FuelSolutions™ W21 Canister Transportation Safety Analysis Report

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1.2.1.2 Other FuelSolutions™ Canister Features

Receptacles, Valves, Testing/Sampling Ports

The ports on a FuelSolutions™ W21 canister include a drain port, a vent port, and an instrument port. The drain and vent ports are used to drain the canister cavity and to backfill it with helium following fuel loading, to provide an inert atmosphere for dry storage and transport. The instrument port is for pressure monitoring during FuelSolutions™ W21 canister reflooding, if unloading is necessary. Additional discussion of the canister design features used for canister SNF loading and unloading are provided in Section 1.2.1.3 of the FuelSolutions™ W21 Canister Storage FSAR.

The FuelSolutions™ W21 canister ports are not part of the FuelSolutions™ Transportation Package containment boundary. The location of receptacles, valves, and ports on the containment boundary of the FuelSolutions™ TS125 Transportation Cask is addressed in Section 1.2.1.6 of the FuelSolutions™ TS125 Transportation Cask SAR.

Heat Dissipation

The design basis heat load of the radioactive contents for a FuelSolutions™ W21 canister for transportation is 22,000 watts, with a maximum linear heat generation rate (LHGR) of 160.6 watts/inch. The design basis axial heat generation profile for the FuelSolutions™ W21 canister is discussed in Section 3.1.3 of this SAR. Heat dissipation from a FuelSolutions™ TS125 Transportation Cask is addressed in Section 1.2.3.4 of the FuelSolutions™ TS125 Transportation Cask SAR.

Coolants

No coolants are used within a FuelSolutions™ W21 canister other than the helium within the canister cavity, as discussed in Chapter 3 of this SAR. Coolants for the FuelSolutions™ TS125 Transportation Cask are addressed in Section 1.2.1.6 of the FuelSolutions™ TS125 Transportation Cask SAR.

Protrusions

There are no protrusions on a FuelSolutions™ W21 canister. Protrusions on the FuelSolutions™ TS125 Transportation Cask are addressed in Section 1.2.1.6 of the FuelSolutions™ TS125 Transportation Cask SAR.

Lifting and Tiedown Devices

The device for lifting a FuelSolutions™ W21 canister to facilitate canister transfer is the top end outer closure plate, which has threaded counterbores for attaching a vertical lift fixture. Additional discussion of the canister design features used for canister transfer are provided in Section 1.2.1.3 of the FuelSolutions™ W21 Canister Storage FSAR.

Since the FuelSolutions™ W21 canister is transported inside of a FuelSolutions™ TS125 Transportation Cask, the requirements for lifting and tiedown devices for transport are not applicable to FuelSolutions™ W21 canister. The design of the FuelSolutions™ TS125 Transportation Cask for lifting and tie down is addressed in Section 1.2.1.6 of the FuelSolutions™ TS125 Transportation Cask SAR.

Pressure Relief System

The FuelSolutions™ W21 canister is a seal welded pressure vessel with no penetrations that is designed to withstand the maximum internal pressure for all design basis conditions. Thus, there is no pressure relief system on a FuelSolutions™ W21 canister. Pressure relief for the FuelSolutions™ TS125 Transportation Cask is addressed in Section 1.2.1.6 of the FuelSolutions™ TS125 Transportation Cask SAR.

Shielding

A FuelSolutions™ W21 canister loaded with SNF assemblies contains both gamma and neutron radiation sources. Biological shielding for the package is provided as follows:

- For the attenuation of gamma radiation, shielding between the radioactive contents and the exterior surface of a package is provided by the FuelSolutions™ TS125 Transportation Cask and also by the FuelSolutions™ W21 canister (the internal basket assembly, cylindrical shell, shield plugs at each end, redundant top closure plates, the bottom closure plate, and the bottom end plate).
- For attenuation of neutron radiation, the center region of the transportation cask body between the impact limiters and the bottom end of the cask have a layer of hydrogenous, solid neutron shielding material.

Further discussion of the shielding characteristics of the FuelSolutions™ W21 canister is provided in Chapter 5 of this SAR. The shielding features for the FuelSolutions™ TS125 Transportation Cask are described in Section 1.2.1.6 of the FuelSolutions™ TS125 Transportation Cask SAR.

Miscellaneous Features

The FuelSolutions™ W21 canister uses fuel assembly spacers to provide an appropriate guide tube cavity cross-section and/or length for some classes of SNF assemblies. Two types of fuel assembly spacers are used. Type I fuel assembly spacers reduce both the transverse and axial void in a basket guide tube for classes of SNF assemblies that are too narrow in width and short in length for a guide tube cavity. Type II fuel assembly spacers reduce only the axial void in the guide tube cavity. Limiting the transverse and axial voids precludes an SNF assembly from imparting an impact load to the FuelSolutions™ W21 canister with sufficient energy to exceed the design basis in HAC drop events. The general arrangement drawings provided in Section 1.3.1 show both types of fuel assembly spacers.

The FuelSolutions™ canister can also be short loaded with 20 rather than 21 fuel assemblies to permit the loading of higher enriched fuel for some fuel assembly types. In this case, a mechanical stop is placed over the center guide tube opening of the basket to prevent a fuel assembly from being loaded at that location. The arrangement of the center guide tube fuel assembly stop for this canister loading configuration is shown in Figure 1.2-3.

Permanent FuelSolutions™ W21 canister identification information is provided on the outside of the top end outer closure plate and the bottom end plate. The permanent identification markings on the FuelSolutions™ W21 canister are discussed further in Section 9.1.7.2 of the FuelSolutions™ W21 Canister Storage FSAR.

Table 1.2-3 - FuelSolutions™ W21 Canister Design Criteria Summary (3 pages)

Type	Criteria or Reference	Basis [1]
External Radiation Standards: Radiation levels	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.47(a)
General Requirements for Fissile Material Packages	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.55
Special Requirements for Irradiated Nuclear Fuel Shipments	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.61
Unknown Contents Properties Assumptions	[2]	10CFR71.83
Preliminary Determinations	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.85
Routine Determinations	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.87
Opening Instructions	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.89
Quality Assurance	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.101(b)
Handling, Storage, and Shipping	See Table 1.2-3 in TS125 Transportation Cask SAR	10CFR71.127
Additional Criteria:	-	-
Thermal:	-	-
Maximum Design (Allowable) Material Temperatures	See Table 3.3-1	-
Insolation	Protected by TS125 Transportation Cask	10CFR71.71(c)(1)
Retrievability (NCT and HAC)	No Encroachment on Spent Fuel	-
NCT Loads and Conditions	See Table 1.2-3 in TS125 Transportation Cask SAR	-
HAC Design Events and Conditions	See Table 1.2-3 in TS125 Transportation Cask SAR	-

Notes:

(1) See Table 1.0-1 for cross-references to applicable SAR sections.

(2) The FuelSolutions™ W21 canister is not evaluated for failed fuel in this SAR; therefore, no assumptions have been made relative to unknown properties of fissile materials.

