thermal evaluation under hypothetical accident conditions						•	•			•	•

[a]Temperature limits for nonexclusive-use shipments are assumed not to apply to SNF packages.
[b]10 CFR 71.71, "Normal Conditions of Transport", primarily 71.71(c)(1) and 71.71(c)(2), for SNF packages.
[c]10 CFR 71.73, "Hypothetical Accident Conditions," primarily 71.73(c)(4), for SNF packages.
Note: 10 CFR 71.33, 71.71, and 71.73 are applicable, in their entirety, to transportation packages for radioactive materials. The bullet (●) indicates the entire regulation as listed in the column heading applies.

3.3.3 General Considerations for Thermal Evaluations

The applicant must properly evaluate the package to demonstrate that it satisfies the thermal requirements specified in 10 CFR Part 71, Subpart E, under the conditions and tests of Subpart F. [10 CFR 71.31(a)(2), 10 CFR 71.35(a), and 10 CFR 71.41(a)]

The package must be evaluated to demonstrate that any system for containing liquid is adequately sealed and has adequate space (i.e., ullage) or other specified provision for expansion of the liquid. [10 CFR 71.87(d)]

The models used in the applicant's thermal evaluation should be described in sufficient detail to permit an independent review, with confirmatory calculations, of the package thermal design.

3.3.4 Evaluation of Accessible Surface Temperatures

The package must be designed, constructed, and prepared for shipment so that the accessible surface temperature of a package in still air at 38 degrees Celsius (°C) [100 degrees Fahrenheit (°F)] in the shade will not exceed 85 °C [185 °F] in an exclusive-use shipment or 50 °C [122 °F] in a nonexclusive-use shipment. [10 CFR 71.43(g), 10 CFR 71.87(k)] (nonexclusive-use shipments are assumed not to apply to SNF packages.)

3.3.5 Thermal Evaluation Under Normal Conditions of Transport

The applicant must evaluate the package design to determine the effects of the conditions and tests under normal conditions of transport. The ambient temperature preceding and following the tests must remain near constant at that value between -29 °C [-20 °F] and +38 °C [100 °F], which is the most unfavorable condition for the feature under consideration [10CFR 71.71(b)]. The initial internal pressure within the containment system must be considered to be the maximum normal operating pressure (MNOP), unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the tests is more unfavorable.

The conditions and tests of 10 CFR 71.71(c)(1) and 10 CFR 71.71(c)(2) for heat and cold, respectively, are the primary thermal tests for normal conditions of transport. [10 CFR 71.71, "Normal Conditions of Transport"]

The package must be designed, constructed, and prepared for transport so that there will be no significant decrease in packaging thermal effectiveness under the tests specified in 10 CFR 71.71. [10 CFR 71.43(f) and 10 CFR 71.51(a)(1)]

The package must have adequate thermal performance to meet the containment, shielding, subcriticality, and temperature requirements of 10 CFR Part 71 under normal conditions of transport.

3.3.6 Thermal Evaluation Under Hypothetical Accident Conditions

The package must have adequate thermal performance to meet the containment, shielding, subcriticality, and temperature requirements of 10 CFR Part 71 under hypothetical accident conditions. The applicant must evaluate the package design to determine the effects of the conditions and tests under a hypothetical accident (fire). This accident includes a sequence of incidents (impact, crush, puncture, thermal, and immersion) on a package (the crush test is generally not applicable to packages for SNF). Except for the water immersion tests, the ambient temperature preceding and following the tests must remain constant at that value between -29 °C [-20 °F] and +38 °C [100 °F], which is the most unfavorable condition for the feature under consideration [10 CFR 71.73(b)]. The initial internal pressure within the containment system must be considered to be the MNOP, unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the tests is more unfavorable. The 30-minute, 800°C [1,475°F] fire test of 10 CFR 71.73(c)(4) on a damaged package is the primary thermal test for hypothetical accident conditions. [10 CFR 71.73]

The applicant must properly evaluate a fissile package designed for air transport to demonstrate that it can remain subcritical after undergoing the thermal test in 10 CFR 71.73(c)(4), except that the duration of the test must be 60 minutes. [10 CFR 71.55(f)(1)(iv)]

The applicant must properly evaluate a package designed for air transport of plutonium to demonstrate that it will meet the performance test requirements of 10 CFR 71.74, "Accident Conditions for Air Transport of Plutonium," in accordance with the requirements in 10 CFR 71.64, "Special Requirements for Plutonium Air Shipments." These tests include physically exposing the package to pool fire for 60 minutes.

When evaluating a package with special-form radioactive material (RAM), reviewers should recognize that the requirement for maintaining 800 °C [1,475 °F] for the 10-minute heat test of 10 CFR 71.75(b)(4) applies only to the special form content and is not equivalent to the thermal test of the package described in 10 CFR 71.73(c)(4) (i.e., 800 °C for 30 minutes).

3.4 Review Procedures

As part of the thermal evaluation, verify that the application adequately describes and evaluates the package design for the thermal tests specified under normal conditions of transport and hypothetical accident conditions, and that it meets the thermal performance requirements of 10 CFR Part 71.

For all packages, the thermal evaluation is based in part on the descriptions and evaluations presented in the General Information, the Structural Evaluation, Shielding Evaluation, and Materials Evaluation chapters of the safety analysis report (SAR). Similarly, the reviewer should consider the results of the thermal evaluation when reviewing the Structural Evaluation, Containment Evaluation, Shielding Evaluation, Criticality Evaluation, Operating Procedures Evaluation, and Acceptance Tests and Maintenance Program Evaluation chapters of the SAR.

Figure 3-1 shows an example of information flow for the thermal evaluation.

The thermal evaluation results could indicate that special additional conditions in the certificate of compliance (CoC) (i.e., types of transport modal restrictions such as no air shipments, minimum ambient temperature for transport, and package leakage testing) are required. Verify that these conditions are consistent with the results from the thermal evaluation.

