ENCLOSURE 2

M190035

GE2000 SAR Amendment Meeting Presentation

Non-Proprietary Information

IMPORTANT NOTICE

This is a non-proprietary version of Enclosure 1 to M190035, which has the proprietary information removed. Portions of the document that have been removed are indicated by an open and closed bracket as shown here [[ ]].

NRC Meeting – Chapter 5 and 7 Technical Approach for the GE Model No. 2000 Safety Analysis Report Amendment to Support Accident Tolerant Fuel

March 11, 2019

Non-Proprietary Information

Meeting Agenda

Non-Proprietary Discussion

- Introductions
- Purpose

Proprietary Discussion

- Chapter 5 Technical Walkthrough for Amending the GE2000 Safety Analysis Report (SAR) to Support Post Irradiated Examination (PIE) of Accident Tolerant Fuel (ATF) Rods
- Application of Chapter 5 as it Relates to Proving Dose Rate and Thermal Limits are Met
  - Examples for Filling Out Chapter 7 Loading Tables (pre-shipment evaluation)
- Clarification of Chapter 3 Amendment.

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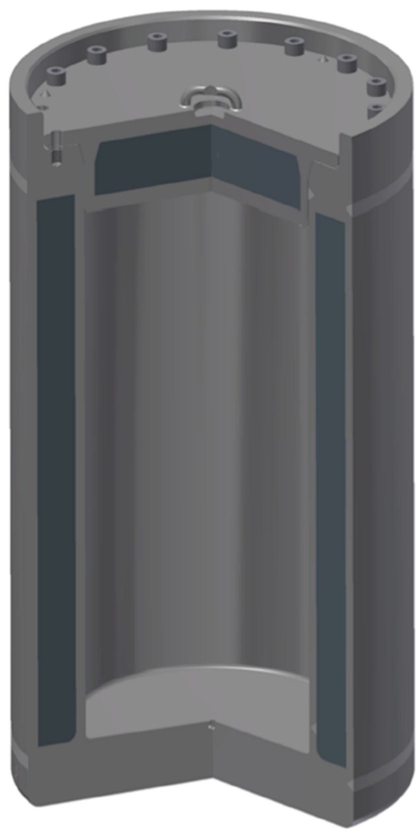
Purpose

- Review the technical approach for amending the GE2000 SAR shielding evaluation and the process for calculating the total dose rate and thermal contribution to support the ATF program.



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End of Public Session

Chapter 5 Amendment Overview

- Amended to include a shielding analysis for irradiated fuel rods.
- No amendment to the dose rate and thermal limits currently imposed in Chapter 5.
    - Dose rates are limited to 90% of the 10 CFR 71.47 and 10 CFR 71.51 regulatory limits.
    - Decay heat thermal limit is 1500 W.
- The method to calculate the dose rate and thermal response for irradiated fuel rods is consistent with the method for Cobalt-60 rods and irradiated hardware in NEDO-33866 Rev. 3 [ML18058A112].
- Fuel rod cladding is treated as irradiated hardware (point source) as stated in NEDO-33866 Rev. 3 Section 5.4.4.3.

Gamma Source Term to Dose Rate – Overview

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  - Five (5) Normal Conditions of Transport (NCT) Locations
  - Three (3) Hypothetical Accident Condition (HAC) Locations
  - [[ ]]
- The MCNP6 calculated dose response is independent of gamma intensity.
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Irradiated Fuel Rod Analysis Parameters

Analysis Parameters for Irradiated Fuel Rods

Parameter	Value
Minimum Cooling Time (days)[a]	120
Maximum Exposure/Burn-up (GWd/MTU)[a,b]	72
U-235 Enrichment Range (wt.%)[b]	1.5 – 6.0
Specific Power (MWth)[a]	40
BWR Moderator Density (g/cm^3)[a,b]	0.1
Maximum Burnable Poison Concentration (wt.% Gadolinium-Oxide)[a]	≤ 10

a) Most conservative value from NUREG/CR-6716 [ML010820352].
b) Maximum validation of ORIGEN-ARP 10x10 BWR cross-section library [ORNL/TM-2005/39, Version 6.1].