Table 1.2-4 - FuelSolutions™ W21 Canister SNF Assembly Acceptance Criteria for Transport

SNF Parameter	Loading/Acceptance Criteria
Payload Description	W21-1: ≤ 21 PWR fuel assemblies or PWR fuel assemblies with or without control components, as defined in Table 1.2-5. If < 21 fuel assemblies are loaded, a dummy fuel assembly is to be placed into each empty canister guide tube. Each dummy fuel assembly is to be the approximate weight and size of the intact fuel assembly class, as defined in Table 1.2-5. W21-2: ≤ 20 PWR fuel assemblies or PWR fuel assemblies with or without control components, as defined in Table 1.2-5. The center canister guide tube location is not to contain a fuel assembly. If < 20 fuel assemblies are loaded, a dummy fuel assembly is to be placed into each empty canister guide tube (except for the center guide tube). Each dummy fuel assembly is to be the approximate weight and size of the intact fuel assembly class, as defined in Table 1.2-5.
Cladding Material/ Condition	Intact zircaloy-clad fuel assemblies with no known or suspected cladding defects greater than hairline cracks or pinhole leaks. Partial fuel assemblies (i.e., fuel assemblies from which fuel rods are missing) must not be loaded into the canister unless dummy fuel rods are inserted into the fuel assembly in the locations of the missing rods. Each dummy fuel rod must displace an amount of water equal to that displaced by the original fuel rod.
Maximum Weight	≤ 1680 pounds per fuel assembly, as defined in Table 1.2-5.
Maximum Heat Load	≤ 1.05 kW total heat load per fuel assembly.(1)
Max. Uranium Loading	The uranium loading varies by fuel assembly class and is not to exceed the maximum value defined in Table 1.2-6.
Maximum Initial Enrichment	The initial enrichment varies by fuel assembly class and type and is not to exceed the maximum value defined in Table 1.2-6 for the fuel assembly parameters defined in Table 6.1-1 of this SAR.
Maximum Burnup	≤ 60,000 MWd/MTU, as defined in Table 1.2-6. The exposure (burnup) of any inserted control component must not exceed that of the host fuel assembly. For burnups exceeding 45,000 MWd/MTU, it is necessary to verify that the cladding oxide layer thickness does not exceed 70 μm by measurement of a statistical sample of limiting fuel assemblies.
Minimum Cooling Time	The cooling time varies as a function of burnup, initial enrichment, and the fuel assembly/control component cobalt content, and must not be less than the minimum cooling time indicated in Table 5.1-3 of this SAR. If an SNF assembly has been further irradiated after having fuel rods replaced by dummy stainless rods, an evaluation must be performed that shows that the active fuel region non-fuel gamma source strength is bounded by the values shown in Table 5.2-8 for the associated burnup and enrichment.

Notes:

(1) As discussed in Section 3.1.3.4, any fuel assembly meeting the cooling time limits of in Table 5.1-3 will not exceed the 1.05 kW heat load limit.

2.6 Normal Conditions of Transport

When subjected to NCT tests specified in 10CFR71.71, the FuelSolutions™ W21 canisters meet the standards specified in Subpart E of 10CFR71. This is demonstrated in the following subsections where each NCT condition is addressed and shown to meet the applicable design criteria. A summary of load combinations used herein, consistent with Regulatory Guide 7.8, is provided in Section 2.1.2.2.

2.6.1 Heat

This section presents the structural evaluation of the FuelSolutions™ W21 canisters for the heat load condition of 10CFR71.71(c)(1). The structural evaluation of the FuelSolutions™ TS125 Transportation Cask for the heat load condition is presented in Section 2.6.1 of the FuelSolutions™ TS125 Transportation Cask SAR. The structural evaluation shows that the heat load condition does not compromise the structural integrity of the package.

The FuelSolutions™ W21 canisters are evaluated in the FuelSolutions™ TS125 Transportation Cask for the thermal gradients and temperatures resulting from:

1. Hot environment thermal conditions, including an ambient temperature of 100°F, maximum fuel decay heat, and insolation in accordance with 10CFR71.71(c)(1).
2. Cold ambient initial conditions, including an ambient temperature of -20°F, maximum fuel decay heat, and no insolation.
3. Cold environment thermal conditions, including an ambient temperature of -40°F, maximum fuel decay heat, and no insolation.

The maximum canister assembly component pressures and temperatures resulting from the NCT thermal conditions are calculated in Section 3.4 of this SAR. The bounding temperatures and pressures used for the structural evaluation of the W21 canister are summarized in Section 2.6.1.1. Differential thermal expansion between the W21 canister shell and the TS125 Transportation Cask cavity, and between the W21 canister basket assembly and shell assembly, are evaluated in Section 2.6.1.2. The stresses in the W21 canister due to NCT thermal loading are evaluated in Section 2.6.1.3. The results of the NCT thermal stress evaluation demonstrate that the W21 canister satisfies the appropriate design criteria for NCT thermal conditions.

2.6.1.1 Summary of Pressures and Temperatures

The FuelSolutions™ TS125 Transportation Cask provides containment of the radioactive internals during transport. Therefore, no credit is taken for the containment or confinement of the radioactive internals provided by the W21 canister shell during transportation. As such, the W21 canister shell assembly is not evaluated for pressure loads associated with transportation conditions. The W21 canister basket also does not retain pressure. Therefore, pressure loads are not addressed in the W21 canister structural analysis for transportation conditions. As shown in Table 3.1-4 of this SAR, the maximum normal operating pressure (MNOP) for the FuelSolutions™ TS125 Transportation Cask with the W21 canister is 11.9 psig. The FuelSolutions™ TS125 Transportation Cask is evaluated for a bounding design pressure of 75 psig in Section 2.6.1 of the FuelSolutions™ TS125 Transportation Cask SAR.

As discussed in Section 3.1.3 of this SAR, the thermal analysis of the W21 canister is performed using two design basis decay heat profiles that are referred to as the "maximum thermal" and "maximum thermal gradient" profiles. The W21 canister temperatures due to NCT thermal conditions are calculated in Section 3.4 and summarized in Table 2.6-1. In addition, the W21 canister bounding design temperatures at which the allowable stresses are calculated are provided in Table 2.6-1. The bounding design temperatures are consistent with those temperatures expected in service, as determined in Section 3.4 of this SAR.

2.6.1.2 Differential Thermal Expansion

Differential thermal expansion between the W21 canister basket assembly, the W21 canister shell assembly, and the TS125 Transportation Cask cavity is evaluated in the following sections. Consideration is given to possible interference resulting from a reduction in gap sizes.

The results of the differential thermal expansion evaluation show that the W21 canister shell expands freely within the TS125 Transportation Cask cavity under the NCT heat load conditions. The W21 canister basket assembly is also shown to expand freely within the W21 canister shell assembly cavity under the NCT heat load conditions.

2.6.1.2.1 Canister Shell

Differential thermal expansion between the FuelSolutions™ canister shell and the TS125 transportation cask cavity is evaluated in Section 2.6.1.2 of the FuelSolutions™ TS125 Transportation Cask SAR. The analysis conservatively assumes a uniform temperature difference of 210°F between the canister shell and cask inner shell over the entire length of the canister shell. Tables 3.4-1 and 3.4-2 of the FuelSolutions™ TS125 Transportation Cask SAR show that the maximum temperature difference between the W21 canister shell and the cask inner shell for all NCT thermal load conditions is 141°F for the NCT cold environment (i.e., -40°F ambient temperature, $LHGR_{max}$ decay heat profile, and no solar).

Therefore, the worst-case differential thermal expansion between the FuelSolutions™ W21 canister shell and the TS125 transportation cask cavity under NCT thermal loading is bounded by the evaluation presented in the FuelSolutions™ TS125 Transportation Cask SAR. Thus, positive clearances remain between the FuelSolutions™ TS125 transportation cask cavity and the FuelSolutions™ W21 canister shell under the worst-case NCT thermal conditions.