Radioactive Materials

The review procedures for RAM are generally applicable to the thermal evaluation of both low-enriched uranium (LEU)-RAM and mixed oxide (MOX)-RAM packages. There may be some differences in emphasis in the thermal review procedures that arise from generic

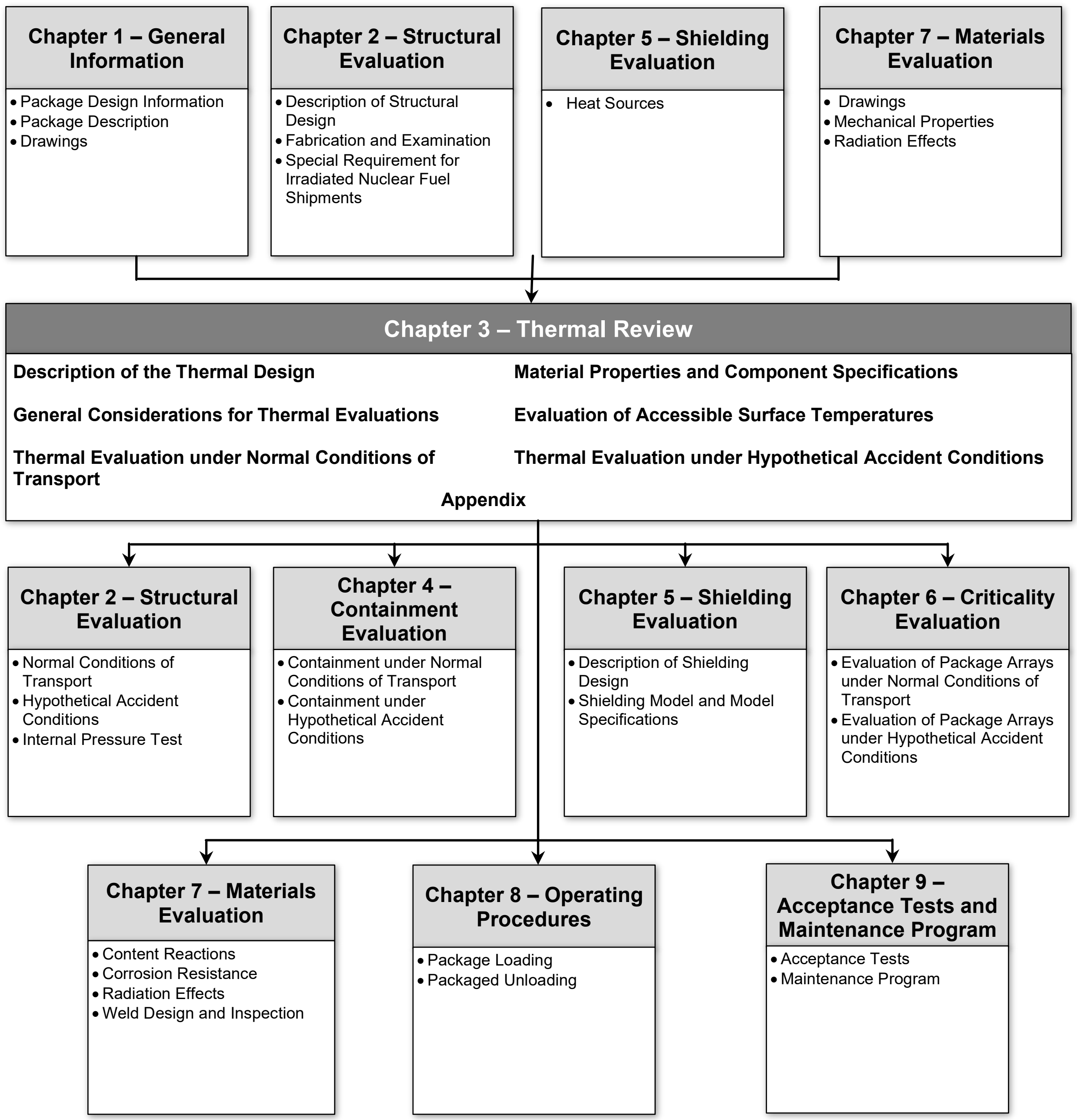

Figure 3-1 Information Flow for the Thermal Evaluation

differences between LEU-RAM and MOX-RAM packaging and contents. Plutonium has a higher specific activity of energetic and short-ranged decay particles (approximately 5 million electron volt alphas) than LEU-RAM does. This results in higher specific content decay heat rates in the MOX-RAM packages than in other LEU-RAM packages (see Appendix B, “Differences Between Thermal and Radiation Properties of MOX and LEU Radioactive Materials,” to this SRP, Attachment 3, “Differences between Thermal and Radiation Properties of MOX and LEU Radioactive Materials”). Also, MOX-fresh-fuel rods and assemblies may need special attention in some of the review procedures provided in this SRP section. The review procedures include the special considerations or attention needed for MOX-RAM packages.

Appendix A to this SRP provides a description for each of the various transportation package types containing RAM and states the safety functions and features. Regarding the areas of safety review, for each package type, the thermal evaluation (and, depending on the safety features, sometimes in conjunction with structural and containment evaluations) is addressed.

Contents that are authorized for transport should be clearly identified in the package application, typically in the General Information section. Applicants are encouraged to include a contents description suitable for inclusion in a CoC. The contents description should be consistent with the package evaluation. The specificity of the contents description may be different for different package types and the safety significance of the contents.

<u>Spent Nuclear Fuel</u>

The review procedures for SNF are generally applicable to the thermal evaluation of both LEU-SNF and MOX-SNF transportation packages. No significant deviations exist in the review procedures and considerations for the two packages. Because packages for shipment of SNF are generally intended to be shipped by exclusive-use, only exclusive-use shipments are assumed in the following SRP review procedures.

3.4.1 Description of the Thermal Design

3.4.1.1 Packaging design features

Verify that all text, drawings, figures, and tables describing the thermal features in the Thermal Evaluation chapter of the SAR are consistent with those of the General Information chapter, as well as those used in the applicant's thermal evaluation. Particular emphasis should be placed on the consistency of the component dimensions, materials, and material properties.

Review the general description of the package presented in the General Information chapter of the SAR and any additional description of the thermal design in the Thermal Evaluation chapter of the SAR. Verify that the package description in the General Information chapter of the SAR includes the following:

- package geometry and materials of construction
- the structural and mechanical features that may affect heat transfer, such as cooling fins, insulating materials, surface conditions of the package components, and gaps or physical contacts between internal components
- a description of any structural and mechanical means for the transfer and dissipation of heat
- the identity and volumes of receptacles containing liquid (e.g., contents, neutron absorber)
- the MNOP of the containment system
- the maximum amount of content-decay heat

Verify that the thermal design does not depend on the presence of a mechanical cooling system to ensure containment.

3.4.1.2 Codes and standards

Verify that the application identifies established codes and standards used in all aspects of the thermal design and evaluation of the package, including material properties and components.

3.4.1.3 Content heat load specification

Verify that the maximum decay heat of the package contents reported in the Thermal Evaluation section of the application is consistent with the decay heat and other contents specifications in the General Information section of the application and that this heat load is appropriately considered in all thermal evaluations.