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Irradiated Fuel Rod ORIGEN-ARP Gamma Intensity

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Gamma Source Term to Dose Rate - Example

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Gamma Source Term to Dose Rate - Example

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Gamma Source Term to Dose Rate – Roll-up

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- Dose rate is calculated for each irradiated fuel rod in the shipment.
- Total shipment dose rate is confirmed using the irradiated fuel rod loading tables in Chapter 7.

External Dose Rate Locations

NCT					HAC		
Top Surface	Side Surface	Bottom Surface	2-meter	Cab	Top 1-meter	Side 1-meter	Bottom 1-meter

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Hand Calculation of Neutron Dose Rate

- The process for determining the dose rate contribution from neutrons (mrem/hr per g U) is identical to that for gammas except that MCNP6 is not required.
- In the absence of shielding, the dose rate for a point and line source can be calculated by hand.

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Hand Calculation of Neutron Dose Rate

- Ignoring the shielding materials is conservative; therefore, hand equations can be used to calculate the neutron point and line source intensities at the external locations.
- Use the ANSI/ANS-6.1.1-1977 neutron flux-to-dose rate conversion factors.

Point Source

$$\phi(r) = \frac{S}{4\pi r^2}$$

Variable	Description	Unit
$\phi(r)$	Flux at radius *r* from the point source *S*	n/sec/cm^2
S	Source strength	n/sec
r	Radius (distance) from the point source *S*	cm

From Lamarsh and Baratta, *Introduction to Nuclear Engineering*, Third Edition.

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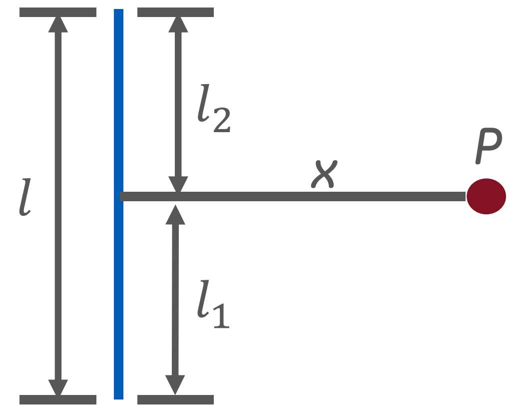
Hand Calculation of Neutron Dose Rate

Line Source

$$\phi(P) = \frac{S'}{4\pi x}\left[\tan^{-1}\frac{l_2}{x} + \tan^{-1}\frac{l_1}{x}\right]$$

$$l = l_2 + l_1$$



Variable	Description	Unit
$\phi(P)$	Flux at point *P*	n/sec/cm^2
S'	Line source strength	n/sec/cm
x	Perpendicular distance from the point *P* to the line source	cm
l_1 and l_2	The length of the line source on either side of the perpendicular distance *x* intersection	cm

From Lamarsh and Baratta, *Introduction to Nuclear Engineering*, Third Edition.

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Hand Calculation of Neutron Dose Rate

- For additional conservativism, a sub-critical multiplication factor is applied to the neutron source intensity.
- Assume a k-effective value of 0.95.

$$mulipplication\ factor = \frac{1}{1-k_{eff}} = \frac{1}{1-0.95} = 20$$

Example Comparison of MCNP6 and Hand Calculation of the Neutron Dose Rate

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The hand calculated neutron dose rate bounds the MCNP6 model.

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Chapter 7 Loading Tables – Implementation of Chapter 5 Analyses into the Required Pre-Shipment Evaluations

Chapter 7 Irradiated Hardware Loading Table

- The loading tables shall be confirmed prior to any shipment of an approved content.
  - Required per Section 5.(b)(2)(i) in the Certificate of Compliance [ML18102B446].
- The process is described in NEDO-33866 Rev. 3 Section 7.5.1.
- Examples are provided in NEDO-33866 Rev. 3 Section 5.5.4.