2.6.1.2.2 Spacer Plates

The FuelSolutions™ W21 spacer plates are designed with a nominal 0.38-inch diametrical clearance inside the canister shell. This clearance is sufficient to allow free diametral thermal expansion of the spacer plates under the worst-case NCT and HAC thermal conditions. The relative diametral expansion between the W21 spacer plates and the canister shell is calculated using the temperature differential between the two components at the hottest axial section because the heat flux and, therefore, the temperature gradient are maximized at that section. The worst-case ΔT is obtained from Section 3.4 of this SAR and corresponds to the maximum thermal gradient profile for the NCT cold environment ambient condition (i.e., -40°F ambient temperature, maximum decay heat, no solar). As shown in Table 2.6-1, the maximum temperatures of the hottest W21 stainless steel and carbon steel spacer plates are approximately

3. THERMAL EVALUATION

This chapter presents the evaluations which demonstrate that the FuelSolutions™ W21 canister meets the thermal requirements of 10CFR71.[1] The FuelSolutions™ W21 canister basket assembly is designed to maintain the geometry of the SNF assemblies during transportation within the FuelSolutions™ TS125 Transportation Cask. Containment of the SNF assemblies during transportation is provided by the TS125 Transportation Cask. The thermal design and safety evaluation for the transportation cask are provided in Chapter 3 of the FuelSolutions™ TS125 Transportation Cask SAR.[2] The thermal evaluation of the FuelSolutions™ W21 canister presented herein is compared with the results presented in the FuelSolutions™ TS125 Transportation Cask SAR to assure that the thermal interface criteria for the transportation cask defined in Chapter 3 of that SAR are met.

The evaluations presented in this chapter assure that the thermal performance of the combined FuelSolutions™ W21 canister and TS125 Transportation Cask system complies with the applicable regulatory safety requirements during normal conditions of transportation (NCT) and hypothetical accident conditions (HAC). Compliance is demonstrated using analytic techniques consistent with the methodology presented in Regulatory Guide 7.6[3] and Regulatory Guide 7.8.[4]

As discussed in Section 3.1.3.1, the design basis SNF assembly heat generation profiles used for the thermal evaluation of the FuelSolutions™ W21 canister bound the maximum heat loads of all SNF assembly classes accommodated by the W21 canister that meet the applicable burnup and cooling time limits. The results of the W21 canister thermal evaluation show that maximum temperatures in the transportation package resulting from the bounding design basis SNF assembly heat loads do not exceed the allowable temperatures of the canister, transportation cask, impact limiters, and SNF assembly cladding materials. This assures that the transportation package and SNF cladding materials are protected against thermal degradation.

The design basis canister heat generation profiles used for the thermal evaluation of the TS125 transportation cask in the FuelSolutions™ TS125 Transportation Cask SAR envelope those used for the W21 canister thermal evaluation. Although the parameters (i.e., Q and LHGR) for the W21 canister design basis heat generation profiles are identical to those upon which the design basis canister heat generation profiles in the FuelSolutions™ TS125 Transportation Cask SAR are based, the W21 canister design basis heat generation profiles result in lower peak temperatures in the transportation cask body. This is primarily due to conservative assumptions concerning the axial thermal profile in the FuelSolutions™ TS125 Transportation Cask SAR, as

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[1] Title 10, Code of Federal Regulations, Part 71 (10CFR71), *Packaging and Transportation of Radioactive Materials*, U.S. Nuclear Regulatory Commission, 2000.

[2] WSNF-120, *FuelSolutions™ TS125 Transportation Cask Safety Analysis Report*, NRC Docket 71-9276, BNFL Fuel Solutions Corporation.

[3] Regulatory Guide 7.6, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, Revision 1, U.S. Nuclear Regulatory Commission, March 1978.

[4] Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material*, Revision 1, U.S. Nuclear Regulatory Commission, March 1989.

discussed in Section 3.1 of that SAR. In this manner, the design basis heat loads used for the thermal evaluation of the W21 canister are demonstrated to be bounded by those used for the thermal evaluation of the TS125 transportation cask, and the thermal safety of both the W21 canister and the TS125 transportation cask is assured.

This chapter presents FuelSolutions™ W21 canister thermal evaluation results for the design basis NCT and HAC cases. Section 3.2 provides the thermal properties for the W21 canister materials, and Section 3.3 provides the corresponding material specifications. Transportation cask material properties and specifications are presented in the FuelSolutions™ TS125 Transportation Cask SAR. W21 canister analytical model descriptions and thermal results are given in Sections 3.4 and 3.5 for NCT and HAC, respectively. The transportation cask analytical model, which interfaces with the W21 canister model, is described in the FuelSolutions™ TS125 Transportation Cask SAR.[2] Supplemental data are presented in the Section 3.6 appendices.

As discussed in Chapter 4 of this SAR, containment of all radioactive materials is provided by the transportation cask containment boundary. The transportation cask maximum internal pressure is dependent on the characteristics of the specific FuelSolutions™ W21 canister and SNF payload contained within the cask. Conservative predictions of transportation cask internal pressure for NCT and HAC are provided in Sections 3.4 and 3.5, respectively.

- *NCT Cold Environment:* A -40°F steady-state ambient temperature with maximum decay heat and zero insolation. This case is used for evaluation of the maximum thermal gradients and is not combined with other structural loads.
- *NCT Cold Environment (no heat):* This case is the same as NCT Cold Environment, but without decay heat. Similar to NCT Cold (no heat), this analytically trivial case establishes minimum material temperatures for material compatibility and for the brittle fracture evaluation presented in Section 2.6.2.
- *HAC Fire (cold):* Thermal conditions are evaluated as a steady-state ambient temperature of -20°F with maximum decay heat and zero insolation prior to the event, followed by a thirty-minute transient with an ambient temperature of 1475°F with maximum decay heat, and then back to a steady-state ambient temperature of -20°F with maximum decay heat and zero insolation. This case is used for evaluation of the thermal gradients expected under the HAC fire conditions. Comparison with the results from the HAC Fire (hot) case below provides an indication of the sensitivity of the package thermal response to the HAC event with the initial starting temperature.
- *HAC Fire (hot):* Thermal conditions are evaluated as a steady-state ambient temperature of 100°F with maximum decay heat and zero insolation prior to the event, followed by a thirty-minute transient with an ambient temperature of 1475°F with maximum decay heat and maximum insolation, and then back to a steady-state ambient temperature of 100°F with maximum decay heat and maximum insolation, per 10CFR71.71(c)(1), averaged over 24 hours. This load case evaluates the peak temperature achieved for the various cask components under the HAC fire event and the associated thermal stresses.

The 10CFR71.71(c)(1) insolation values are applied to the transportation cask as discussed in Section 3.1.2 of the FuelSolutions™ TS125 Transportation Cask SAR[2] and their effects are included in the W21 canister thermal evaluations provided herein. The insolation values are applied to the transportation package as a 24-hour average. Transient insolation modeling is not considered[7,8] due to the large thermal inertia of the transportation package and the relative magnitude of the insolation load compared to the heat load provided by the SNF.

3.1.3 Design Basis Axial Heat Generation Profile

The FuelSolutions™ W21 canister is designed to accommodate most classes and types of commercial PWR fuel. In order to assure that all of the W21 canister design configurations presented in Section 1.2 of this SAR are qualified to accommodate the worst-case thermal loads, a conservative design basis SNF assembly axial heat generation profile is used for the W21 canister thermal evaluation. The SNF assembly axial heat generation profile and, hence, the temperature profile within the FuelSolutions™ W21 canister, are dependent on the variation in

[7] Brown, N., Gianoulakis, S., and Lake, W., *Comparison of 10 CFR 71 Normal Conditions with Bounding US "Hot Day" Extremes,* Sandia Report SAND91-2255C, October 1992.

