6.5.2 PWR Fuel Qualification

Chapter 6 presents the shielding analysis for design basis fuel. For the EOS-37PTH DSC, HLZC 4 results in bounding dose rates. HLZC 4 features 1.6 kW fuel in the peripheral region. HLZC 5 has a mixture of 2.4 kW and 0.85 kW fuel in the peripheral region, and HLZC 5 dose rates are similar to HLZC 4. HLZC 7 and HLZC 9 have similar peripheral heat loads compared to HLZC 4 and HLZC 5, respectively. HLZC 1, 2, 3, 6, or 8 do not result in bounding dose rates.

To provide an additional constraint on dose rates, a relationship between decay heat, burnup, enrichment, cooling time, and source terms is developed for 2.4 kW and 1.6 kW fuel and provided as fuel qualification tables (FQTs). The methodology to develop these FQTs is the same as used to develop the design basis source terms.

The purpose of the FQTs is solely to provide an additional dose rate constraint. Decay heat for each fuel assembly to be loaded is determined using NRC Regulatory Guide 3.54, ORIGEN-ARP, or other acceptable method.

The FQT developed based on 2.4 kW is a global constraint and is applied to every PWR fuel assembly to be loaded. This FQT is provided as TS Table 7b. The 1.6 kW FQT is applicable only to fuel located in the peripheral regions of HLZC 4 and 7 and is provided in Table 6-62. The peripheral basket region is defined in Figure 6-1.

A range of burnup, enrichment, and cooling time combinations are considered for the inner regions of HLZC 4 and 5, as documented in Table 6-8. The design basis source terms in the inner regions of HLZC 4 and 5 are optimized to maximize dose rates. However, dose rates, both transfer cask and storage, are dominated by thermally hot fuel in the peripheral region because inner locations are heavily self-shielded by peripheral fuel assemblies. Because the inner basket locations do not contribute appreciably to the total dose rate, an FQT constraint on the inner basket locations is not imposed.

The burnup in the FQTs is expressed in units of GWd/FA rather than GWd/MTU. The burnup in GWd/FA is the burnup in GWd/MTU multiplied by the MTU of the fuel assembly. The minimum cooling times are obtained from these tables using linear interpolation.

As documented in Section 6.2.8, a small percentage (<0.5%) of fuel assemblies are low-enrichment outlier fuel (LEOF). LEOF is rare, occurring at a rate of approximately 1 per 200 fuel assemblies. To determine if a fuel assembly is LEOF, the enrichment is compared to the minimum value specified in TS Table 7a. LEOF would not affect storage dose rates, which are gamma dominated, but could have a small effect (< 5%) on transfer cask dose rates. Based on these considerations, only 4 LEOFs are allowed in the peripheral region, a maximum of one per quadrant. Additional LEOF shall be stored in the inner locations only.

Because LEOF, by definition, is below the minimum enrichments provided in the FQTs, minimum cooling times for LEOF may be obtained by extrapolating the FQT cooling times using an appropriate method. Because minimum cooling times increase with lower enrichments, this extraplolation provides an additional cooling time penalty.

The overall method for application of these FQTs and qualification of LEOF is provided below.

1. Determine the decay heat of all fuel to be loaded in an EOS-37PTH DSC. Confirm the decay heat limit is met for each basket location.

2. Determine if LEOF is present in the fuel to be loaded by application of TS Table 7a.

    a. Up to 4 LEOF are allowed in the peripheral region, one per quadrant.

    b. Additional LEOF shall be placed in the inner basket locations only.

3. Verify all fuel to be loaded meets the cooling time limitations of TS Table 7b. Fuel that does not meet the cooling time limitations of this table cannot be loaded.

4. For fuel in the peripheral regions of HLZC 4 or 7, minimum cooling times are provided in Table 6-62. This table does not apply to HLZC 1, 2, 3, 5, 6, 8, or 9, or to the inner basket locations of HLZC 4 or 7.

These FQTs provide an additional constraint to ensure compliance with the dose rate limitations in TS 5.1.2(c).

<u>Examples</u>

Examples to illustrate application of TS Table 7a, TS Table 7b, and Table 6-62 are provided below.

