FUELSOLUTIONS

FuelSolutions™ TS125 Transportation Cask Safety Analysis Report

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LIST OF EFFECTIVE PAGES

Page	Active Revision
i	5
ii	5
iii	5
iv	5
v	5
vi	5
vii	5
viii	5
ix	5
x	5
xi	5
xii	5
xiii	5
xiv	5
xv	5
xvi	5
xvii	5
xviii	5
xix	5
xx	5
xxi	5
xxii	5
xxiii	5
xxiv	5
xxv	5
xxvi	5
1-1	1
1-2	0
1-3	0
1-4	0
1-5	0
1-6	0
1-7	0
1-8	0
1-9	0
1-10	0
1-11	0
1-12	0
1-13	0
1-14	0
1-15	0
1-16	0
1-17	0
1-18	0

Page	Active Revision
1-19	0
1-20	0
1.1-1	1
1.1-2	0
1.1-3	0
1.1-4	0
1.1-5	1
1.1-6	0
1.2-1	0
1.2-2	0
1.2-3	0
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1.2-8	0
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1.2-17	1
1.2-18	1
1.2-19	1
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1.2-23	1
1.2-24	1
1.2-25	1
1.2-26	1
1.2-27	5
1.2-28	1
1.2-29	1
1.2-30	1
1.2-31	5
1.2-32	1
1.2-33	1
1.2-34	1
1.2-35	1
1.2-36	1

Page	Active Revision
1.2-37	1
1.2-38	1
1.2-39	1
1.2-40	1
1.2-41	1
1.2-42	1
1.2-43	1
1.2-44	1
1.2-45	1
1.2-46	1
1.2-47	1
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1.3-2	0
1.3-3	0
1.3-4	0
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FS-205	2
FS-210	2
FS-220	1
FS-230	1
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1.3-6	0
1.3-7	0
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1.3-9	0
1.3-10	0
1.3-11	0
1.3-12	1
1.3-13	0
1.3-14	0
1.3-15	0
1.3-16	0
1.3-17	0
1.3-18	0
1.3-19	0
1.3-20	0
1.3-21	0
1.3-22	0
1.3-23	0
1.3-24	0
1.3-25	3
1.3-26	0
1.3-27	0

LIST OF EFFECTIVE PAGES

Page	Active Revision
1.3-28	0
2-1	1
2-2	1
2.1-1	0
2.1-2	1
2.1-3	1
2.1-4	3
2.1-5	3
2.1-6	3
2.1-7	3
2.1-8	3
2.1-9	3
2.1-10	3
2.1-11	3
2.1-12	3
2.1-13	3
2.1-14	3
2.1-15	3
2.1-16	3
2.1-17	3
2.1-18	3
2.1-19	3
2.1-20	3
2.1-21	1
2.1-22	3
2.1-23	1
2.1-24	1
2.1-25	1
2.1-26	1
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2.2-2	0
2.2-3	0
2.2-4	0
2.3-1	1
2.3-2	1
2.3-3	1
2.3-4	1
2.3-5	1
2.3-6	1
2.3-7	1
2.3-8	1
2.3-9	1
2.3-10	1
2.3-11	1

Page	Active Revision
2.3-12	1
2.3-13	3
2.3-14	1
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2.5-16	1
2.5-17	1
2.5-18	1
2.5-19	1
2.5-20	1
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2.5-22	1
2.5-23	1
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2.5-28	1
2.5-29	1
2.5-30	1
2.5-31	1
2.5-32	1
2.5-33	1
2.5-34	1
2.5-35	1
2.5-36	1
2.5-37	1

Page	Active Revision
2.5-38	1
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2.5-40	1
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2.6-2	1
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2.6-4	0
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2.6-6	3
2.6-7	3
2.6-8	3
2.6-9	3
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2.6-11	3
2.6-12	3
2.6-13	3
2.6-14	3
2.6-15	3
2.6-16	3
2.6-17	3
2.6-18	3
2.6-19	3
2.6-20	3
2.6-21	3
2.6-22	3
2.6-23	3
2.6-24	3
2.6-25	3
2.6-26	3
2.6-27	3
2.6-28	3
2.6-29	3
2.6-30	3
2.6-31	3
2.6-32	3
2.6-33	3
2.6-34	3
2.6-35	3
2.6-36	3
2.6-37	3
2.6-38	3
2.6-39	3
2.6-40	3
2.6-41	3

LIST OF EFFECTIVE PAGES

Page	Active Revision
2.6-42	3
2.6-43	3
2.6-44	3
2.7-1	0
2.7-2	1
2.7-3	0
2.7-4	0
2.7-5	1
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2.7-35	3
2.7-36	3
2.7-37	3
2.7-38	3
2.7-39	3
2.7-40	3
2.7-41	3

Page	Active Revision
2.7-42	3
2.7-43	0
2.7-44	0
2.7-45	3
2.7-46	3
2.7-47	3
2.7-48	3
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2.7-67	0
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2.7-69	0
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2.8-2	1
2.8-3	3
2.8-4	0
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Page	Active Revision
2.12-4	0
2.12-5	0
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2.12-43	0
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2.12-46	0
2.12-47	0

LIST OF EFFECTIVE PAGES

Page	Active Revision
2.12-48	0
2.12-49	0
2.12-50	0
2.12-51	0
2.12-52	0
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2.12-74	3
2.12-75	1
2.12-76	1
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2.12-80	1
2.12-81	1
2.12-82	1
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2.12-85	1
2.12-86	1
2.12-87	1
2.12-88	1
2.12-89	1
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2.12-91	1

Page	Active Revision
2.12-92	1
2.12-93	1
2.12-94	1
2.12-95	1
2.12-96	1
2.12-97	1
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2.12-133	1
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2.12-135	1

Page	Active Revision
2.12-136	1
2.12-137	1
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LIST OF EFFECTIVE PAGES

Page	Active Revision
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3.2-3	0
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3.5-2	0
3.5-3	0

Page	Active Revision
3.5-4	1
3.5-5	1
3.5-6	1
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5.3-3	1

Page	Active Revision
5.3-4	1
5.3-5	1
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5.3-7	0
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7-1	1
7-2	1
7-3	1
7-4	1
7-5	1
7-6	1
7-7	0
7-8	0
7-9	1

LIST OF EFFECTIVE PAGES

TABLE OF CONTENTS

Section	Title	Page

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

Figure **Title** **Page**

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Figure **Title** **Page**

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Placement of the transportation cask on the railcar is nearly the reverse of that described above. Placement or removal of the transportation cask to and from a barge or heavy-haul trailer is similar.