Coordinate with the shielding reviewer to review the method in which the actual heat load is determined and to ensure that the heat load is properly determined for the maximum allowed radioactive contents; for SNF, this means the content specifications of burnup, enrichment, and cooling time that result in the maximum decay heat load. If the heat load is based on the mass and decay energies of the contents, verify, in consultation with the shielding reviewer, that the applicant properly determined such. The computer codes discussed in Section 5.5.2 of this SRP for determination of neutron and gamma sources are often useful for calculating content decay heat loads. These codes are especially useful for SNF that contains a large number of radionuclide species. Consider the information in Appendix C to this SRP for reviews of MOX-SNF. For example, depending on the grade of plutonium in the MOX-SNF, the decay heat for MOX-SNF may be significantly larger than for LEU-SNF.

3.4.1.4 Summary tables of temperatures

<u>Radioactive Materials</u>

Confirm that summary tables of the maximum, minimum, and allowable temperatures that affect structural integrity, containment, shielding, and criticality are presented for both normal conditions of transport and hypothetical accident conditions. For the fire-test condition, the tables should also include the following:

- the maximum temperatures and the time at which they occur after fire initiation
- the maximum temperatures of the post-fire steady-state condition

Coordinate with the structural and containment reviewers to confirm that these temperatures are consistent.

Ensure that the summary tables of the temperatures of package components including, but not limited to, the fuel and cladding, basket, impact limiters, containment vessel, seals, shielding, and neutron absorbers are consistent with the temperatures presented in the General Information and Structural Evaluation chapters of the SAR for the normal conditions of transport and hypothetical accident conditions.

Spent Nuclear Fuel

Confirm that summary tables of the temperatures of package components including, but not limited to, the fuel and cladding, basket, impact limiters, containment vessel, seals, shielding, and neutron absorbers are consistent with the temperatures presented in the General Information and Structural Evaluation chapters of the SAR for the normal conditions of transport and hypothetical accident conditions. Confirm that the summary tables contain the design temperature limits for each of the components for the normal conditions of transport and hypothetical accident conditions. For the hypothetical accident condition fire, ensure that these summarized temperatures also include the maximum temperatures after fire, the elapsed time from the beginning of the fire to the occurrence of these maximum temperatures, and the post-fire steady-state temperatures of each package component. Confirm that the temperatures and design temperature limit criteria for the package components are consistent throughout the appropriate chapters of the SAR.

3.4.1.5 Summary tables of pressures in the containment system

Coordinate with the structural and containment reviewers to verify that summary tables of the pressure in the containment system under the normal conditions of transport and hypothetical accident conditions are consistent with the pressures presented in the General Information, Structural Evaluation, Containment Evaluation, and Acceptance Tests and Maintenance Program chapters of the SAR. Ensure also that the tables present the design pressure limits of the package components at the temperatures producing the pressures.

3.4.2 Material Properties and Component Specifications

3.4.2.1 Material thermal properties

Confirm that the application presents the thermal properties necessary to calculate thermal transport in the package as well as from the package to the environment. These properties include, but are not limited to, the following:

- thermal conductivity
- specific heat
- density
- emissivity

Verify that the thermal emissivities are appropriate for the specific package surface conditions. The thermal radiation absorptivity on the external packaging surface may be conservatively assumed to be unity to compensate for changes in the package surface from dirt, weathering, and handling during its lifetime. Consideration of a proposed value of less than unity in the SAR should be based on the demonstration that controls and procedures will be in place to ensure such a value throughout the package lifetime. Periodic visual examination followed by paint touch-up or washing may be sufficient if the absorptivity takes adequate account of weathering. These controls and procedures should appear in the Operating Procedures and Acceptance Tests and Maintenance Program chapters of the SAR.

Verify that, for surrounding air and any fluids present within the package, the following additional properties are presented:

- viscosity
- Prandtl number

Confirm that the given fluid properties are adequate for evaluating thermal convection parameters such as the Prandtl number (a dimensionless number defined as the ratio of the momentum diffusivity to the thermal diffusivity), which can be determined from the other thermal properties presented.

Confirm that the thermomechanical properties of any packaging material that may cause temperature-induced pressures or stresses within the package materials are presented. These properties include, but are not limited to, the following:

- coefficient of thermal expansion
- modulus of elasticity
- Poisson’s ratio

The coefficient of thermal expansion is usually the linear coefficient for isotropic solids and the volumetric coefficient for fluids. For an isotropic material, the linear coefficient is one-third the volumetric coefficient.

Coordinate with the structural reviewer to ensure that the structural properties that affect thermal stresses are consistent with the values reported in the Structural Evaluation chapter of the SAR.

If a package material is anisotropic, confirm that the application includes the directional properties of, for example, the thermal conductivity, modulus of elasticity, and the linear expansion coefficient.

Confirm that the application presents temperatures at which phase changes, radiolysis/decomposition, dehydration, and combustion will occur, along with thermal and thermomechanical properties resulting from the change.

Confirm that the thermal properties used for the analyses of the package are appropriate for the material specified for the package in the General Information chapter of the SAR and are consistent with those used in the Structural Evaluation chapter of the SAR. Verify that the sources of the thermal properties used in the SAR are referenced. Authoritative sources of material properties data include, but are not limited to, those that reference experimental measurements. In general, textbooks are an unacceptable source of material properties data. If the applicant experimentally measures the thermal properties of the material and components used in the package, ensure that the experiments are performed under an approved quality assurance program.

Confirm the appropriateness of the use of temperature-dependent thermal properties in an analysis of the package response to thermal loads. If the material properties are not presented as a function of temperature, verify that the value conservatively under- or over-predicts temperatures or stresses, as appropriate, compared to the equivalent temperature-dependent property.

3.4.2.2 Specifications of components

Confirm that the maximum allowable service temperatures or pressures are specified for each package component, as appropriate. Ensure that specifications are provided for applicable package components (e.g., pressure-relief valves and fusible plugs).

Verify that the application identifies references for the specifications of package components such as O-rings, pressure-relief valves, and bolts. Confirm also that the application identifies any temperature constraints on the function of the components (such as the allowable stress in a bolt). Verify that the minimum allowable service temperature of all components is less than or equal to -40 °C [-40 °F], unless a minimum heat load is specified (see Section 3.4.5.1 of this SRP chapter).

3.4.2.3 Thermal design limits of package materials and components

<u>Spent Nuclear Fuel</u>

Confirm that the application specifies the maximum allowable temperatures for each component that could affect the containment, shielding, and criticality functions of the package. Acceptable maximum allowable cladding temperature limits are provided Section 7.4.14.2 of this SRP. Verify that the limits specified in the application are consistent with this section.