[8] Manson, S., and Gianoulakis, S., *Comparison of Spent Fuel Shipping Cask Response to 10CFR71 Normal Conditions and Realistic Hot Day Extremes,* Sandia Report SAND94-0812, April 1994.

the heat load and axial position of the particular fuel assembly loaded within each basket. The distribution of the heat load within the canister is a function of: (1) the SNF assembly class; (2) the corresponding heavy metal content, burnup, and cooling time; (3) the number of SNF assemblies in the canister; (4) the active length of the SNF assemblies; and (5) the axial position of the SNF assembly active fuel length within the canister. The above variables are set by the canister type and the characteristics of the specific SNF assembly class to be loaded. The specific SNF assembly classes and characteristics that are accommodated by the W21 canister are presented in Table 1.2-4 of this SAR. Sections 3.1.3.1 and 3.1.3.2 describe how the design basis SNF assembly axial heat generation profiles are determined and applied. Section 3.1.3.3 demonstrates the compliance of the W21 canister SNF assembly design basis axial heat generation profiles with the TS125 transportation cask thermal requirements specified in Section 3.1.3.3 of the FuelSolutions™ TS125 Transportation Cask SAR. In addition, Section 3.1.3.4 provides an evaluation demonstrating that PWR fuel assemblies that meet the cooling time requirements in Table 5.1-3 are acceptable for transport from a thermal standpoint.

3.1.3.1 Development of Design Basis Axial Heat Generation Profiles

In order to address the expected variation of SNF assembly axial heat generation profile within all PWR fuel assembly classes loaded in the W21 canister, the SNF assembly design basis axial heat profiles used for the W21 canister thermal evaluation are developed considering both the maximum overall SNF assembly heat generation (Q_{Total}), and the maximum SNF assembly heat generation per unit length (i.e., kW/inch) within the active fuel zone, hereafter referred to as the Linear Heat Generation Rate (LHGR). Assembly thermal profiles that do not exceed the overall heat generation or the peak local heat generation of the design basis thermal profile cannot produce higher peak cask system component temperatures.

All sources of heat are conservatively combined in the active fuel region of the thermal models including UO_2 fuel sources, fuel assembly hardware both inside and outside the active fuel zone, and control component hardware. The design approach described in Section 3.1.3.2 is to construct the axial profile, then increase the total heat generation rate iteratively to find the system's maximum heat load capacity.

The W21 canister thermal analyses are performed using two different design basis SNF assembly axial heat generation profiles, which are referred to as the "max thermal" or "Q_{max}" and "max thermal gradient" or "$LHGR_{max}$" profiles. Figure 3.1-1 shows the normalized "max thermal" and "max thermal gradient" design basis SNF assembly heat generation profiles used for the W21 canister thermal evaluation. Both design basis SNF assembly heat generation profiles are based upon the representative normalized 44 GWd/MTU burnup PWR fuel assembly heat generation profile shown in Figure 3.1-1 of the FuelSolutions™ TS125 Transportation Cask SAR. This axial heat generation profile has a peaking factor (i.e., peak to average ratio for local heat generation) of 1.095.

The Q_{max} profile is based on a total canister heat generation of 22.0 kW (1.05 kW per SNF assembly), a maximum LHGR of 0.1606 kW/inch (7.665 W/inch per SNF assembly), and an active fuel length of 150 inches. The active fuel length and position used for the Q_{max} profile are based on the CE 16x16 PWR assembly class. As shown in Figure 3.1-1, the active fuel region (and associated axial heat generation profile) of the CE 16x16 PWR assembly spans from

12 inches to 162 inches, as measured from the bottom of the canister. Figure 3.1-2 of the FuelSolutions™ TS125 Transportation Cask SAR shows that the active fuel regions for all PWR assembly classes are positioned within the axial span covered by the CE 16x16 assembly profile. Therefore, the Q_{max} profile is bounding for any individual PWR fuel assembly having a maximum total heat generation that does not exceed 1.05 kW and a maximum LHGR that does not exceed 7.665 W/inch.

The $LHGR_{max}$ profile has a total heat generation of 17.5 kW and a maximum LHGR of 0.211 kW/inch, and is based on an active fuel length of 91 inches, which is representative of the PWR assembly with the shortest active fuel length (e.g., Yankee Rowe PWR fuel) that is accommodated in the W21 canister. The magnitude of the $LHGR_{max}$ profile produces temperatures within the transportation package that reach, but do not exceed, the material temperature limits for the controlling thermal condition. This profile was developed to examine the effects of SNF assemblies having short active fuel lengths with high LHGR levels (i.e., higher than the Q_{max} profile.) SNF assemblies having this heat generation profile will produce bounding axial and radial thermal gradients in the transportation package that may result in higher thermal stresses. Note that the maximum LHGR of the $LHGR_{max}$ profile exceeds that of the Q_{max} profile, even though, as is shown in Section 3.1.3.4, all PWR assemblies that meet the burnup, initial enrichment, cobalt content, and cooling time limits given in Table 5.1-3 are expected to have maximum LHGRs that are significantly lower than the Q_{max} profile. Thus, the $LHGR_{max}$ profile is a conservative design basis heat generation profile that is evaluated for its effect on thermal stresses in the transportation package, but it does not form the basis of total heat generation or LHGR limits for the W21 canister.

3.1.3.2 Application of Axial Heat Generation Profiles for Canister Analysis

The FuelSolutions™ W21 canister analytical model used for the thermal evaluation includes simulation of the individual fuel assemblies within the basket. The local decay heat (Q_{local}) at any specific axial location within the fuel assemblies is determined using the axial profiles in Figure 3.1-1 as follows:

$$Q_{local} = \left(\frac{Q_{Assy}}{AFL}\right) \cdot N(z) \cdot L$$

where:

- Q_{local} = Local fuel assembly heat load at the nodal location
- Q_{Assy} = Total fuel assembly heat load (kW) for the given axial profile
- AFL = Active fuel length in inches for the associated axial profile (i.e., 150 inches for the Q_{max} profile and 91 inches for the $LHGR_{max}$ profiles)
- N(z) = Normalized heat generation (kW/inch) at the center of the region being modeled (from Figure 3.1-1 or Table 3.1-2)
- L = Axial length in inches of the region being modeled

The total canister heat generation of the Q_{max} and $LHGR_{max}$ profiles were determined by uniformly increasing the magnitude of all 21 SNF assembly heat load profiles shown in Figure 3.1-1 (i.e., increasing Q_{Total}) until one or more of the cask component temperatures

approach the associated material temperature limit. The value of "Q_{Total}" that results in the cask material temperature limits being reached for the Q_{max} profile is the maximum allowable total canister heat generation, provided it does not exceed the Q_{max} limit for the TS125 Transportation Cask, as specified in Section 3.1.3.3 of the FuelSolutions™ Transportation Cask SAR. The corresponding maximum LHGR for each profile is equal to the average heat generation (Q_{Total}/AFL) multiplied by the maximum peaking factor (PF). As discussed in Section 3.1.3.1, the $LHGR_{max}$ profile does not form the basis for the W21 canister thermal limits.

3.1.3.3 Compliance with Transportation Cask Thermal Requirements

As discussed in Section 3.1.3.3 of the FuelSolutions™ TS125 Transportation Cask SAR, the total heat load for candidate canisters must not exceed 22.0 kW, and the canister must not produce a peak temperature in the inner shell of the TS125 Transportation Cask that exceeds the peak temperature calculated for the transportation cask's Q_{max} thermal profile.

The Q_{max} profile used for the thermal evaluation of the W21 canister has a maximum heat generation of 22.0 kW and a maximum LHGR of 0.1606 kW/inch. Since it is enveloped by the TS125 Transportation Cask's Q_{max} thermal profile, the resulting cask inner shell peak temperature does not exceed the peak temperature calculated for the transportation cask's Q_{max} thermal profile. This is demonstrated by comparing the temperatures from Table 3.4-1 of this SAR to Table 3.4-1 of the FuelSolutions™ TS125 Transportation Cask SAR. Therefore, the transportation cask thermal requirements are met.