1.2.2.4 Canister Loading, Closure, and Opening

Basic FuelSolutions™ canister loading, closure, and opening operations are described in Sections 1.2.2.1 and 1.2.2.2 of the FuelSolutions™ Storage System SAR. Canister-specific operations, if any, are provided in Sections 1.2.2.1 and 1.2.2.2 of the respective FuelSolutions™ Canister Storage FSAR.

1.2.3 Contents of Packaging

1.2.3.1 Spent Fuel to be Transported

The FuelSolutions™ SFMS is designed to dimensionally accommodate all domestic commercial PWR SNF assembly classes and Big Rock Point (BRP) BWR SNF assemblies, with the following exceptions at this time:

- Haddam Neck SNF assemblies
- Indian Point SNF assemblies
- LaCrosse SNF assemblies
- San Onofre 1 SNF assemblies
- South Texas SNF assemblies
- CE 16x16 and CE System 80 SNF assemblies with control components.

The many classes of existing SNF assemblies have a broad range of physical and nuclear characteristics (i.e., length, width, number of fuel rods, initial enrichment, burnup, etc.) and include PWR SNF assemblies and BRP BWR SNF assemblies. The SNF assembly classes and characteristics (including enrichment, burnup, and cooling time) that are accommodated by each FuelSolutions™ canister are identified in the respective FuelSolutions™ Canister Transportation SAR.

The base design of the FuelSolutions™ Transportation Package is for intact zircaloy-clad SNF assemblies with no known or suspected gross cladding failures. Some FuelSolutions™ canisters are also designed to accommodate damaged SNF assemblies, partial SNF assemblies, and MOX SNF assemblies. The allowable contents of FuelSolutions™ canisters are described in Section 1.2.3 of the respective FuelSolutions™ Canister Transportation SAR.

SNF assemblies that are considered to be intact (i.e., undamaged) can be placed in any cell location within the basket of a FuelSolutions™ canister for which it is qualified. SNF assemblies with known or suspected cladding defects greater than a hairline crack or a pinhole leak are considered damaged. Damaged fuel rods in an otherwise intact fuel assembly may be replaced with dummy rods that displace an equal amount of water as the original undamaged rod. Partial fuel assemblies that have missing fuel rods but are otherwise intact are acceptable for loading, when specifically qualified for the respective FuelSolutions™ canister. Similarly, fuel assemblies with damage to non-fuel assembly hardware (e.g., end fittings, nozzles, grid spacers) are acceptable for loading, when specifically qualified for the respective FuelSolutions™ canister.

Several means can be used to verify that an SNF assembly is intact/undamaged, including a review of reactor/plant records, visual inspections, fuel rod sipping evaluations, and other means of non-destructive examination. At a minimum, a review of reactor records is to be performed to verify that each fuel assembly is undamaged, followed by an external visual examination of each fuel assembly for any obvious damage prior to canister loading. The purpose of this demonstration is to provide reasonable assurance that the fuel assembly is undamaged or that the damaged fuel assembly to be loaded into a FuelSolutions™ canister is canned as described below.

Damaged SNF assemblies, as defined above, should be canned to confine gross fuel particles to a known, subcritical volume. The damaged fuel assembly cans are handle-able and retrievable, and contain holes covered by mesh screens that allow water to flow in and out of the can interior, but which prevent fissile material from the damaged fuel assemblies (e.g., pellets, rod fragments) from exiting the can. These damaged fuel cans are placed in specified cell locations within the canister basket in accordance with the respective FuelSolutions™ canister qualification basis. SNF in the form of debris, particles, loose pellets, and fragmented rods with plutonium in excess of 20 curies per package must be packaged in a separate inner container (second containment system) in accordance with 10CFR71.63(b).

The FuelSolutions™ TS125 Transportation Cask design is based on the bounding FuelSolutions™ canister dimensions and payload weights, and the bounding thermal and radiological source terms that form the basis for the structural, thermal, and shielding safety analyses documented in this SAR. These include the following canister interface parameter values:

- The transportation cask can physically accommodate any FuelSolutions™ canister with an outside diameter of 66 inches, a maximum length of 192.25 inches, and a maximum dry loaded weight of 85,000 pounds. Short canisters require use of a cask cavity spacer, the weight of which is included in the maximum canister weight.
- The transportation cask can accommodate any FuelSolutions™ canister with a total canister heat load of 22.0 kW or less, provided that the canister thermal evaluation shows that the peak temperature in the transportation cask's inner shell does not exceed that calculated for the design basis canister Q_{max} thermal profile in Chapter 3.
- The transportation cask is designed to maintain the through-wall contact surface dose rate to 200 mrem/hr or less, and a dose rate of 10 mrem/hr or less at 2 meters from the package conveyance. The transportation cask can accommodate any FuelSolutions™ canister and payload that does not exceed the rated radiological dose rate value.

The basis for these bounding FuelSolutions™ canister interface parameters and the corresponding design basis analysis of the FuelSolutions™ TS125 Transportation Cask are provided in Chapters 2, 3, and 5 of this SAR. The design criteria for the FuelSolutions™ TS125 Transportation Cask are listed in Table 1.2-3.