Verify that the maximum allowable fuel and cladding temperature is justified. The justification should consider the fuel and clad materials, irradiation conditions (e.g., the absorbed dose, neutron spectrum, and fuel burnup), and the shipping environment including the fill gas. Other necessary considerations include the elapsed time from removal of the SNF from the core to its placement into the transportation packaging, its time duration in the packaging, and its post-transport disposition (e.g., storage). Examples of temperature limits include, but are not limited to, the following:

- the temperature limit for metal fuel less than the lowest melting point eutectic of the fuel
- the temperature limit on the irradiated clad in an inert gas environment, as determined by creep, creep rupture, or diffusion-controlled cavity growth (Levy et al. 1987; Schwartz and Witte 1987), as appropriate

Verify that the temperature range of the thermal and structural properties for each package material exceed the specified and predicted temperature limits for the material.

3.4.3 General Considerations for Thermal Evaluations

Thermal evaluations of the package design can be performed by either analysis or test, or by a combination of both. Verify that the package is modeled in the manner in which it is transported (e.g., with or without a container compliant with the International Organization for Standardization). If the package is shipped in an ISO-compliant container, verify that the CoC explicitly states this requirement.

The use of analysis to evaluate the thermal performance of a package will allow any associated conservatisms, uncertainties, and analytical errors to be determined. Note that because of their mass and cost and the difficulty of decay-heat simulation, SNF packages are normally evaluated by analysis.

Review the Structural Evaluation and Thermal Evaluation chapters of the SAR to determine the response of the package to the normal conditions of transport and hypothetical accident conditions. Verify that the corresponding models used in the thermal analyses are consistent with the effects of normal and accident conditions. For example, the package might have impact limiters or an external neutron shield that would be damaged during the structural and thermal tests of 10 CFR 71.73.

3.4.3.1 Evaluation by analyses

For each thermal analysis, verify that the applicant has provided information on any computer-based modeling, as described in Attachment 2A to Chapter 2, "Structural Evaluation," of this SRP, and evaluate the thermal analyses the applicant submitted, in accordance with the attachment.

Further guidance for reviewing computational fluid dynamics and heat transfer applications for transportation package thermal evaluations is provided in NUREG-2152, "Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications," issued March 2013. When warranted, confirm that the application provides solution verification results by calculating the grid convergence index (GCI). Guidance to calculate the GCI is provided in NUREG-2152 and the American Society of Mechanical Engineers' (ASME's) "Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer" (ASME V&V 20).

Verify that the GCI calculation follows the assumptions used to develop the GCI method, as described in NUREG-2152 and ASME V&V 20. These are summarized as follows:

- Grid refinement or coarsening is performed systematically in all directions; that is, the refinement or coarsening should be structured even if the grid is unstructured.

- The observed order of accuracy should not vary greatly from the theoretical order of accuracy (i.e., the order of accuracy of the numerical method used in the analysis).

- A minimum of four grids is required to demonstrate that the observed order of accuracy is constant for a simulation series.

- A three-grid solution for the observed order of accuracy may be adequate if the values of the target variable (for example, peak cladding temperature, total heat transfer rate, or mass flow rate) predicted on the three grids are in the asymptotic region for the simulation series.

- Methods to test for asymptotic behavior of the target variable predicted values are provided in ASME V&V 20.

- The factor of safety value is 1.25 if the target values on the three grids are in the asymptotic region and the observed order of accuracy does not vary greatly from the theoretical order of accuracy. Otherwise a factor of safety of 3.0 is used.

The GCI is calculated using the observed order of accuracy if it is smaller than the theoretical value. Otherwise the theoretical order of accuracy is used.

Spent Nuclear Fuel

Under the conditions where any of the cask component temperatures are close (within 5 percent) to their limiting values during an accident, or the MNOP is within 10 percent of its design basis pressure, or any other special conditions, verify that the applicant considered, by analysis, the potential impact of the fission gas in the canister to the cask component temperature limits and the cask internal pressurization.

3.4.3.2 Evaluation by Tests

Radioactive Materials

Temperature-sensing devices should be placed in critical package locations. For example, for MOX-fresh-fuel rods and assemblies, temperature-sensing devices should be placed on the test package's simulated fuel basket and fuel rods.

Verify that the application describes the test package, test facility, and test procedures in adequate detail. Confirm that the applicant used proper quality assurance programs to fabricate the test package, operate the test facility, and evaluate the test results. Verify that the test package has been adequately designed, as specified below:

- The thermal performance of the test package, including simulated package contents and any attached test instrumentation and mounting hardware, should be representative or prototypical of the actual package design.

- The temperature-sensing instrumentation should be located to measure the appropriate maximum package component temperatures and characterize the significant heat transfer pathways.

- Test package instrumentation (such as temperature- or pressure-sensing devices) should be mounted at locations that minimize their effects on local test package temperatures.

Review the ability of both the test facility (pool-fire or furnace facility) and the test procedures to meet the range of thermal conditions (e.g., insolation and fire heat fluxes or temperatures). Additional guidance for review of thermal testing is presented in Section 3.4.6 of this SRP chapter.

- Verify that the appropriate results from normal conditions of transport and hypothetical accident condition thermal tests, as specified below, are adequately presented:

- initial conditions (e.g., temperatures, pressures) and changes in the package resulting from structural tests

- maximum steady-state temperatures or pressures (e.g., hot normal conditions of transport, pre-fire conditions)

- maximum temperatures and pressures during the fire and post-fire periods

- physical changes in the package condition resulting from the fire test, such as changes in package material properties caused by combustion or melting of not important to safety package components

Some conditions, such as ambient temperature, decay heat of the contents, or package emissivity or absorptivity, may not be exactly represented in a thermal test. Verify that the thermal evaluation includes appropriate corrections or evaluations to account for these differences. For example, the thermal evaluation should include a temperature correction if the ambient temperature at the onset of the fire test was lower than 38 °C [100 °F]. Additional insight about evaluation by test is also presented in the following paragraphs.

<u>Spent Nuclear Fuel</u>

For those results determined by tests, verify that the applicant reported a description of the test package, the test facility, and the test procedures used for simulating either the normal conditions of transport or hypothetical accident conditions in adequate detail. Confirm that the applicant used proper quality assurance programs to fabricate the test package, operate the test facility, and evaluate the test results.

Review the ability of both the test facilities and test procedures to meet the range of specified temperatures: from -29 °C [-20 °F] to 38 °C [100 °F] for normal conditions of transport and both 38 °C [100 °F] and 800 °C [1,475 °F] for hypothetical accident conditions. Note that an evaluation by test will also have to consider the -40 °C [-40 °F] cold test [10 CFR 71.71(c)(2)]. Confirm that the facilities can simulate the specified heat-transfer boundary conditions, as follows:

- incident heat fluxes equivalent to or exceeding the specified insolation requirements during the normal conditions of transport or the post-fire environment for hypothetical accident conditions

- incident heat fluxes equivalent to or exceeding the specified convective and radiative heat transfer environment, including specified emissivities, for a minimum 30-minute period representing the hypothetical accident condition fire (e.g., fully engulfing)

- an environment that assures an adequate supply and circulation of oxygen for initiating and naturally terminating the combustion of any burnable package component.