As discussed in Section 3.1.3.1, the $LHGR_{max}$ profile used for the thermal evaluation of the W21 canister has a maximum LHGR of 0.211 kW/inch. The $LHGR_{max}$ profile used for the W21 canister thermal evaluation is bounded by the $LHGR_{max}$ profile used for the thermal evaluation in the FuelSolutions™ TS125 Transportation Cask SAR. However, as discussed in Section 3.1.3.3 of the FuelSolutions™ TS125 Transportation Cask SAR, the $LHGR_{max}$ profile, which is a conservative design basis profile that is evaluated for its effects on thermal stress, has no associated canister thermal limits.

3.1.3.4 Comparison to Cooling Tables Limits

This section shows why fuel assemblies that meet the cooling time requirements in Table 5.1-3 of this SAR are acceptable for transport from a thermal standpoint. Two issues are discussed: the overall canister heat load corresponding to the cooling table limits, and the effect of fuel peaking factor on thermal margin.

Calculations were performed using the ORIGEN2.1 point-depletion code to find the heat generation, per kilogram of spent UO_2 fuel, for the assembly burnup, initial enrichment, and cooling time combinations shown in Table 5.1-3. The detailed assumptions made in ORIGEN2.1 are summarized in Table 5.2-1. The resulting unit heat generation rates were multiplied by the maximum allowable PWR assembly uranium loading of 471 kg to yield the maximum fuel assembly heat generation rates. Heat production from irradiated fuel assembly hardware and control components was included. Table 3.1-5 summarizes these rates and compares them to the design basis assembly heat generation rate of 1.05 kW/assy. As can been seen in the far right column, the W21 cooling times are driven by dose because no qualified fuel assemblies will generate the 1.05 kW heat load assumed in the Q_{max} case. As an example, the heat generation for

a qualified 40 GWd/MTU fuel assembly could be no more than 77% of that assumed in the Q_{max} design basis thermal model. This significant margin is in addition to the temperature margins already indicated by the thermal results.

The design basis thermal models include assumptions for fuel peaking factors. The fuel peaking factor is not, however, specified as a fuel qualification parameter. Two discussions are presented that show there is sufficient thermal margin in the TS125 transportation package containing a W21 canister to offset the secondary effects of the expected variations in PWR fuel peaking factors.

First, the thermal analyses show that the limiting thermal margins for the more highly peaked $LHGR_{max}$ profile are higher than those assumed for the Q_{max} profile. Comparing the values in Table 3.4-1 and Table 3.4-2, the controlling temperature margin for the W21 system occurs in the neutron shield material, where the calculated temperature for the Q_{max} case is 10°F under the material's allowable temperature of 300°F. For the $LHGR_{max}$ case, the limiting temperature margin also occurs in the neutron shield, but increases from 10°F to 33°F. The thermal margin is therefore more sensitive to the total heat input (ΔQ = -20%) than LHGR ($\Delta LHGR$ = +31%). The temperature margin for canister internals decreases for the $LHGR_{max}$ case; but since these margins are not controlling, qualified fuel with a higher peaking factor than that assumed in the Q_{max} profile results in a higher overall thermal margin.

Second, it is possible to express the additional thermal margin shown in Table 3.1-5 so as to compare it to the peaking profiles of a large population of PWR fuel assemblies[9]. Table 3.1-6 shows the calculation of LHGR ratios as a function of fuel burnup. The data in Table 3.1-6 are intended to illustrate the additional thermal margin inherent in the W21 fuel specification process and are not part of the safety analysis. The LHGR ratio is the peak-to-average ratio between the peak LHGR assumed in the Q_{max} thermal model and the average LHGR for fuel of a given burnup. This ratio can be compared directly to the peaking factors for spent fuel. It represents the peaking factor that a fuel assembly would require to have the same peak LHGR as was assumed for the Q_{max} heat generation profile. Figure 3.1-2 shows the LHGR ratio curve superimposed on a scatter plot of the peaking factors for 3169 U.S. PWR fuel assemblies. The LHGR ratio curve envelopes every point in the database, although it is not a requirement that fuel peaking factors must be bounded by the curve. The figure shows that, even considering outlier fuel assemblies, a substantial amount of additional thermal margin exists between the LHGR of candidate PWR assemblies and the Q_{max} profile assumed in the thermal analysis.

In summary, Table 3.1-5 shows that fuel assemblies that are qualified for the W21 canister using Table 5.1-3 are thermally acceptable because they have less than the design basis thermal generation rate of 22.0 kW assumed in the Q_{max} thermal model. Peaking factors are not necessary as a fuel qualification parameter because more highly peaked profiles, such as the $LHGR_{max}$ profile, do not decrease the minimum thermal margin. This is further supported by comparing the LHGR ratios calculated in Table 3.1-6 to the U.S. PWR inventory shown in Figure 3.1-2.

[9] PWR-AXBUPRO-SNL, *Axial Burnup Profile Database for Pressurized Water Reactors*, DLC -201, Radiation Safety Information Computational Center, ORNL, September 2000.

3.1.4 W21 Canister Temperature Summary

The maximum allowable material temperatures for the W21 canister components are presented in Section 3.3.1, while the spent fuel cladding allowable temperature is presented in Section 3.3.2. The canister system temperatures under the various bounding thermal load conditions for transportation are presented in Sections 3.4 and 3.5 for NCT and HAC, respectively. These system temperatures are determined by applying the W21 canister design basis Q_{max} and $LHGR_{max}$ profiles presented in Table 3.1-3 or zero decay heat, depending on the applicable thermal load condition summarized in Table 3.1-1.

The figures and tables in Section 3.4 provide a comprehensive overview of the thermal performance of the W21 canister in the TS125 cask under NCT conditions. As the thermal analysis of Section 3.4 demonstrates, all of the temperatures and temperature distributions noted from the analysis are well within the established thermal limits for both the canister and the cask. The predicted peak fuel cladding temperature is 704°F (373°C), or 48°F below the conservatively established allowable temperature for the fuel cladding. The peak spacer plate temperature of 646°F and the peak canister shell temperature of 484°F are both below their allowable limits.

The predicted peak cask shell temperature is 358°F, or 442°F below the established allowable temperature for the structural stainless steel. The maximum predicted temperature of the lead material forming the gamma shield is 352°F, or 268°F below the established melting point for the lead. The bulk average temperature for the lead shield under the bounding NCT load condition is 319°F. The bulk average temperature of the solid neutron shield material is 252°F, or 48°F below the 300°F limitation established to limit the loss of hydrogen from the material.

Likewise, the thermal evaluations for HAC conditions presented in Section 3.5 demonstrate that the canister and cask component temperatures will remain below their respective accident allowable temperatures. Despite conservative assumptions for emissivity and absorptivity and the worst-case modeling for potential damage to the impact limiters, the thermal evaluations demonstrate that fuel cladding, spacer plates, and other canister components remain within their long-term allowable temperatures, the cask containment boundary remains intact, and the lead will remain well below its established melting point. The predicted peak fuel cladding temperature is 349°C, or only 9°C above its pre-fire level. Likewise, the peak spacer plate temperature and the peak canister shell temperatures are only 20 and 33°F, respectively, above their pre-fire temperature levels.

The peak cask component temperatures seen for HAC conditions are within their allowable limits. A full discussion of the performance of the TS125 cask under HAC conditions is provided in the FuelSolutions™ TS125 Transportation Cask SAR.[2]

3.1.5 Transportation Cask Internal Pressure Summary

Although designed as a confinement boundary for storage conditions, the FuelSolutions™ W21 canister shell assembly is not considered a containment boundary for transportation conditions. Instead, the transportation cask serves this function. In addition to the cask cavity backfill gas, the transportation cask is conservatively assumed to be pressurized due to a postulated release of fuel rod fill gas, fuel rod fission gas, control component gas (for applicable fuel assembly types and canister configurations), and canister backfill gas directly to the transportation cask cavity.