The qualification of SNF assemblies to be transported consistent with the design basis analysis of the FuelSolutions™ TS125 Transportation Cask is provided in Section 1.2.3 of each FuelSolutions™ Canister Transportation SAR. Criticality safety is conservatively based on fresh (i.e., unburned) fuel assumptions with optimum moderation and the use of fixed neutron absorbers incorporated into each FuelSolutions™ canister basket design, as described in the respective FuelSolutions™ Canister Transportation SAR.

1.2.3.2 Radionuclide Inventory

The design basis gamma and neutron radiation source terms for the total payload contents and the corresponding radionuclide inventory of the FuelSolutions™ transportation cask varies with the characteristics of the payload for each FuelSolutions™ canister. The canister-specific gamma and neutron radiation source term values are discussed in Section 1.2.3.2 of the respective FuelSolutions™ Canister Transportation SAR.

1.2.3.3 Maximum Payload Weight

The maximum payload weight for the FuelSolutions™ transportation cask, including the weight of the FuelSolutions™ canister, the radioactive contents, and the cask cavity spacer for short canisters, is 85,000 lbs. This weight occurs for the FuelSolutions™ canister and contents that is the heaviest of all loaded FuelSolutions™ canisters. The specific payload weights are provided in the respective FuelSolutions™ Canister Transportation SARs.

1.2.3.4 Maximum Decay Heat

The design basis decay heat load for the FuelSolutions™ TS125 Transportation Cask is 22,000 watts. The basis for this value and a discussion of the FuelSolutions™ Transportation Package thermal characteristics are provided in Chapter 3 of this SAR.

1.2.3.5 Maximum Pressure Buildup

The FuelSolutions™ TS125 Transportation Cask is designed for a maximum internal pressure of 75 psig. The MNOP and maximum HAC internal pressures are considerably less than the design pressure, as discussed in Section 3.1.5 of this SAR. The MNOP for the transportation cask is provided in Section 1.2.3.5 of the respective FuelSolutions™ Canister Transportation SAR. Note that although no credit is taken for the containment capability of the canister shell assembly, the transportation cask would only be subjected to these internal pressures if the canister shell is leaking or is breached.

The FuelSolutions™ TS125 Transportation Cask is designed for a maximum external pressure of 290 psig in accordance with 10CFR71.61, as discussed in Section 1.1.

1.2.4 Compliance with 10CFR71

The FuelSolutions™ TS125 Transportation Cask described in this SAR, together with the FuelSolutions™ canisters described in the FuelSolutions™ Canister Transportation SAR, fully comply with the requirements of 10CFR71. These include the general standards for all packages specified in 10CFR71.43, the requirements for NCTs defined in 10CFR71.71, and the requirements for HACs defined in 10CFR71.73. The specific SAR sections that address these 10CFR71 requirements are identified in Table 1.0-1. The structural, thermal, containment, shielding, and criticality requirements of 10CFR71 are addressed in Chapters 2 through 6 of this SAR and the FuelSolutions™ Canister Transportation SARs. The operational requirements of 10CFR71 are addressed in Chapter 7 of this SAR. Operations that are specific to a FuelSolutions™ canister are addressed in Chapter 7 of the respective FuelSolutions™ Canister Transportation SAR. The acceptance test and maintenance program requirements for the FuelSolutions™ TS125 Transportation Cask and impact limiters are addressed in Chapter 8 of this SAR. The acceptance test and maintenance program requirements for a FuelSolutions™ canister are addressed in Chapter 9 of the respective FuelSolutions™ Canister Storage FSAR.

Table 1.2-3 - Transportation Cask Design Criteria Summary (7 pages)

Type	Criteria or Reference	Basis[1]
Amount/Identity of Nonfissile Materials Used as Neutron Absorbers or Moderators	" "	10CFR71.33(b)(4)
Atomic Ratio of Moderator to Fissile Constituents	" "	10CFR71.33(b)(4)
Maximum Normal Operating Pressure (MNOP)	See Section 3.1.5 of FuelSolutions™ Canister Transportation SAR	10CFR71.33(b)(5)
Maximum Design Pressure	75 psig	-
Maximum Weight	285,000 lbs. (including loaded canister and impact limiters)	10CFR71.33(b)(6)
Maximum Amount of Decay Heat	22,000 watts [2]	10CFR71.33(b)(7)
Identification/Volumes of Any Coolants	N/A	10CFR71.33(b)(8)
Package Evaluation:	-	-
Allowable Number of Packages that May Be Transported in the Same Vehicle	Unlimited	10CFR71.35(b)
General Package Standards:	Smallest dimension is ≥ 10 cm.	10CFR71.43(a)
	External, durable, intact tamper-indicating device is provided.	10CFR71.43(b)
	Bolted containment system fasteners are used.	10CFR71.43(c)
	Materials/construction assure no significant chemical, galvanic, or other reactions.	10CFR71.43(d)
	Valves: None.	10CFR71.43(e)
	Designed, fabricated, and tested to prevent content loss or dispersal, external radiation increase, and no packaging effectiveness reduction during NCT.	10CFR71.43(f)
	Designed, fabricated, and configured to limit accessible surface temperature ≤ 185°F in still air at 100°F in shade.	10CFR71.43(g)
	No venting during transport.	10CFR71.43(h)

Table 1.2-3 - Transportation Cask Design Criteria Summary (7 pages)