Confirm that the test package, with a simulated package contents and any attached test instrumentation or hardware, adequately simulates the thermal behavior of the actual package design.

Verify that figures in the SAR show the locations of the temperature and heat flux sensing devices. Verify that the temperature sensing devices are placed on the test package in the following manner:

- on applicable components

- they do not unduly affect local temperatures

- in locations where maximum temperatures are expected and where other temperatures need to be determined

- in locations that permit reasonable interpolation or extrapolation of measured temperatures for estimating temperatures in unmonitored regions of the package

The applicable components include, but are not limited to, the containment vessel, fuel basket, seals, radiation shielding, criticality controls, and impact limiters. Confirm that the temperature-sensing devices are measuring the temperature of the component, not that of the component environment.

Verify that the test time is sufficient for temperatures to reach steady-state conditions under normal conditions of transport or their peak following cessation of the hypothetical accident condition fire. To the extent that specified boundary conditions, the decay heat of the contents, or specified temperatures are not achieved during a test, verify that the evaluations include appropriate corrections to the temperature data.

Additional guidelines on reviewing thermal tests under hypothetical accident conditions are available for further reading (see NUREG/CR-5636, “Fire and Furnace Testing of Transportation Packages for Radioactive Materials,” issued January 1999; Gregory et al. 1987; Hovingh and Carlson 1994; VanSant et al. 1993, ASTM E2230).

3.4.3.3 Confirmatory analyses

The rigor required of the confirmatory analysis will depend on the size of the margin between the maximum package component temperatures determined by the applicant and the maximum temperature limit specified for a material or component or the regulatory limit determined by the type of shipment. A conservative method of analysis of the fire portion of the hypothetical accident is to mathematically apply an 800°C [1,475°F] surface temperature for 30 minutes to the package with the appropriate initial temperature distribution and content decay heat. This will eliminate the questions about the flame velocity and its effect on the convection heat input into the package. The analysis will still require the appropriate boundary conditions during cooldown to calculate the maximum component temperatures, recognizing that peak temperatures often occur hours after the 30-minute test because of a package’s thermal mass and the content’s decay heat.

3.4.3.4 Effects of uncertainties

Verify that the thermal evaluations appropriately address the effects of uncertainties in thermal and structural properties of materials, test conditions and diagnostics, and analytical methods, as applicable.

3.4.3.5 Conservatisms

Verify that the applicant discussed, quantified, and reported in the SAR any conservatisms associated with the thermal models. For cases with small margin, ensure that the SAR includes a table of results showing how the associated conservatisms affect the safety parameters (e.g., calculated peak cladding temperature, confinement seal temperatures, operating pressure). The table of results should be supported with fully documented analytical models and calculations. In order to justify a small thermal margin, the identified model conservatisms should demonstrate a positive increase in the predicted margin. Verify that these discussions include the effects of uncertainties and analytical error in thermal properties, test conditions and diagnostics, and analytical methods. If the evaluations are performed by test, verify that the test results are reliable and repeatable. For additional guidance, see NUREG-2152, ASME V&V 20, and ASME Performance Test Code 19.1-2005, “Test Uncertainty.”

3.4.4 Evaluation of Accessible Surface Temperatures

Verify that the SAR presents the thermal model used for the calculation of the accessible surface temperature. This model should consist of a heat balance at the surface of the package in which the decay heat from the contents at the surface of the package is equal to the convective and radiative heat loses to the environment at an ambient temperature of 38 °C [100 °F].

If the maximum surface temperature of a package exceeds the regulatory limit, a personnel barrier can be placed around the package. This personnel barrier becomes the accessible package surface. Verify that the applicant considered the thermal impedance of the barrier when determining the package temperatures for normal conditions of transport.

Confirm that the maximum accessible surface temperature the applicant determined is consistent with the General Information chapter of the SAR.

When appropriate, perform an independent analysis as described in Section 3.4.3.3 of this SRP chapter to confirm the maximum accessible surface temperature the applicant determined.

Ensure that the maximum temperature of the accessible package surface does not exceed 85 °C [185 °F] for exclusive-use shipment and 50 °C [122 °F] for nonexclusive-use shipment when the package is subjected to the heat conditions of 10 CFR 71.43(g). SNF packages generally are shipped as an exclusive-use shipment.

3.4.5 Thermal Evaluation Under Normal Conditions of Transport

3.4.5.1 Heat and cold

Confirm that the thermal evaluation demonstrates that the tests for normal conditions of transport do not result in significant reduction in packaging effectiveness, including the following:

- degradation of the heat-transfer capability of the packaging (such as creation of new gaps between components)
- changes in material conditions or properties (e.g., expansion, contraction, gas generation, and thermal stresses) that affect the structural performance
- changes in the packaging or contents that affect containment, shielding, or criticality, such as thermal decomposition or melting of materials
- ability of the package to withstand the tests under hypothetical accident conditions

Verify that the component temperatures and pressures do not exceed their allowable values.

Ensure that the maximum temperature of the accessible package surface is less than 50 °C [122 °F] for nonexclusive-use shipment or 85 °C [185 °F] for exclusive-use shipment when the package is subjected to the heat conditions of 10 CFR 71.43(g).

Verify that the SAR properly determines the maximum temperatures of the package components during normal conditions of transport when the package is in 38 °C [100 °F] still air with insolation, according to the table in 10 CFR 71.71(c)(1), and the content heat load is the maximum allowable. Temperatures of special interest include, but are not limited to, those of the radioactive contents/fuel/cladding, containment vessel, seals, shielding, criticality controls, and impact limiters. Confirm that applicant has determined the volume-averaged temperature of gases. Verify that the results are consistent with the General Information and Structural Evaluation chapters of the SAR.

Ensure that the SAR determines the minimum temperatures of the package components during normal conditions of transport when the package is in -40 °C [-40 °F] still air without insolation and the content heat load is the minimum allowable. If the SAR does not restrict the minimum heat load, the package should be considered at a uniform temperature of -40 °C [-40 °F]. Verify that these temperatures are consistent with the Structural Evaluation chapter of the SAR.

Confirm that the maximum temperatures do not exceed their allowable limits and minimum temperatures do not extend below their allowable limits, as specified in Section 3.4.2.3 of this SRP chapter.