As discussed in Chapter 7 of this SAR, the W21 canister is backfilled with helium during closure operations. The quantity in moles of inert gas needed for canister cavity backfill is determined in order to achieve 10 psig (1.68 atm) in the canister cavity under normal hot storage conditions (i.e., 100°F ambient at the maximum W21 canister heat load for storage within the FuelSolutions™ W150 Storage Cask) with 1% rod failures. The transportation cask cavity is conservatively assumed to be backfilled with helium to achieve 1 atm at room temperature (70°F). Since it can safely be assumed that the canister/cask temperatures will be above 70°F at the time of backfill, the actual cask cavity pressures will be less than those determined based on this assumed quantity of helium backfill gas.

The W21 canister and TS125 Transportation Cask maximum internal pressure is dependent on the characteristics of the specific FuelSolutions™ W21 canister and its SNF payload. A FuelSolutions™ TS125 Transportation Cask design pressure of 75 psig has been established to bound the maximum pressures resulting from the worst-case combination of canister and SNF. Conservative predictions of transportation cask internal pressure for NCT and HAC are provided in Sections 3.4 and 3.5, respectively. The calculations for NCT assume the rupture of 3% of the SNF and PWR control component rods, while those for HAC assume the rupture 100% of the SNF and PWR control component rods.[10] The release of 100% of the rod fill gas, 30% of the SNF rod fission gas, and 30% of the gas generated within PWR control components is conservatively assumed for each postulated failed rod.

The maximum normal operating pressure (MNOP) for NCT hot and NCT cold conditions and the HAC pressure are presented in Table 3.1-4. As shown, both the MNOP and the HAC pressure generated with a bounding W21 canister remains within the design pressure rating for the FuelSolutions™ TS125 Transportation Cask.

[10] Table 4-1, NUREG-1617, *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel*, Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555-0001, March 2000.

Table 3.1-1 - Transportation Design Basis Thermal Conditions

Case	Description	Applicable Conditions				
		Ambient Temperature	Insolation		Decay Heat	
		(°F)	Max.[1]	Zero	Max.	Zero
1	NCT Hot[2]	100	×		×	
2	NCT Hot (no solar)[2,3,6]	100		×	×	
3	NCT Cold[2,3]	-20		×	×	
4	NCT Cold (no heat)[4]	-20		×		×
5	NCT Cold Environment[5]	-40		×	×	
6	NCT Cold Environment (no heat)[4]	-40		×		×
7	HAC Fire (cold)[3]	-20/1475/-20		×	×	
8	HAC Fire (hot)[3]	100/1475/100	×		×	

Notes:

(1) Insolation in accordance with 10CFR71.71(c)(1), averaged over 24 hours.

(2) Thermal conditions used to evaluate thermal acceptance criteria and for structural load combinations.

(3) For the HAC fire event, a transient consisting of an initial steady-state initial condition (i.e. Case 2 or Case 3), followed by a 30-minute fire event, and concluded with a post-fire transient analysis to establish the peak temperatures.

(4) NCT Cold and Cold Environment are evaluated without decay heat to establish minimum material temperatures for material compatibility and brittle fracture considerations.

(5) NCT Cold Environment evaluated with maximum decay heat to establish the worst-case spacer plate thermal gradients.

(6) NCT Hot (no solar) used to assure compliance with 10CFR71.43(g) criteria for accessible surface temperature.

Table 3.1-2 - W21 Canister Design Basis Axial Heat Profiles

Q_{max} Profile		$LHGR_{max}$ Profile	
Axial Location[1] (inches)	Peaking Factor[2]	Axial Location[1] (inches)	Peaking Factor[2]
0.0	0.0	0.0	0.0
12.0	0.0	68.7	0.0
12.01	0.600	68.75	0.400
20.0	0.803	70.0	0.665
30.0	1.018	80.0	1.03
40.0	1.081	90.0	1.092
50.0	1.095	100.0	1.095
60.0	1.094	110.0	1.094
70.0	1.092	120.0	1.087
80.0	1.090	130.0	1.082
90.0	1.088	140.0	1.061
100.0	1.086	150.0	0.875
110.0	1.083	159.7	0.650
120.0	1.077	159.75	0.0
130.0	1.060	192.0	0.0
140.0	0.996		
150.0	0.800		
160.0	0.600		
162.0	0.400		
162.01	0.0		
192.0	0.0		

Notes:

(1) Axial location is given with respect to the bottom end of the canister.

(2) Intermediate values are determined by linear interpolation.

Table 3.1-3 - Maximum Analyzed Local and Overall W21 Canister Heat Generation Levels

Axial Heat Profile	Q_{Total} (kW)	LHGR (kW/in)
Max Thermal (Q_{max})	22.0	0.1606
Max Thermal Gradient ($LHGR_{max}$)	17.5	0.211

Table 3.1-4 - Transportation Cask Internal Pressures with Loaded W21 Canister

Condition	TS125 Transportation Cask Pressure	Max. Design Pressure
MNOP(1)	11.9 psig	75 psig
MNOP cold(2)	9.7 psig	75 psig
Max. HAC Internal Pressure	68.2 psig	75 psig

Notes:

(1) At maximum canister rating and with 100°F ambient and solar.

(2) At maximum canister rating and with -20°F ambient and no solar.

Table 3.1-5 - Comparison of Allowable to Analyzed Heat Generation Rate as a Function of Burnup

Allowable Fuel Parameters[1]			Heat Generation (Whole Fuel Assembly)			Fraction of Q_{max}[5]
Burnup (GWd/MTU)	^{235}U Enrichment	Cooling Time (years)	UO_2 Only (W/assy)[2]	% from Assy Hardware[3]	Total (W/assy)[4]	
15	2.8%	6	297.1	5.4	314.1	30%
20	2.8%	6	406.8	5.4	430.0	41%
25	2.8%	6	525.2	5.4	555.2	53%
30	2.8%	6	655.2	5.4	692.6	66%
35	2.8%	6	800.7	4.2	835.8	80%
40	3.0%	8	773.4	3.7	803.1	77%
45	3.3%	10	826.6	3.7	858.4	82%
50	3.5%	12	879.4	3.2	908.5	87%
55	3.8%	15	908.1	3.2	938.1	90%
60	4.0%	18	947.2	3.2	978.5	93%

Notes:

(1) Burnup, enrichment, and minimum required cooling times from Table 5.1-3. Lowest allowable cooling times are used to result in highest possible heat loads.

(2) Thermal contribution from UO_2 fuel. Calculated using ORIGEN2.1 for the allowable fuel parameters, a maximum PWR assembly uranium loading of 471 kg/assy, and the parameters in Table 5.2-1.

(3) Thermal contribution from non-UO_2 sources, including hardware, end fittings, and control components. Expressed as a percentage of total assembly heat generation[11].

(4) Calculated by multiplying the UO_2 heat generation by [100/(100-P)] where P is the hardware percentage in column 5.

(5) Ratio of Q_{max} heat load (22,000 W / 21 assy = 1048 W/assy) to the heat load for fuel qualified using Table 5.1-3.

[11] REAC-M-204, Fero, A.H., *Reactor Internals and Core Structure Decay Heat*, Westinghouse Electric Company, Nuclear Services Division, August 25, 1998.