Type	Criteria or Reference	Basis[1]
Ambient Outside Temperatures:	-	-
NCT Conditions: Minimum	-40°F	ANSI/ANS 57.9
Maximum	100°F	ANSI/ANS 57.9
HAC Conditions: Minimum	-20°F	ANSI/ANS 57.9
Maximum	100°F	ANSI/ANS 57.9
Ambient Plant Temperatures:	-	-
Spent Fuel Pool	120°F	ANSI/ANS 57.9
Fuel Building	77°F	ANSI/ANS 57.9
Lifting/Tiedown Standards:	-	-
Lifting Devices	Minimum safety factor of 3 against yield.	10CFR71.45(a)
	Failure does not impair other functional requirements of package.	10CFR71.45(a)
	Other lifting devices are rendered inoperable during transport.	10CFR71.45(a)
Tiedown Devices	No stresses > yield for 2g vertical, 10g axial, and 5g transverse at package's center of gravity.	10CFR71.45(b)(1)
	Other tiedown devices are rendered inoperable during transport.	10CFR71.45(b)(2)
	Failure does not impair other functional requirements of package.	10CFR71.45(b)(3)
External Radiation Standards: Radiation levels	$\leq$ 1000 mrem/hr. on surface of transportation cask. $\leq$ 200 mrem/hr. on surface of personnel barrier and impact limiters. $\leq$ 10 mrem/hr. at 2 meters from the conveyance.	10CFR71.47(b)
General Requirements for Fissile Material Packages	Remains subcritical if water leaks into the containment system for all design basis conditions if:	-
	Most reactive credible configuration consistent with chemical/physical form of material exists.	10CFR71.55(b)(1)/(e)(1)
	Moderation by water to the most reactive credible extent occurs.	10CFR71.55(b)(2)/(e)(2)
	Close full reflection of the containment system by water on all sides occurs.	10CFR71.55(b)(3)/(e)(3)

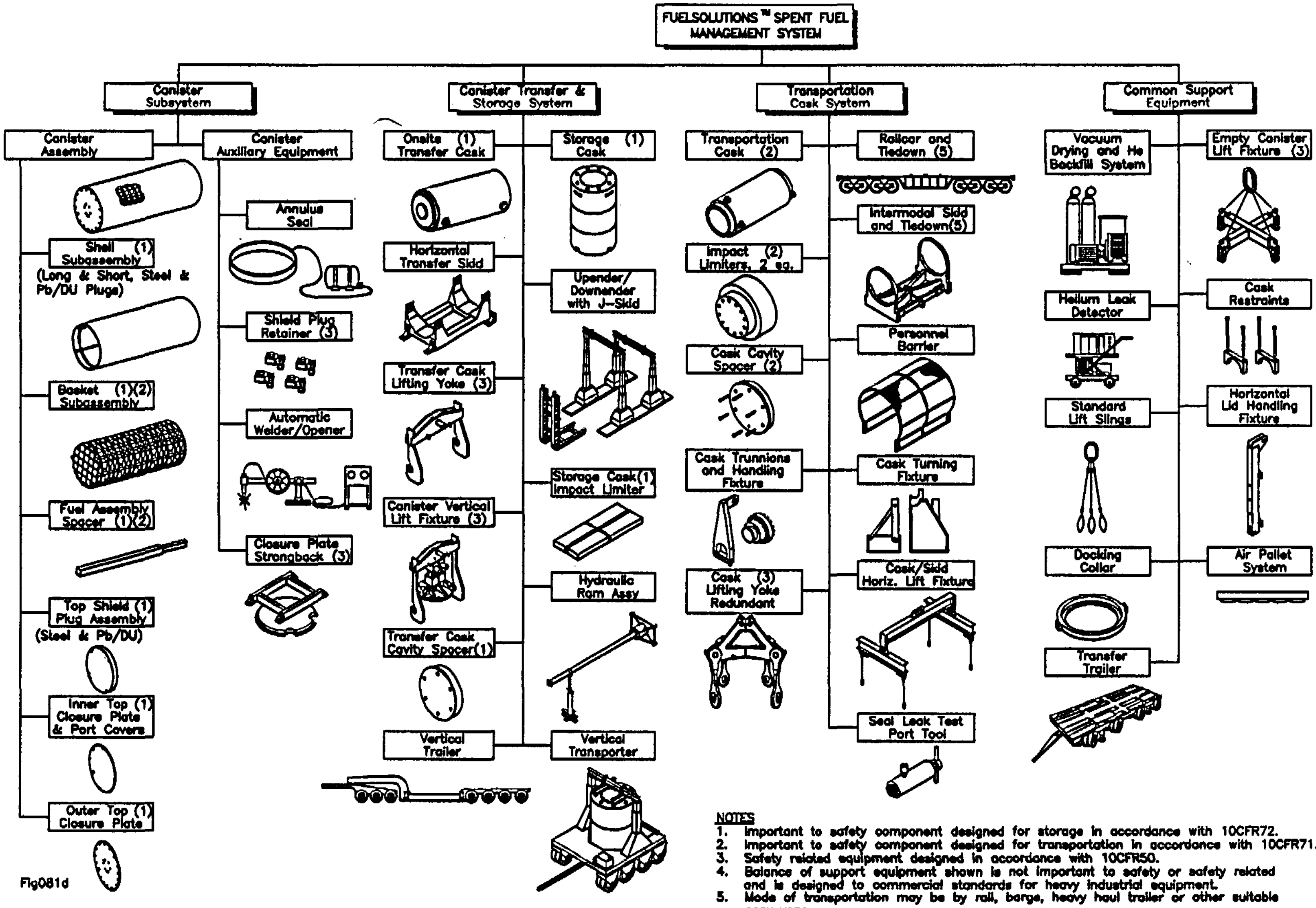
Table 1.2-3 - Transportation Cask Design Criteria Summary (7 pages)

Type	Criteria or Reference	Basis[1]
Other NCT Loads and Conditions:		
Wet/Dry Loading	Wet/Dry	-
Transfer Orientation	Vertical or Horizontal	-
Lifting Trunnion Test Load	150% of vertical design load (dead + handling)	NUREG-0612 & ANSI N14.6
HAC Design Events and Conditions:	-	-
End Drop	30 feet with impact limiters	-
Side Drop	30 feet with impact limiters	-
Corner Drop	30 feet with impact limiters	-
Puncture	40-inch drop onto 6-inch diameter solid, vertical, cylindrical, mild steel bar mounted in essentially unyielding horizontal surface.	10CFR71.73(c)(3)
Fire	-	-
Duration (min.)	30 minutes	10CFR71.73(c)(4)
Temperature (avg. min.)	1,475°F	10CFR71.73(c)(4)
Load Combinations	per Regulatory Guide 7.8	-

Notes:

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

(2) As discussed in Section 3.1.3.3, a FuelSolutions™ canister's thermal evaluation must show that the peak temperature of the cask inner shell does not exceed the value calculated for the Q_{max} profile in Chapter 3 of this SAR.