3.4.5.2 Maximum normal operating pressure

For all packages, including MOX-fresh-fuel rods and assemblies, the thermal evaluation shall determine the MNOP when the package has been subjected to the heat condition specified in 10 CFR 71.71(c)(1) (which includes insolation) for 1 year. Ensure that the evaluation has considered all possible sources of gases, such as those present in the package at closure, water vapor, radiolysis, dehydration, outgassing, or fill gas released from the MOX-fresh-fuel rods.

The evaluation of MOX powder and pellets on the MNOP should be similar to that of plutonium oxide powder and pellets.

For powders, however, it should be noted that there is the possibility that hydrogen and other gases may be produced from the thermal- or radiation-induced decomposition of the moisture associated with impure plutonium-containing oxide powders. Given that the ratio of plutonium oxide powder to uranium oxide powder with respect to the total amount of MOX powder is expected to be small, any additional contributions from such gases should also be expected to be small.

By the time the MOX powders are converted to fuel pellets, the processing temperatures should have removed all of the impurities from the plutonium oxide. From this point on (i.e., from MOX pellets, to MOX fuel rods, to full fuel assemblies), the evaluations of MOX pellets and LEU pellets should be virtually identical.

To summarize, ensure that the maximum normal operating pressure calculation has considered all possible sources of gases, such as the following:

- gases initially present in package
- saturated vapor, including water vapor from the contents or packaging
- helium from the radioactive decay of the contents

- hydrogen or other gases resulting from thermal- or radiation-induced decomposition of materials such as water or plastics

Ensure that the application demonstrates that hydrogen and other flammable gases make up less than 5 percent by volume of the total gas inventory, or lower if warranted by the flammable gas, within any confined volume. Confirm that the maximum normal operating pressure is consistent with that in the General Information, Structural Evaluation, and Acceptance Tests and Maintenance Program chapters of the SAR.

Verify that packages that have confined liquids, whether as content or as part of the design (e.g., liquid neutron absorber), are designed such that there is sufficient ullage, or other specified provision, for expansion of the liquid.

Spent Nuclear Fuel

Confirm that the SAR determines the maximum normal operating pressure when the package has been subjected to the heat condition for 1 year, as specified in 10 CFR 71.71(c)(1). Ensure that the evaluation has considered all possible sources of gases, such as the following:

- gases present in the package at closure
- fill gas released from the SNF rods
- backfilled helium and generated helium from a failed burnable poison rod assembly (BPRA)
- fission product gases released from the SNF
- saturated vapor from material in the containment vessel, including water vapor desorbed from the containment system components or the package contents
- helium from the α-decay of the SNF contents
- hydrogen and other gases from radiolysis or chemical reactions (e.g., sodium-water)
- hydrogen and other gases from the dehydration, combustion, or decomposition of package components

Guidance on release of fill gas and fission product gas for pressurized-water reactor (PWR) and boiling-water reactor (BWR) fuel is provided in Table 4-2, “Release Fractions and Specific Activities for the Contributors to the Releasable Source Term for Packages Designed to Transport Irradiated Fuel Rods,” of this SRP.

Verify that the MNOP in the application is consistent with the Structural Evaluation chapter of the SAR.

If the package has any confined volumes other than the containment vessel (e.g., coolant tanks), confirm that their pressures are properly determined (including consideration of ullage for liquids) and consistent with the Structural Evaluation chapter of the SAR.

3.4.6 Thermal Evaluation Under Hypothetical Accident Conditions

Verify that the package has been evaluated to demonstrate the effects of the tests for hypothetical accident conditions.

3.4.6.1 Initial conditions

For all packages, including MOX-fresh-fuel rods and assemblies, the internal heat load of the contents are to be at its maximum allowable power, unless a lower power, consistent with the temperature and pressure, is more unfavorable.

Before the fire test, the package is to be evaluated for the effects of the crush (if applicable), drop, and puncture tests. Ensure that the physical condition of the package represented in the thermal evaluations under hypothetical accident conditions is consistent with the post-structural hypothetical accident conditions test results from the Structural Evaluation chapter of the SAR.

Verify that the application justifies the most unfavorable initial conditions of the following:

- an ambient temperature between -29 °C [-20 °F] with no insolation and 38 °C [100 °F)] with insolation (typically, the temperature will be the latter)
- an internal pressure of the package equal to the maximum normal operating pressure unless a lower internal pressure, consistent with the ambient temperature, is less favorable
- contents at maximum decay heat unless a lower heat, consistent with the temperature and pressure, is less favorable

Confirm that the initial steady-state temperature distribution is consistent with the thermal evaluation under normal conditions of transport.

3.4.6.2 Fire test

For all packages, including MOX-fresh-fuel rods and assemblies, the internal heat load of the contents is to be at its maximum allowable power, unless a lower power, consistent with the temperature and pressure, is more unfavorable.

Confirm that the package design is evaluated for the effects of the fire test. Ensure that the evaluation (likely done by computer analysis) appropriately addresses the fire test conditions, including the following:

- dimensions of the pool fire (i.e., package should be fully engulfed)
- fire temperature and duration (see below)

Ensure that the evaluation accounts for the following characteristics of the package:

- orientation and placement in the fire
- internal heat load (i.e., maximum possible heat loading)

For the after-fire verification, see the last paragraph of this section, as the listed four conditions (bullets) are applicable to both categories of transportation packages (i.e., RAM and SNF).

Verify that the package is exposed to the 800°C [1,475°F] fire environment for a minimum of 30 minutes and that surface and fire emissivity are greater than or equal to 0.8 and 0.9, respectively. Confirm that the application specifies flame velocities that are appropriate for the hydrocarbon fire and uses the appropriate correlation for convection in the fire as a boundary condition (see Gregory et al. 1987).

Note that after the fire, emissivity and absorptivity values for the package surfaces would tend to be higher because of the layer of soot deposited on the package surfaces from the fire.

Verify that the evaluation accounts for the following conditions after the fire exposure:

- no artificial cooling of the package surface (i.e., no water stream)
- the package is subjected to full solar insolation
- the evaluation continues until the post-fire, steady-state condition is achieved
- all combustion is allowed to proceed until it terminates naturally

See Section 3.4.7.2 of this SRP chapter for additional insight on the description of the fire test.

3.4.6.3 Maximum temperatures and pressures

Verify that the SAR appropriately evaluates the transient peak temperatures of the package components as a function of time after the fire. The maximum temperatures in the components will occur following cessation of the fire, with the delay time increasing with the distance inward from the package surface. Verify also that the SAR determines the maximum temperatures of the post-fire, steady-state condition.

Confirm that the maximum temperatures do not exceed the maximum allowable temperature limits. If lead is utilized for shielding, confirm that the lead does not reach melting temperature as a result of the hypothetical accident conditions thermal test.