Column

Row	1	2	3	4	5	6	7	8	9	10	11
	Radionuclide	Activity (Ci)	Thermal Power (W)	NCT (mrem/hr)					HAC (mrem/hr)		
				DR_{surf}			DR_{2m}	DR_{cab}	DR_{1m}		
				Top	Side	Bottom			Top	Side	Bottom
A	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
		⋮				⋮			⋮		
B	Total	-	B3	B4	B5	B6	B7	B8	B9	B10	B11
C	Limit	-	C3	180	180	180	9	1.8	900	900	900
D	Criteria Met?	-	D3	D4	D5	D6	D7	D8	D9	D10	D11
E					Filled out by:	E1					

Figure 7.5.1-1 Irradiated Hardware and Byproduct Loading Table

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Chapter 7 Irradiated Hardware Loading Table – Hafnium (Hf) Poison Rod Example – Steps 1 – 4

Figure 7.5.1-1

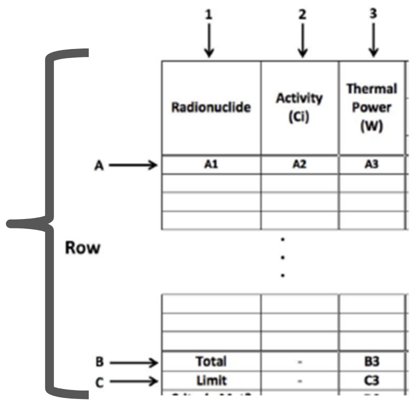

Table 5.5-27

Radionuclide	% Activity	Total Activity (Ci)
Hf-175	4.21%	10,650
Hf-181	90.09%	228,000
Ta-182	5.70%	14,422
Total	100.00%	253,072

1. Enter the thermal limit of 1500 W for the shipment in Cell C3.
2. Starting in Cell A1 enter the first radionuclide into the loading table.
3. In Cell A2 enter the activity in curies of the respective radionuclide.
4. In Cell A3 enter the thermal power for each radionuclide in W.
   a) The thermal power is calculated by multiplying the activity of the radionuclide in Cell A2 by the thermal power conversion factor from Table 5.5-24.

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Chapter 7 Irradiated Hardware Loading Table – Hf Poison Rod Example - Steps 1 – 4

Activity From Table 5.5-27

Thermal Power Conversion Factors From Table 5.5-24

Radionuclide	Total Activity (Ci)	Decay Heat (W/Ci)
Hf-175	10,650	2.355E-03
Hf-181	228,000	4.328E-03
Ta-182	14,422	8.985E-03

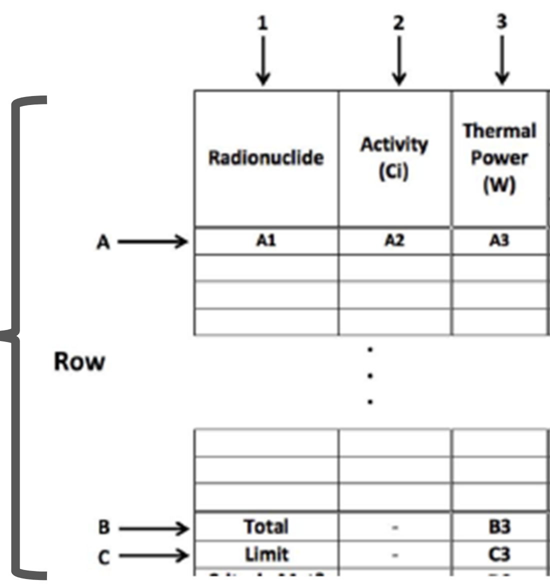

Figure 7.5.1-1

Radionuclide	Activity (Ci)	Decay Heat (W)
Hf-175	10,650	25.1
Hf-181	228,000	986.8
Ta-182	14,422	129.6
Total	-	1141.5
Limit	-	1500

Table 5.5-30

Chapter 7 Irradiated Hardware Loading Table – Hf Poison Rod Example – Steps 5 – 7

Figure 7.5.1-1

Thermal Power (W)	NCT (mrem/hr)					HAC (mrem/hr)		
	DR_{surf}			DR_{2m}	DR_{cab}	DR_{1m}		
	Top	Side	Bottom			Top	Side	Bottom
A3	A4	A5	A6	A7	A8	A9	A10	A11
			⋮			⋮		
B3	B4	B5	B6	B7	B8	B9	B10	B11

5. In Cells A4 through A11, enter the dose rate contribution for the respective radionuclide for the appropriate dose rate location.
   a) The dose rate is calculated by multiplying the activity of the radionuclide by the dose rate conversion factor for the respective dose rate location.
   b) NCT and HAC dose rates are provided in Table 5.4-2 and Table 5.4-3, respectively.
6. Repeat Steps 2 through 5 for each radionuclide in the shipment.
7. In Cell B3 sum the total thermal contribution from all radionuclides in Column 3.