NOTES
1. Important to safety component designed for storage in accordance with 10CFR72.
2. Important to safety component designed for transportation in accordance with 10CFR71.
3. Safety related equipment designed in accordance with 10CFR50.
4. Balance of support equipment shown is not important to safety or safety related and is designed to commercial standards for heavy industrial equipment.
5. Mode of transportation may be by rail, barge, heavy haul trailer or other suitable conveyance.

Figure 1.2-1 - FuelSolutions™ Spent Fuel Management System

- *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 of100°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 presented in Table 3.1-2. These values are applied to the transportation package as a 24-hour average. Transient insolation modeling is not considered[6,7] 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 heat load content of the payload within the transportation cask is specified by a design basis axial heat generation profile. The axial heat generation profile is dependent on the SNF decay heat generation within the particular FuelSolutions™ canister to be transported. The variation in heat generation within a canister is a function of: (1) the SNF assembly class; (2) the corresponding heavy metal content, burnup, and cooling time; (3) the total number of SNF assemblies in the canister; (4) the active fuel length of the SNF assemblies; and (5) the axial position of the SNF assembly active fuel length within the canister. These variables are set by either the canister type or the characteristics of the specific SNF assembly class to be loaded. The specific SNF assembly classes and characteristics that are accommodated by each FuelSolutions™ canister are discussed in the respective FuelSolutions™ Canister Transportation SAR.

Several factors, including burnup, determine the SNF assembly's total heat load (kW) at the time of reactor discharge, and the profile of the heat load versus fuel axial position. A uniform burnup over the entire active fuel length would result in a flat axial heat profile with no peaks (i.e., a peaking factor of 1.0). Since fuel does not burn uniformly over the entire axial length, the heat generation from the fuel will exhibit a peak in the center region of the assembly. As burnup

[6] 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.

[7] Manson, S., and Gianoulakis, S., *Comparison of Spent Fuel Shipping Cask Response to 10 CFR 71 Normal Conditions and Realistic Hot Day Extremes,* Sandia Report SAND94-0812, April 1994.

increases, the total heat load from the SNF assembly also increases, and the axial heat profile becomes more uniform along the active fuel length. SNF assemblies with low burnup may have a relatively low total heat load, but they typically exhibit locally high linear heat generation rates (kW/in). Thus, it is possible for a low burnup SNF assembly with limited cooling time to yield higher local temperatures in the canister and cask due to this locally high linear heat generation rate even though the assembly has a lower overall heat load. Assemblies with shorter active fuel lengths may also yield higher local heat generation levels, despite having a lower total heat generation level.

To ensure that the cask system component temperatures calculated in the licensing basis analyses are not exceeded for any individual canister, both the overall heat generation (Q_{Total}) and the maximum Local Heat Generation Rate (LHGR) of the loaded SNF assemblies are controlled parameters, as discussed in Section 3.1.3.3. Another effect that is considered in the licensing basis analysis is variation in the axial position of the SNF assembly's active fuel region (over which the majority of heat is generated) within the transportation cask geometry for different SNF assembly types and canister types. As discussed below in Section 3.1.3.1, a conservative design basis axial heat generation profile, which addresses these effects, is developed and used for the Transportation Cask thermal evaluation.

3.1.3.1 Development of Design Basis Axial Heat Generation Profiles

Figure 3.1-1 presents the representative normalized axial heat generation profiles used for the PWR and BWR fuel assembly classes accommodated by FuelSolutions™ canisters. These profiles are based on axial burnup profiles presented in published reports for 44 GWd/MTU burnup PWR fuel[8] and for 29 GWd/MTU burnup BWR fuel[9] (i.e., for typical PWR and BWR assembly burnup levels). As can be seen from the figure, while the shapes of the axial heat generation profile curves are generally similar, the BWR fuel generates a greater portion of its heat in the lower half of the active fuel length and exhibits a faster fall-off in heat near the ends. In both cases, however, the magnitude of the curves are normalized such that the average heat generation over the length of the curve is equal to 1.0. As such, distributing the total heat generation along the length of the active portion of the SNF assembly according to the values specified by the curve yields the LHGR, while conserving the total heat generation.

The "peaking factor" of an axial heat generation profile is defined as the maximum LHGR (kW/inch) that occurs anywhere in the profile, divided by the assembly average LHGR (kW/inch) that occurs over the entire span of the profile. "Normalized" axial heat generation profiles, such as those shown in Figure 3.1-1, are scaled such that the integrated average LHGR is set equal to 1.0. The normalized profiles show variation in the ratio of the LHGR at each axial location to the assembly average LHGR along the entire length of active fuel. Thus, the maximum value on the normalized profile is the peaking factor. As shown in Figure 3.1-1, the representative PWR and BWR axial heat generation profiles have peaking factors of 1.095 and 1.22, respectively.

[8] DOE/RW-0495, *Depletion and Package Modeling Assumptions for Actinide-Only Burnup Credit*, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, May 1997.

[9] NFS:BND:95-083, Commonwealth Edison BWR Fuel Data, Letter from A. S. Pallotta of BWR Nuclear Design, Nuclear Fuel Services to A. G. Panagos, July 10, 1995.