Verify that the evaluation of the maximum pressure in the package design is based on MNOP (see Section 3.4.5.2 of this SRP chapter) as it is affected by the fire-induced increases in package component temperatures.

Verify that maximum temperatures and pressures are consistent with those in the Structural and Containment Evaluation chapters of the SAR.

Ensure that the application demonstrates that hydrogen and other flammable gases make up less than 5 percent by volume of the total gas inventory, or lower if warranted by the flammable gas, within any confined volume.

<u>Radioactive Materials</u>

Confirm that the applicant considered possible increases in gas inventory, caused by fire-induced thermal combustion or decomposition processes, in the pressure determination.

For MOX-fresh-fuel rods and assemblies, the applicant shall consider the possible increases in gas inventory (e.g., from an unlikely failure of a fuel rod) in the pressure determination.

For MOX powders and fuel pellets, the processing temperatures should have removed all of the impurities from the plutonium oxide. The only additional increase in pressure should be the result of any helium released from the contents as a result of the increased temperature. However, because any increase in temperature as a result of the thermal testing should be small when compared to the processing temperatures, any increase in pressure should likewise be small.

Verify that maximum temperatures and pressures are consistent with the Structural and Containment Evaluations of the SAR.

Spent Nuclear Fuel

Confirm that the applicant considered possible increases in gas inventory (e.g., from fuel rod failure, BPRA failure) in the pressure determination.

If the package has any confined volumes other than the containment vessel (e.g., coolant tanks), confirm that their pressures are properly determined.

For high-burnup fuel (burnup exceeding 45,000 megawatt days per metric ton of uranium), verify that the thermal evaluation considers credible or bounding fuel reconfigurations, for example, possible accumulation and relocation of damaged fuel near temperature-sensitive components such as seals.

Verify that maximum temperatures and pressures are consistent with the Structural and Containment Evaluations of the SAR.

3.4.7 Appendix

An appendix may include a list of references, copies of any applicable references not generally available to the reviewer, computer code descriptions, input and output files, test facility and instrumentation descriptions, test results, supplemental analyses, and other appropriate supplemental information.

3.4.7.1 Radioactive materials

Description of Test Facilities

For cases where the package is evaluated by a fire test, confirm that the descriptions of the test facility include the following:

- type of facility (furnace, pool-fire)
- method of heating the package (gas burners, electrical heaters)
- volume and emissivity of the furnace interior
- method of simulating decay heat, if applicable
- types, locations, and measurement uncertainties of all sensors used to measure the fire heat fluxes, fire temperatures, and test package component temperatures and pressures
- how the post-fire environment is maintained to adequately attain the post-fire steady-state condition

- methods for maintaining and measuring an adequate supply and circulation of oxygen for initiating and naturally terminating the combustion of any burnable package component throughout both the fire and post-fire periods

Test Descriptions

This description should include the following:

- test procedures
- test package description
- test initial and boundary conditions
- test chronologies (planned and actual)
- photographs of the package components, including any structural or thermal damage, before and after the tests
- test measurements, including, at a minimum, documentation of test package physical changes and temperature and heat flux histories
- corrected test results (if applicable)
- methods used to obtain these corrected results.

Confirm that all sensors that measure heat fluxes and temperatures are positioned to measure values affecting critical components such as seals, valves, pressure, and structural components. The sensors should have proper operating ranges for the test conditions. Verify that the applicant appropriately considered possible perturbations caused by the presence of these sensors (e.g., by disturbing local convective heat transfer conditions).

For a pool-fire facility, verify that the fire dimensions and test package relative location conform to the following specifications in 10 CFR 71.73(c)(4):

- The fire width should extend horizontally between 1 and 4 meters [40 inches and 13 feet] beyond any external surface of the package.
- The package should be positioned 1 meter [40 inches] above the surface of the fuel source.

Because it is probable that the method of supporting the package in the test facility will locally perturb fire conditions adjoining the test package, verify that the applicant has appropriately incorporated such an effect into the thermal evaluation.

Applicable Supporting Documents or Specifications

Review any reference documents included in the SAR appendix. In addition to the documents noted in Sections 3.4.7.1 and 3.4.7.2 of this SRP chapter, these documents may include a variety of items such as thermal specifications of O-rings and other components and documentation of the thermal properties.

For MOX-fresh-fuel rods and assemblies, the application should include the applicable sections from reference documents. These documents may include the test plans used for the thermal tests, the thermal specifications of O-rings, fuel clad, and other components, and the documentation of the thermal properties of non-ASME-approved materials used in the package.

Verify that similar documentation is also included for MOX powders and pellets.

Analyses Details

Supplemental calculations may be required to support evaluations presented in the Thermal Evaluation chapter of the SAR. Verify that all such analyses are prepared in a manner consistent with Section 3.4.3.1 of this SRP chapter.

3.4.7.2 Spent nuclear fuel

Justification for Assumptions or Analytical Procedures

Confirm that the applicant has stated and justified all assumptions used in the evaluation of the package.

Review the appropriateness of and justification for the applicant's assumptions and analytical procedures.

Computer Program Description

Confirm that the applicant described all the computer programs used in the thermal evaluation of the package. Verify that the applicant identified space dimensionality and method of analysis (i.e., finite difference, finite element). Verify that the application describes the range of applications and phenomena (linear, nonlinear; steady state, transient) as well as the material properties and material models (isotropic, anisotropic). Verify that the application describes the various types of initial boundary conditions and thermal loads. Verify that the application identifies solution techniques (direct or iterative for steady state; explicit and implicit for transient). Also, verify that the application identifies and describes any other capabilities (enclosure radiation with view factor calculation, thermal stress analysis) that are applicable to the applicant's thermal evaluation. Verify that the computer programs are appropriate for the problem to which they are applied.

Computer Input and Output Files

Confirm that the applicant has submitted annotated input files, as applicable, for each problem (maximum accessible surface temperature, normal conditions of transport, calculation of initial temperature distribution for hypothetical accident, initial temperature distribution for analysis of thermal hypothetical accident) analyzed using a computer code. Confirm that the applicant has submitted annotated output files, as applicable, for each problem (maximum accessible surface temperature, normal conditions of transport, calculation of initial temperature distribution for hypothetical accident conditions, and temperature distribution histories for the thermal hypothetical accident condition during and following the 30-minute fire, until all the package component temperatures have reached their maxima).

Description of Test Facilities

Verify that the application describes the facilities used for performing thermal tests. The description should include, but is not limited to, the following:

- the type of facility (furnace, pool fire)
- the method of heating the package (gas burners, electrical heaters)

Verify that the description of a furnace facility includes the volume and emissivity of the furnace interior as well as the method of measuring the interior temperature. The oxygen concentration in a furnace test should be consistent with that of a hydrocarbon-fuel fire.