<u>Example 1 (no LEOF)</u>

A fuel assembly has a burnup of 50 GWd/MTU, 0.45 MTU, enrichment of 3.5%, and a cooling time of 4 years. Assume the decay heat has been computed and shown to be acceptable for the basket location of interest. Is this fuel assembly LEOF? Does this fuel assembly meet TS Table 7b requirements?

- The minimum enrichment for 50 GWd/MTU, per TS Table 7a, is 50/16 = 3.125%, which is rounded down to 3.1%. As E = 3.5% > 3.1%, this fuel assembly is within the minimum enrichment bounds of TS Table 7a and is not LEOF.
- Burnup in GWd/FA is (50 GWd/MTU)(0.45 MTU) = 22.5 GWd/FA

- Linearly interpolate on enrichment (first) and burnup (second) to determine the minimum cooling time
- Linearly interpolating for E = 3.5% in the 22.14 GWd/FA row of TS Table 7b, CT = 2.95 years
- Linearly interpolating for E = 3.5% in the 24.6 GWd/FA row of TS Table 7b, CT = 3.29 years
- Linearly interpolating for BU = 22.5 GWd/FA between CT = 2.95 years and CT = 3.29 years, the minimum cooling time is CT = 3.00 years.

Because 4 years > 3.00 years, the fuel assembly meets the TS Table 7b requirements.

Example 2 (with LEOF)

A fuel assembly has a burnup of 50 GWd/MTU, 0.45 MTU, enrichment of 2.9%, and a cooling time of 4 years. Assume the decay heat has been computed and shown to be acceptable for the basket location of interest. Is this fuel assembly LEOF? Does this fuel assembly meet TS Table 7b requirements?

- The minimum enrichment for 50 GWd/MTU, per TS Table 7a, is 50/16 = 3.125%, which is rounded down to 3.1%. As E = 2.9% < 3.1%, this fuel assembly is LEOF. It is the only LEOF to be loaded in this DSC.
- Burnup in GWd/FA is (50 GWd/MTU)(0.45 MTU) = 22.5 GWd/FA
- Linearly interpolate or extrapolate on enrichment (first) and burnup (second) to determine the minimum cooling time. Because the fuel is LEOF, extrapolation on the enrichment value beyond TS Table 7b is acceptable. Extrapolating to a lower enrichment value increases the minimum cooling time, which is a conservative penalty.
- Linearly interpolating for E = 2.9% in the 22.14 GWd/FA row of TS Table 7b, CT = 3.05 years
- Linearly extrapolating for E = 2.9% in the 24.6 GWd/FA row of TS Table 7b for the two nearest enrichments, CT = 3.41 years. Other extrapolation methods could be employed, although the data in this row is following a linear trend.
- Linearly interpolating for BU = 22.5 GWd/FA between CT = 3.05 years and CT = 3.41 years, the minimum cooling time is CT = 3.10 years.

Because 4 years > 3.10 years, the fuel assembly meets the TS Table 7b requirements. Because it is the only LEOF assembly in the DSC, it may be stored in any location.

Example 3 (HLZC 1)

A 2.0 kW fuel assembly will be loaded in HLZC 1 in zone 2 (inner basket location). Assume the decay heat has been computed and shown to be acceptable for this basket location. Does Table 6-62 apply?

No, Table 6-62 applies only to the peripheral region of HLZC 4 or 7.

Example 4 (HLZC 4 inner)

A 1.625 kW fuel assembly will be loaded in HLZC 4 in zone 2 (inner basket location). Assume the decay heat has been computed and shown to be acceptable for this basket location. Does Table 6-62 apply?

No, Table 6-62 applies only to the peripheral region of HLZC 4 or 7.

Example 5 (HLZC 4 peripheral)

The fuel assembly in Example 1 has a burnup of 50 GWd/MTU, 0.45 MTU, enrichment of 3.5%, and a cooling time of 4 years. It is to be loaded in HLZC 4 zone 3 (peripheral region). Assume the decay heat has been computed and shown to be acceptable for the basket location of interest. Does this fuel assembly meet Table 6-62 requirements?

It is known this fuel assembly is not LEOF and meets the TS Table 7b per Example 1. However, Table 6-62 applies because fuel is loaded in the peripheral region of HLZC 4.