The transportation cask thermal analyses are performed using two different design basis canister axial heat generation profiles, which are referred to as the "Max Thermal" (or Q_{max}) and "Max Thermal Gradient" (or $LHGR_{max}$) profiles. The transportation cask design basis canister axial heat generation profiles are shown in Figure 3.1-2. Figure 3.1-2 also shows the normalized axial heat generation profiles of various PWR and BWR fuel assembly classes to illustrate how the axial span of the design basis canister axial heat generation profiles bound those covered by the active fuel regions of the various PWR assembly classes. The design basis canister axial heat generation profiles are developed based on the PWR normalized heat generation profile shown in Figure 3.1-1. Use of the PWR normalized heat generation profile rather than the BWR profile maximizes the total heat generation since both profiles are limited to the same maximum LHGR, as discussed in Section 3.1.3.3, and the PWR profile is more uniform (i.e., has a lower peaking factor) than the BWR profile. Thus, the design basis Q_{max} profile will produce higher peak temperatures in the cask body than any BWR assembly meeting the same LHGR limit.

The Q_{max} profile is based on a total canister heat load of 22.0 kW, a maximum LHGR of 0.1606 kW/inch, and an active fuel length of 150 inches. However, this profile is "stretched" at the top end to a length of 160 inches to cover possible variations in the position of active fuel regions within the transport cask. In addition, the heat generation profile between the top end of the 160-inch active fuel region and the top end of the canister is maintained at 0.0296 kW/inch (i.e., 0.184 times the maximum LHGR.) This, along with the "stretching" of the modeled active fuel region, produces a total heat load that exceeds 22.0 kW and maximizes the temperatures of the cask closure seals that are located in the lid. These effects add to the inherent conservatism in the transportation cask thermal analyses.

The $LHGR_{max}$ profile has a total heat load of 17.5 kW and a maximum LHGR of 0.2106 kW/inch, and is based on an active fuel length of 91 inches, which is representative of the shortest PWR fuel length (e.g., Yankee Rowe PWR fuel) anticipated to be accommodated by the TS125 Transportation Cask. The magnitude of the $LHGR_{max}$ profile is set to produce temperatures within the transportation package that reach, but do not exceed, the material temperature limits for the controlling thermal condition. This profile was developed solely to examine the effects of minimum active fuel lengths, combined with maximum possible LHGR values, which produce the maximum axial and radial thermal gradients in the cask body that are considered in the TS125 Transportation Cask structural evaluation. The $LHGR_{max}$ profile does not form the basis of any thermal requirements for FuelSolutions™ canisters to be transported in the TS125 Transportation Cask, as discussed in Section 3.1.3.3.

3.1.3.2 Application of Axial Heat Generation Profiles for Cask Analysis

The transportation cask thermal model includes the canister shell assembly, including the shield plugs, as boundary conditions for the qualification thermal model. The cask thermal analysis models heat generation within the canister shell and lids, based upon one of the two design basis canister axial heat generation profiles shown in Figure 3.1-2. Based upon those profiles, the local heat load (Q_{Local}) at a specific axial location in the analytical models is determined as follows:

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

where:

Q_{Local}	=	Local canister heat at the nodal location
Q_{Total}	=	Total canister heat load (kW)
AFL	=	Active fuel length in inches for the associated axial profile (i.e., 150 inches for the Q_{max} and 91 inches for the $LHGR_{max}$ profiles)
N(z)	=	Normalized heat generation (kW/inch) at the center of the region being modeled
L	=	Axial length in inches of the region being modeled

The maximum heat generation magnitudes of the Q_{max} and $LHGR_{max}$ profiles were determined by increasing the magnitude of the heat generation profiles shown in Figure 3.1-2 (i.e., increasing Q_{Total}) until one or more of the cask component temperatures reach 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 thermal rating of the transportation cask. The corresponding maximum LHGR for each profile is equal to the average heat load (Q_{Total}/AFL) multiplied by the peaking factor (PF). The peaking factor is simply the maximum value of N(z) for the normalized heat generation profile. The maximum LHGR for the Q_{max} profile is the maximum allowable LHGR for the TS125 Transportation Cask. As discussed in Section 3.1.3.1, the $LHGR_{max}$ profile does not form the basis for either the total heat generation or LHGR limits for the TS125 Transportation Cask.

Note that the LHGR levels for the Q_{max} profile are based upon the total heat generation level being analyzed, divided by 150 inches, even though the actual Q_{max} profile is over 160 inches long, with additional heat being applied at the canister top end. Thus, due to the "axial stretching" of the heat generation profile (discussed in Section 3.1.3.1), the thermal analyses actually model more overall heat generation than the defined heat generation level that is being analyzed. This is done to conservatively account for variations in axial positions of actual assembly fuel zones (and heat generation profiles). Nevertheless, loaded canisters are still required to have overall heat generation levels equal to or less than the defined maximum total heat generation level that is analyzed (i.e., ≤ 22.0 kW).

3.1.3.3 Allowable Canister Axial Heat Generation Profiles

The maximum allowable transportation cask heat loads are determined independent of the allowable heat loads for the canisters. The derivation of allowable heat load for each FuelSolutions™ canister for transport in the TS125 Transportation Cask is provided in Chapter 3 of the respective FuelSolutions™ Canister Transportation SAR.

In order to assure that the design basis canister heat loads are not exceeded, the total heat load for any FuelSolutions™ canisters to be shipped in the TS125 Transportation Cask must not exceed 22.0 kW. In addition, the canister thermal evaluation must show that the peak temperature in the transportation cask's inner shell does not exceed that calculated for the TS125 Transportation Cask design basis Q_{max} thermal profile. A FuelSolutions™ canister with a design basis axial heat generation profile that is enveloped by the design basis Q_{max} profile used for the TS125 Transportation Cask thermal evaluation will always satisfy this criteria. Furthermore, a

FuelSolutions™ canister with a design basis axial heat generation profile that is less than 22.0 kW but is not enveloped by the transportation cask's Q_{max} thermal profile (e.g., the FuelSolutions™ W74 Canister) may satisfy this criteria because the local heat generated by the SNF assemblies tends to be spread axially as it is transferred outward radially through the canister to the cask inner shell.