Chapter 7 Irradiated Hardware Loading Table – Hf Poison Rod Example - Steps 5 – 7

Dose Rate Conversion Factors

Radionuclide	Dose Rate (mrem/hr/Ci)							
	Top Surface	Side Surface	Bottom Surface	2-meter	Cab	Top 1-meter	Side 1-meter	Bottom 1-meter
Hf-175	1.642E-13	1.917E-15	3.513E-16	1.167E-17	1.891E-18	1.676E-12	4.820E-16	7.744E-16
Hf-181	1.968E-11	2.116E-11	3.427E-12	2.749E-13	4.721E-14	1.493E-10	6.868E-12	5.073E-12
Ta-182	1.343E-04	3.273E-03	1.997E-04	4.080E-05	6.989E-06	1.976E-04	6.138E-04	1.176E-04

NCT From Table 5.4-2

HAC From Table 5.4-3

Radionuclide	Total Activity (Ci)
Hf-175	10,650
Hf-181	228,000
Ta-182	14,422
Total	253,072

Table 5.5-30

Radionuclide	Activity (Ci)	Decay Heat (W)	NCT (mrem/hr)					HAC (mrem/hr)		
			DR_{surf}			DR_{2m}	DR_{cab}	DR_{1m}		
			Top	Side	Bottom			Top	Side	Bottom
Hf-175	10,650	25.1	1.75E-09	2.04E-11	3.74E-12	1.24E-13	2.01E-14	1.78E-08	5.13E-12	8.25E-12
Hf-181	228,000	986.8	4.49E-06	4.82E-06	7.81E-07	6.27E-08	1.08E-08	3.40E-05	1.57E-06	1.16E-06
Ta-182	14,422	129.6	1.94E+00	4.72E+01	2.88E+00	5.90E-01	1.01E-01	2.85E+00	8.85E+00	1.70E+00
Total	-	1141.5	1.94	47.20	2.88	0.59	0.10	2.85	8.85	1.70

Chapter 7 Irradiated Hardware Loading Table – Hf Poison Rod Example – Steps 8 – 11

Figure 7.5.1-1

Total	-	B3	B4	B5	B6	B7	B8	B9	B10	B11
Limit	-	C3	180	180	180	9	1.8	900	900	900
Criteria Met?	-	D3	D4	D5	D6	D7	D8	D9	D10	D11

E ⟶ Filled out by: E1

Table 5.5-30

Radionuclide	Activity (Ci)	Decay Heat (W)	NCT (mrem/hr)					HAC (mrem/hr)		
			DR_{surf}			DR_{2m}	DR_{cab}	DR_{1m}		
			Top	Side	Bottom			Top	Side	Bottom
Hf-175	10,650	25.1	1.75E-09	2.04E-11	3.74E-12	1.24E-13	2.01E-14	1.78E-08	5.13E-12	8.25E-12
Hf-181	228,000	986.8	4.49E-06	4.82E-06	7.81E-07	6.27E-08	1.08E-08	3.40E-05	1.57E-06	1.16E-06
Ta-182	14,422	129.6	1.94E+00	4.72E+01	2.88E+00	5.90E-01	1.01E-01	2.85E+00	8.85E+00	1.70E+00
Total	-	1141.5	1.94	47.20	2.88	0.59	0.10	2.85	8.85	1.70
Limit	-	1500	180	180	180	9	1.8	900	900	900
Criteria Met?	-	YES	YES	YES	YES	YES	YES	YES	YES	YES

8. Cells B4 – B11 sum the dose rate contribution from all radionuclides in the column.
9. Cell D3 – D11, if the respective value in Row B is less than or equal to the value in Row C (dose rate limit), then enter "Yes."
10. If all cells in Row D say "Yes," then the irradiated contents meet all thermal and dose rate criteria.
11. Enter the name of the person filling out the Irradiated Hardware and Byproduct Table in Cell E1.