For a pool-fire facility, verify that the application specifies the size of the fire relative to the size of the package. Verify that the fire dimension conforms to 10 CFR 71.73(c)(4), which requires the fire thickness to extend horizontally at least 1 meter {[40 inches (but not more than 3 meters [10 feet]} beyond any external surface of the package. The package will be positioned 1 meter [40 inches] above the surface of the fuel source. Verify that the application describes the method of support of the package in a test facility and presents an analysis of the heat loss from the package through the support to “ground.” Review to ensure that the analysis of the heat loss from the package through the support is appropriate.

Confirm that the application identifies and describes the sensors used to measure heat flux and temperature. Verify that the application presents the applicable operating ranges of the sensors. Verify that the application presents and quantifies the perturbation by the sensor (e.g., from heat losses along thermocouple leads, shadowing by heat flux measuring devices) on the quantity to be measured (temperature, heat flux). Review to ensure that the heat flux and temperature sensors are appropriate and that the measurements are corrected for the perturbations by the sensors on the quantity to be measured. Verify that if calorimeters are used to measure heat flux, the applicant corrected the calorimeter readings to account for the difference in thermal inertia between the calorimeter and the package (unless the measured data have reached steady state). Verify that the application presents the method of correction of the calorimeter reading; review the method for appropriateness. For additional information, see ASME PCT 19.5.

Test Results

Verify that the application presents test measurements, including temperatures (or temperature histories) and flux (or flux histories). Verify that the corrected test results are presented and that appropriate methods are used to obtain these corrections. Verify that, for the thermal portion of the hypothetical accident, the application clearly notes the time at which the 30-minute test starts and ends. Verify that the measurements (and corrected results) are continued until steady state occurs (for tests for normal conditions of transport) or until the maximum temperature occurs in all the package components (for tests of the thermal portion of the regulatory hypothetical accident).

Verify that the application presents photographs of the package components before and following the tests. Verify that the application presents photographs of regions of components with thermal damage (such as charring of the insulation, damage to O-rings).

Applicable Supporting Documents or Specifications

Verify that the application includes the applicable sections from reference documents. These documents may include the test plans used for the thermal tests, the thermal specifications of O-rings and other components, and the documentation of the thermal properties of non-ASME-approved materials used in the package.

Additional Analyses

Frequently, thermally driven processes will occur in a package. These processes may include, but are not limited to, the following:

- generation of gases within the containment system
- effects of phase changes on package materials
- combustion, decomposition, or dehydration of package materials

The production of gases (e.g., hydrogen by radiolysis) or thermal decomposition of materials (e.g., a neutron shield) may occur in the package. Phase changes of material resulting in a decrease of the material density occurring in the containment system or in a lead shield can result in a pressure increase in the system. The tests under hypothetical accident conditions may cause combustion, decomposition, or dehydration of components such as an impact limiter or the neutron shield material.

Confirm that the applicant has identified all thermally driven special processes that will occur in the package. Verify that the applicant has stated and justified all assumptions used in the quantification and evaluation of these additional processes. Review the appropriateness of and justification for the applicant's assumptions and analytical procedures. Verify that the results are incorporated in the appropriate subsections of the Thermal Evaluation chapter of the SAR.

Other supplemental calculations may be required to support evaluations presented in the Thermal Evaluation chapter. Verify that all such analyses meet the goals discussed in Section 3.4.3.1 of this SRP chapter.

3.5 Evaluation Findings

Prepare evaluation findings upon satisfaction of the regulatory requirements in Section 3.3 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:

F3-1 The staff has reviewed the package description and evaluation and concludes that they satisfy the thermal requirements of 10 CFR Part 71.

F3-2 The staff has reviewed the material properties and component specifications used in the thermal evaluation and concludes that they are sufficient to provide a basis for evaluation of the package against the thermal requirements of 10 CFR Part 71.

F3-3 The staff has reviewed the methods used in the thermal evaluation and concludes that they are described in sufficient detail to permit an independent review, with confirmatory calculations, of the package thermal design.

F3-4 The staff has reviewed the accessible surface temperatures of the package as it will be prepared for shipment and concludes that they satisfy 10 CFR 71.43(g) for packages transported by exclusive-use vehicle.

F3-5 The staff has reviewed the package design, construction, and preparations for shipment and concludes that the package material and component temperatures will not extend beyond the specified allowable limits during normal conditions of transport consistent with the tests specified in 10 CFR 71.71.

F3-6 The staff has reviewed the package design, construction, and preparations for shipment and concludes that the package material and component temperatures will not exceed the specified allowable short-term limits during hypothetical accident conditions consistent with the tests specified in 10 CFR 71.73.

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 thermal design has been adequately described and evaluated, and that the thermal performance of the package meets the thermal requirements of 10 CFR Part 71.

3.6 References

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

American Society of Mechanical Engineers (ASME) V&V 20, "Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer," New York, NY.

ASME PTC 19.1-2005, "Test Uncertainty," New York, NY.

ASTM E2230, "Standard Practice for Thermal Qualification of Type B Packages for Radioactive Material".

NUREG-2152, U.S. Nuclear Regulatory Commission, "Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications," March 2013, Agencywide Documents Access and Management System Accession No. ML13086A202.

NUREG/CR-5636, U.S. Nuclear Regulatory Commission, "Fire and Furnace Testing of Transportation Packages for Radioactive Materials," January 1999.

Gregory, J.J., R. Mata, and N.R. Keltner, "Thermal Measurements in a Series of Large Pool Fires," SAND85-0196, TTC-0659, UC-71, Sandia National Laboratories, Albuquerque, NM, August 1987.

Hovingh, J. and R.W. Carlson, "Thermal Testing Transport Packages 1994 for Radioactive Materials - Reality vs. Regulation," ASME 1994 Pressure Vessel & Piping Conference, Minneapolis, MN, June 1994.

Levy, I.S. et al., "Recommended Temperature Limits for Dry Storage of Spent Light Water Reactor Zircaloy-Clad Fuel Rods in Inert Gas," PNL-6189, Pacific Northwest Laboratory, Richland, WA, May 1987.

Schwartz, M.W. and M.C. Witte, "Spent Fuel Cladding Integrity During Dry Storage," UCID-21181, Lawrence Livermore National Laboratory, Livermore, CA, September 1987.

VanSant, J.H., R.W. Carlson, L.E. Fischer, and J. Hovingh, "A Guide for Thermal Testing Transport Packages for Radioactive Material - Hypothetical Accident Conditions," UCRL-ID-110445, Lawrence Livermore National Laboratory, Livermore, CA, February 9, 1993.