As discussed in Section 3.1.3.2, the $LHGR_{max}$ profile analysis performed in this SAR yields the maximum possible thermal gradients that could occur without cask component temperature limits being exceeded. This is due to the fact that the overall heat load of the $LHGR_{max}$ profile that was analyzed was not limited such that its peak LHGR remained at or below that of the Q_{max} design basis profile. Instead, the heat load was increased further, until the cask component temperatures (above the peak section of the profile) reached their limits. Due to this conservative approach used in the transportation cask evaluation, there are no requirements related to the $LHGR_{max}$ profile analysis that must be met by loaded canisters.

3.1.4 Cask Component Temperature Summary

The maximum allowable material temperatures for the FuelSolutions™ TS125 Transportation Cask and impact limiters are presented in Section 3.3. The transportation cask and impact limiter temperatures under the various bounding thermal load conditions are presented in Sections 3.4 and 3.5 for NCT and HAC, respectively. These system temperatures are determined by applying either the maximum transportation cask thermal ratings presented in Table 3.1-3 or zero decay heat, depending on the applicable thermal load condition as defined in Table 3.1-1.

The figures and tables in Section 3.4 provide a comprehensive overview of the thermal performance of the transportation 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 the cask. The predicted peak cask shell temperature is 369°F, or 431°F below the established allowable temperature for the structural steel. The maximum predicted temperature of the lead material forming the gamma shield is 362°F, or 258°F below the established melting point for the lead. The bulk average temperature for the lead shield under the bounding NCT load condition is 322°F. The bulk average temperature of the solid neutron shield material is 249°F, or 51°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 cask component temperatures will remain within the 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 cask containment boundary will remain intact and that the lead will remain well below its established melting point. While the ends of the cask are predicted to reach peak temperatures in excess of 950°F (due to the conservative modeling assumption that the impact limiters provide no thermal shielding during the 30-minute fire), these temperatures occur only at the outer surface of the cask and remote from the location of the lead. The thermal mass presented by the cask lid/bottom, the support rings, and the upper and lower forgings are sufficient to absorb the fire imposed heat flux and still maintain the metal temperatures in the vicinity of the lead to a peak temperature of 457°F, well below the 620°F lead melt point. In actuality, the presence of the impact limiters will provide a significant thermal shield between the cask ends and the fire. As such, the peak temperatures at the cask ends are expected to be nearer to that seen for the center of the cask than to the levels predicted by this conservative modeling approach. Evaluation of the temperature distributions in the vicinity of the shear block shows that the thermal mass in this area of the cask is also sufficient to prevent lead melt temperatures from being reached during all portions of the HAC fire event.

3.1.5 Transportation Cask Internal Pressure Summary

Although the FuelSolutions™ canister shell is designed as a confinement boundary for storage conditions, the canister 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 gases, and canister backfill gas directly to the transportation cask cavity. The canister is backfilled with helium during closure operations. The quantity in moles of inert backfill gas needed for the FuelSolutions™ W21 and W74 canisters 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 canister thermal rating for storage within the FuelSolutions™ W150 Storage Cask) and with 1% rod failures.

The transportation cask cavity is conservatively assumed to be backfilled with a quantity of helium sufficient 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 transportation cask maximum internal pressure is dependent on the characteristics of the specific FuelSolutions™ canister and SNF payload contained within the cask. A 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. As such, the maximum normal operating pressure (MNOP) for the FuelSolutions™ TS125 cask with a generic canister is 75 psig. Conservative predictions of transportation cask internal pressure for NCT and HAC are provided in Sections 3.4 and 3.5 of the corresponding FuelSolutions™ Canister Transportation SARs. These calculations assume the rupture of 3% of the SNF and PWR control component rods under the NCT hot and NCT cold conditions, and 100% of the SNF and PWR control component rods under HAC conditions.[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. A canister will not be qualified for transport within the FuelSolutions™ TS125 Transportation Cask unless the maximum MNOP of the cask/canister combination is demonstrated to be less than 75 psig.

[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, DC 20555-0001, March 2000.

Table 3.1-1 - Transportation Package Design Basis Thermal Load Conditions

Case	Description	Applicable Conditions				
		Ambient Temperature (°F)	Insolation		Decay Heat	
			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 load conditions are evaluated without decay heat to establish minimum material temperatures for material compatibility and brittle fracture considerations.

(5) NCT Cold Environment condition 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 - Insolation Data per 10CFR71.71(c)(1)

Form and Location of Surface	Total Insolation for a 12-hour Period (g cal/cm^2)[(1)]
Flat surfaces transported horizontally; base surface	None
Flat surfaces transported horizontally; all other surfaces	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

Notes:

(1) The 12-hour period covers the daylight hours. Insolation for the remaining 12 hours (nights) is zero. The 12-hour insolation values are averaged over a 24-hour period for use in the steady-state modeling due to the large thermal mass of the transportation package.