Table 3.1-6 - LHGR Ratio vs. Burnup

Allowable Fuel Parameters[1]			Average LHGR (Watts/inch-assembly) (Active Fuel Zone Only)			LHGR Ratio[4]
Burnup (GWd/MTU)	^{235}U Enrichment	Cooling Time (years)	UO_2 Fuel[2]	Fuel Zone Hardware[3]	Total	
15	2.8%	6	2.062	0.054	2.116	3.622
20	2.8%	6	2.824	0.071	2.895	2.647
25	2.8%	6	3.646	0.088	3.734	2.053
30	2.8%	6	4.549	0.105	4.654	1.647
35	2.8%	6	5.559	0.123	5.682	1.349
40	3.0%	8	5.369	0.103	5.472	1.401
45	3.3%	10	5.739	0.070	5.809	1.320
50	3.5%	12	6.105	0.066	6.171	1.242
55	3.8%	15	6.305	0.047	6.351	1.207
60	4.0%	18	6.576	0.033	6.609	1.160

Notes:

(1) Burnup, enrichment, and minimum required cooling times from Table 5.1-3. Lower cooling times are used because they result in the highest possible heat loads.

(2) Thermal contribution from UO_2 fuel. Calculated using ORIGEN2.1 for the allowable fuel parameters, a maximum PWR axial uranium loading of 3.27 kg/in-assy, and the parameters in Table 5.2-1.

(3) Thermal contribution from activated fuel-zone hardware and control components. Calculated using ORIGEN2.1 for the allowable fuel components, a cobalt loading of 11 g/assy, and a lower-bound fuel length of 128 inches.

(4) Obtained by dividing the peak LHGR in the design basis Q_{max} thermal profile (7.665 watts/assy) by the average LHGR in the sixth column. A fuel assembly would need an axial peaking factor with this ratio to have a peak LHGR equal to that assumed in the Q_{max} thermal model. Figure 3.1-2 compares these LHGR ratios to the U.S. PWR spent fuel inventory.

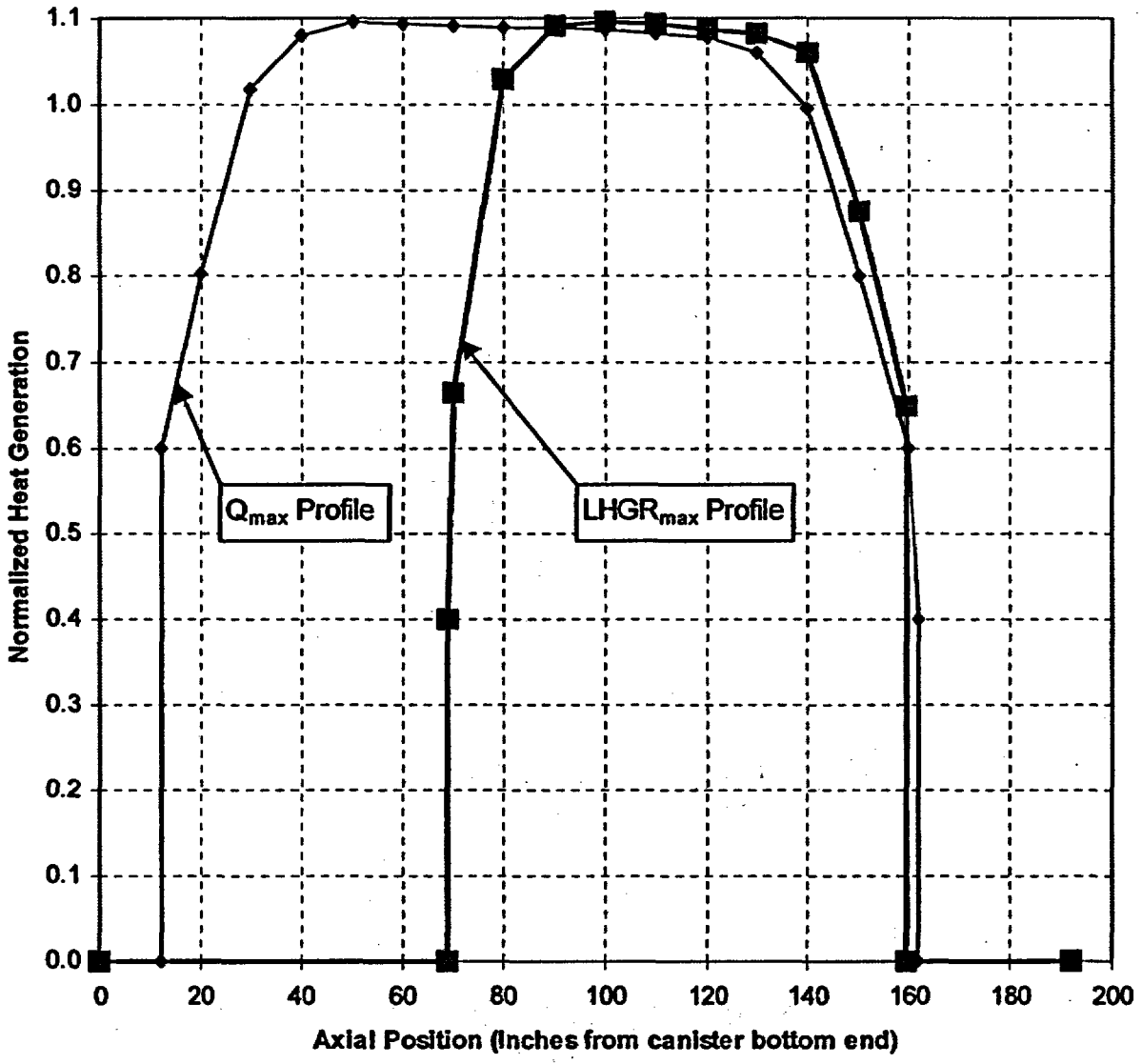

Figure 3.1-1 - Design Basis Axial Heat Generation Profiles for W21 Canister Analysis