- Burnup in GWd/FA is (50 GWd/MTU)(0.45 MTU) = 22.5 GWd/FA
- Linearly interpolate on enrichment (first) and burnup (second) to determine the minimum cooling time
- Linearly interpolating for E = 3.5% for the 22.14 GWd/FA row of Table 6-62, CT = 4.19 years
- Linearly interpolating for E = 3.5% for the 24.6 GWd/FA row of Table 6-62, CT = 4.80 years
- Linearly interpolating for BU = 22.5 GWd/FA between CT = 4.19 years and CT = 4.80 years, the minimum cooling time is CT = 4.28 years.

Because 4 years < 4.28 years, the fuel assembly cannot be loaded unless an evaluation is performed to demonstrate that TS 5.1.2(c) dose rate limits are met. Because the decay heat is known and shown to be below 1.6 kW, there is a high likelihood that acceptable dose rates could be demonstrated when site-specific fuel and irradiation parameters are incorporated.

Table 6-62
Fuel Qualification Table for the EOS-37PTH DSC, HLZC 4 and 7, Peripheral Region

(Minimum required years of cooling time after reactor core discharge)

Burnup (GWd/FA)	Fuel Assembly Average Initial U-235 Enrichment (wt.%)												
	0.7	1.3	1.8	2.0	2.5	2.8	3.1	3.4	3.7	3.8	4.0	4.5	5.0
2.95	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
4.92		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
9.84			2.27	2.24	2.18	2.16	2.13	2.11	2.09	2.08	2.07	2.05	2.02
14.76			3.11	3.07	2.99	2.94	2.90	2.87	2.84	2.83	2.81	2.76	2.73
19.68					3.89	3.82	3.76	3.70	3.65	3.64	3.61	3.54	3.48
22.14						4.36	4.28	4.21	4.15	4.13	4.09	4.00	3.93
24.60			LEOF Region				4.93	4.83	4.75	4.72	4.67	4.55	4.45
27.06								5.62	5.50	5.46	5.40	5.24	5.10
29.52									6.50	6.44	6.35	6.12	5.93
30.50										6.92	6.81	6.55	6.33

Notes: (1) The burnup in GWd/FA is the assembly average burnup in GWd/MTU multiplied by the MTU of the fuel assembly.

(2) Linear interpolation is allowed to obtain a cooling time between burnup and enrichment values.

(3) Extrapolation is allowed to obtain a cooling time for LOW-ENRICHED OUTLIER FUEL.

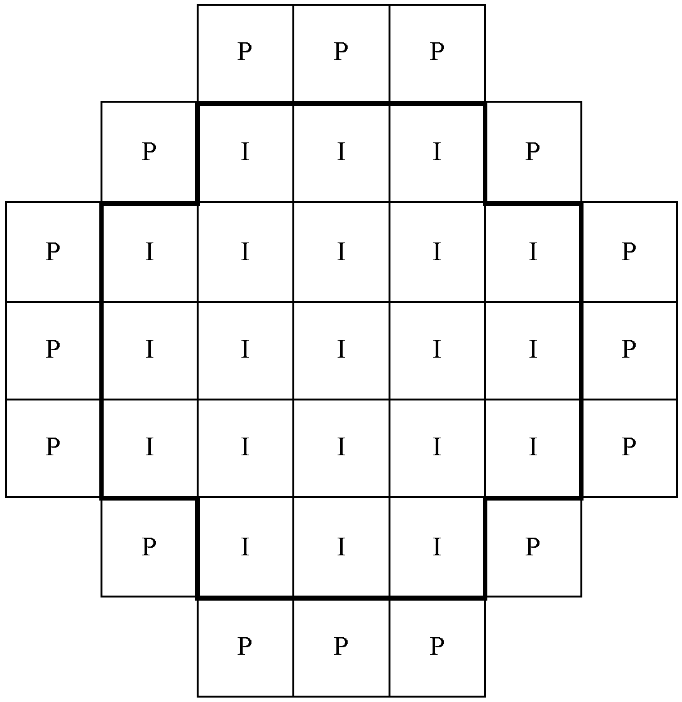

Figure 6-1
Peripheral and Inner Fuel Locations for the EOS-37PTH DSC