Table 3.1-3 - TS125 Transportation Cask Thermal Evaluation Axial Heat Generation Profile Parameters

Design Basis Profile	Total Canister Heat Load (kW)	Maximum LHGR (kW/in)
Max Thermal (Q_{max})	22.0	0.1606
Max Thermal Gradient ($LHGR_{max}$)	17.5	0.2106

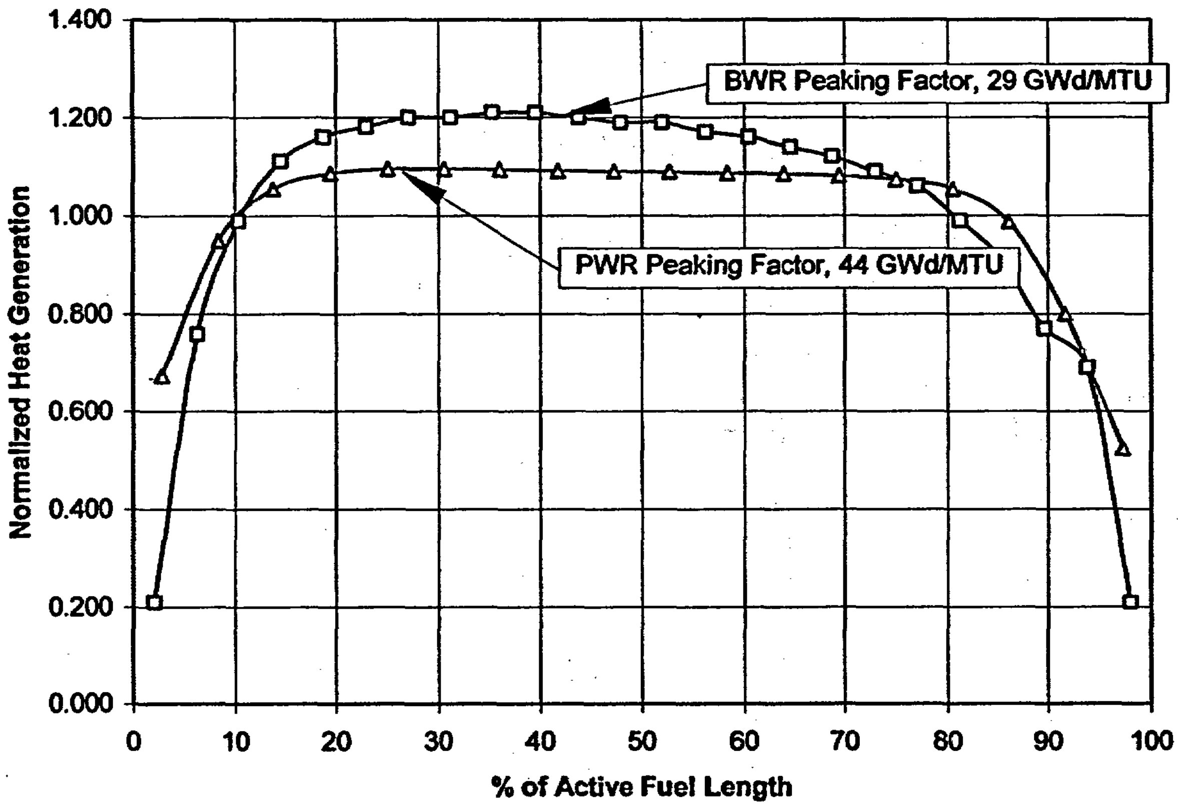


Figure 3.1-1 - Design Basis Axial Peaking Factors for PWR and BWR Fuels

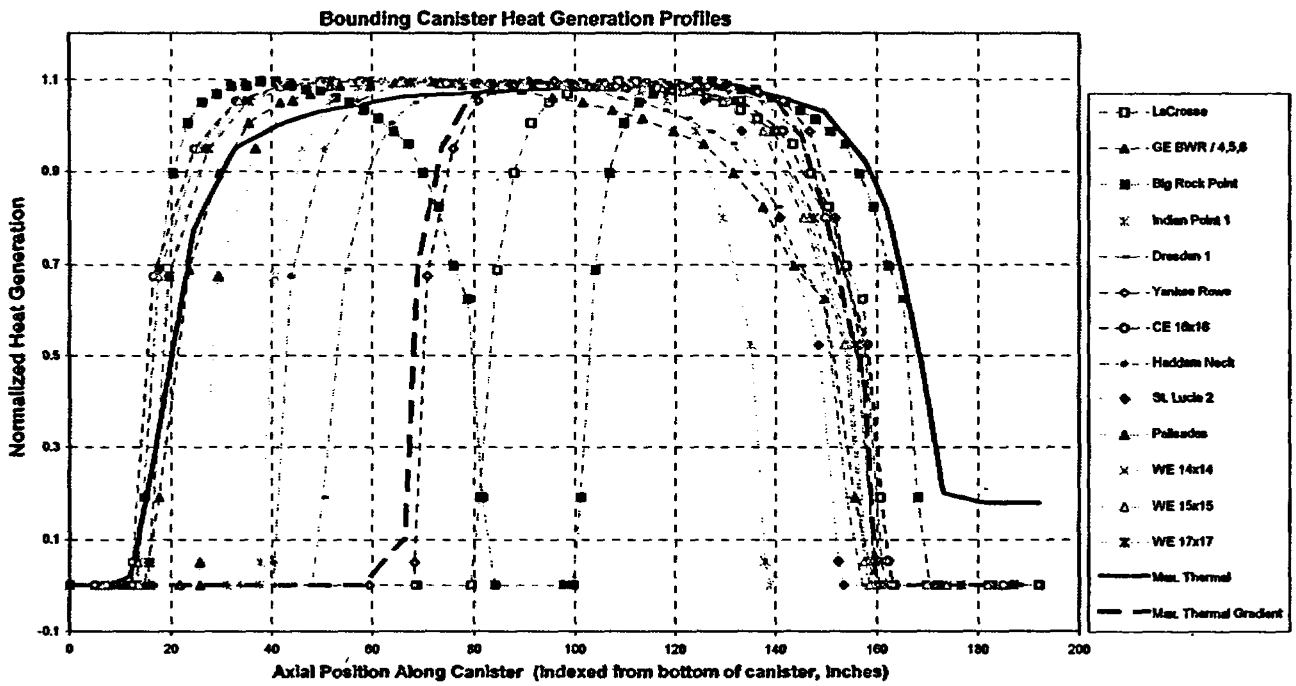


Figure 3.1-2 - Design Basis Canister Axial Heat Generation Profiles