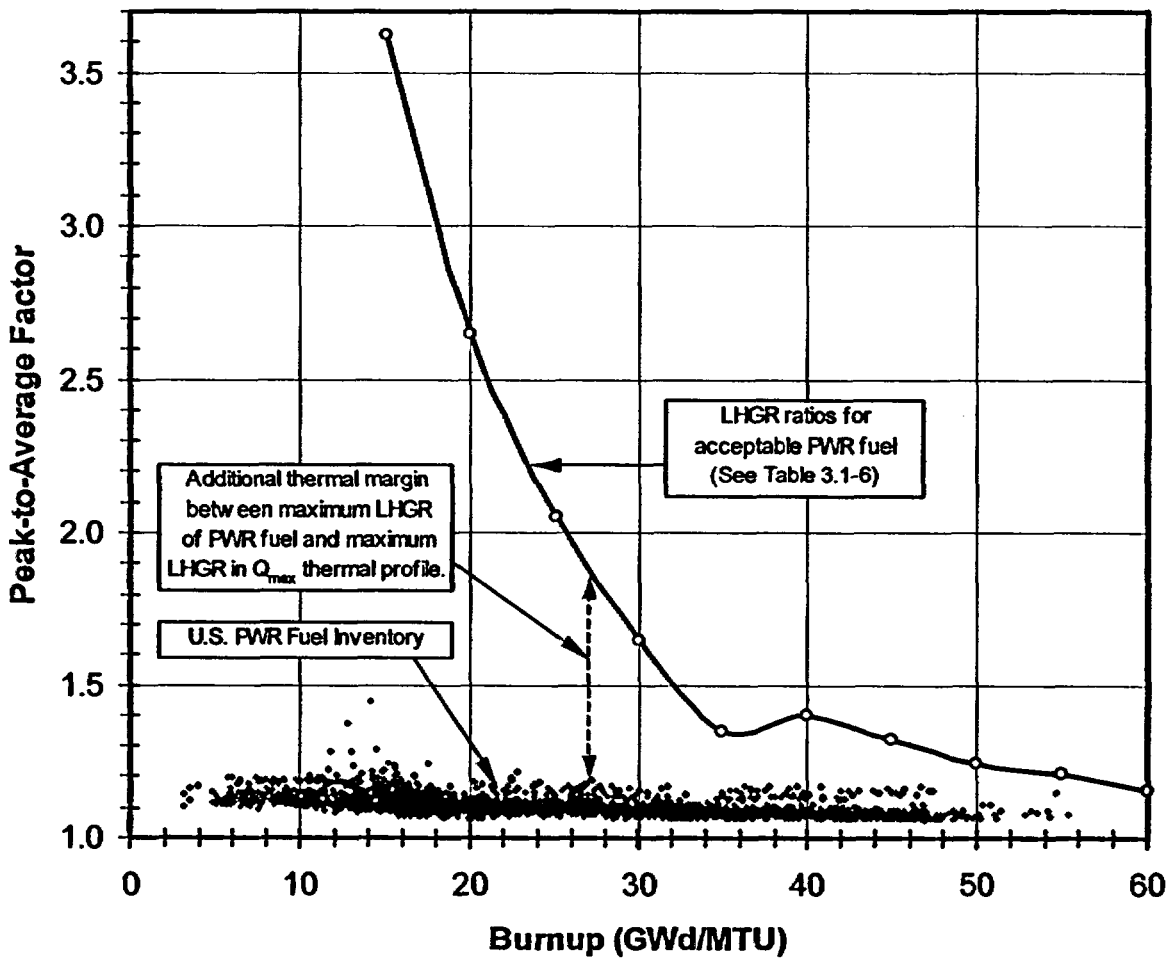

Figure 3.1-2 - Comparison of LHGR Ratio With U.S. PWR Spent Fuel Inventory

as part of the Manteufel and Todreas[12] non-linear form of the lumped k_{eff}/h_{edge} model for a typical PWR fuel assembly (see Section 3.2.2).

Canister to Transportation Cask Model

The W21 canister thermal model described above is combined with the TS125 Transportation Cask thermal model to allow a thermal analysis of the composite transportation package. The transportation cask assembly thermal model is described in detail in Section 3.4.1 of the FuelSolutions™ TS125 Transportation Cask SAR.[2] The modeling of the W21 canister in the transportation cask is accomplished using the Thermal Desktop®[5] program to define the geometric relationship between the TS125 cask thermal model and the W21 canister thermal model. Once defined, the Thermal Desktop® program automatically computes the conduction and radiation links between the various thermal nodes representing the W21 canister shell and those representing the interior of the TS125 Transportation Cask.

The canister does not sit symmetrically within the transportation cask, but rests on two 1/8-inch thick guide rails attached to the transportation cask inner shell. Since this configuration results in eccentric positioning of the canister within the cask, the Thermal Desktop® conservatively calculated the gap conductance between the canister shell and the inner shell of the cask as a function of the position around the canister's circumference. The contact conductance[27] between the canister and the guide rails is computed based on the weight of the canister and the area of contact between the canister and the guide rails.

Impact of Fission Gases on the Thermal Performance of the Canister and Cask

The predicted change in gas mixture properties as a function of fission gas concentration is made using the mole fractions of the various constituents of the gas mixture and a complex function of viscosities and molecular weights. The estimation technique is based on the kinetic theory of gases. The evaluation, presented in Section 3.6.4, demonstrates that the bounding safety analysis for the FuelSolutions™ W21 canister in the TS125 Transportation Cask will be achieved if the effects of fission gas release are ignored.

3.4.1.2 Test Thermal Model

In accordance with 10CFR71.41, and as presented herein, detailed thermal analyses of the W21 canister within the transportation cask are performed to demonstrate compliance with the NCT tests specified in 10CFR71.71. As a result, subsequent transportation package or scale model thermal testing is not required. However, thermal acceptance testing of the transportation cask will be performed as discussed in Section 8.1.6 of the FuelSolutions™ TS125 Transportation SAR.[2]

3.4.2 Maximum Temperatures

The FuelSolutions™ W21 design basis thermal load cases are summarized in Table 3.1-1. For the determination of the W21 canister thermal rating, only steady-state NCT hot (case 1) is

[27] Based on Curve #11 in Figure 8, page 4-19, Rohsenow, Harnett, and Ganic, *Handbook of Heat Transfer Fundamentals*, 2nd Edition, McGraw-Hill, Inc., 1989.

considered. The combined W21 canister and transportation cask thermal model is exercised using the NCT hot boundary conditions (100°F ambient w/solar) for determination of the W21 canister thermal rating.

The methodology discussed in Section 3.1.3.2 is implemented for the thermal rating case. The two design basis canister axial heat profiles presented in Figure 3.1-1 are applied as boundary conditions for NCT hot. The allowable material temperatures in Table 3.3-1 are assumed and the total canister heat load (Q_{Total}) is gradually increased for each axial heat profile until an allowable material temperature is reached. As expected, the Q_{max} rating is achieved using the "max. thermal" profile, and the $LHGR_{max}$ rating is achieved using the "max. thermal gradient" profile. Table 3.1-3 provides a summary of the thermal ratings determined for the W21 canister.

Comparisons of the resulting canister and cask component temperatures with the allowable component temperatures for operations at the qualified W21 canister thermal ratings are presented under the Case 1 columns in Table 3.4-1 and Table 3.4-2 for Q_{max} and $LHGR_{max}$, respectively. Figure 3.4-9 and Figure 3.4-10 present the sensitivity of the W21 canister and transportation cask components to variations in heat loads using the "max. thermal" and "max. thermal gradient" profiles, respectively. As seen from the tables and figures, substantial thermal margin exists for all components of the canister and cask at the Q_{max} and $LHGR_{max}$ thermal ratings, with the exception of the NS-4-FR solid neutron shield material.

The NS-4-FR solid neutron shield material exhibits a maximum temperature within 15°F of the maximum allowable temperature (338°F) for the Q_{max} thermal load at the NCT hot condition, while the peak radial average temperature is within 10°F of the maximum allowable radial average temperature (300°F). The transportation cask impact limiter bulk honeycomb temperature is approximately 50°F below the 200°F allowable temperature set for structural considerations. The cask closure seals are more than 680°F below their long-term allowable temperature, while the vent and drain port seals are 430°F below their long-term allowable temperature. All other W21 canister and TS125 Transportation Cask materials have a relatively large thermal margin.

As seen from Table 3.4-2 and Figure 3.4-10, operations at the $LHGR_{max}$ thermal rating yield even greater thermal margins. While this indicates a higher thermal rating is possible, the $LHGR_{max}$ thermal rating of the W21 canister is limited to the maximum rating for the FuelSolutions™ TS125 Transportation Cask with a generic canister. In addition, the fact that the W21 canister thermal ratings are limited by the TS125 Transportation Cask materials, which occurs despite the conservative assumption of treating the solid neutron shielding material as having the properties of air, demonstrates that even greater thermal margins are expected under actual operation for the cask and canister.

The FuelSolutions™ W21 canister maximum thermal ratings within the TS125 Transportation Cask are applied for the full range of NCT cases presented in Table 3.1-1 in order to determine the resultant transportation package system temperatures. Maximum component temperatures are presented in Table 3.4-1 and Table 3.4-2 for Q_{max} and $LHGR_{max}$, respectively. All W21 canister component temperatures are within their material allowable temperatures for each load case. A presentation of the bounding transportation cask temperatures at the cask thermal ratings is provided in the FuelSolutions™ TS125 Transportation Cask SAR.[2]