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Chapter 7 Irradiated Fuel Rods Loading Table

- The loading tables shall be confirmed prior to any shipment of a specified content.
- Similar process as described in NEDO-33866 Rev. 0 Section 7.5.1 for irradiated fuel [ML16126A499].
- Key differences between irradiated fuel rod loading table and irradiated hardware:
  - Confirming uranium mass.
  - The thermal and dose rate responses are based on a given exposure and enrichment.
- Accounting for irradiated fuel rod cladding uses the exact same method as irradiated hardware in NEDO-33866 Rev. 3 Section 7.5.1.
  - Incorporated in a combined content table as described in NEDO-33866 Rev. 0 Section 7.5.4.
- Examples will be provided in the Amendment to NEDO-33866 Rev. 3.

Chapter 7 Irradiated Fuel Rod Loading Table – NEDO-33866 Rev. 0 Example – Steps 1 – 3

NEDO-33866 Rev. 0 Figure 7.5.1-1

Column

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Segment #	Segment Length (inches)	Initial Enrichment (wt% U235)	Burunup (GWd/MTU)	Uranium Mass (g)	Thermal Power (W)	NCT (mrem/hr)					HAC (mrem/hr)		
							DR_{surf}			DR_{2m}	DR_{cab}	DR_{1m}		
							Top	Side	Bottom			Top	Side	Bottom
A	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
			⋮					⋮				⋮		
B	Minimum	B2		Total	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
C	Limit	7.75		Limit		C6	180	180	180	9	1.8	900	900	900
D	Meets Criteria?	D2		Meets Criteria?	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14
E								Filled out by:				E1		

1. Enter the thermal limit of 1500 W for the shipment in Cell C6.
2. Enter the fuel rod segment number in Cell A1.
3. Enter the active fuel height in Cell A2 (must be greater than 7.75 inches).

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Chapter 7 Irradiated Fuel Rod Loading Table – NEDO-33866 Rev. 0 Example – Steps 4 – 7

NEDO-33866 Rev. 0 Figure 7.5.1-1

Column

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Segment #	Segment Length (inches)	Initial Enrichment (wt% U235)	Burunup (GWd/MTU)	Uranium Mass (g)	Thermal Power (W)	NCT (mrem/hr)					HAC (mrem/hr)		
							DR_{surf}			DR_{2m}	DR_{cab}	DR_{1m}		
							Top	Side	Bottom			Top	Side	Bottom
A →	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14

4. Enter the initial fuel rod U-235 enrichment range in Cell A3.
5. Enter the fuel rod exposure range in Cell A4.
6. Enter the initial mass of uranium (g) in Cell A5.
7. Enter the thermal power in Cell A6.
   - A. Multiply the uranium mass in Cell A5 by the corresponding thermal power value.
   - B. Thermal power conversion factors will be provided in summary tables for a given U-235 enrichment and exposure.

Chapter 7 Irradiated Fuel Rod Loading Table – NEDO-33866 Rev. 0 Example – Steps 8 – 9

NEDO-33866 Rev. 0 Figure 7.5.1-1

Column

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Segment #	Segment Length (inches)	Initial Enrichment (wt% U235)	Burunup (GWd/MTU)	Uranium Mass (g)	Thermal Power (W)	NCT (mrem/hr)					HAC (mrem/hr)		
							DR_{surf}			DR_{2m}	DR_{cab}	DR_{1m}		
							Top	Side	Bottom			Top	Side	Bottom
A	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14

8. In Cells A7 through A14 enter the dose rate contribution.
   - A. Multiply the uranium mass in Cell A5 by the corresponding external dose rate.
   - B. External dose rate conversion factors are provided in summary tables for a given U-235 enrichment and exposure.
9. Repeat Steps 2 through 8 for all irradiated fuel rods within the shipment.

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Chapter 7 Irradiated Fuel Rod Loading Table – NEDO-33866 Rev. 0 Example – Steps 10 – 15

NEDO-33866 Rev. 0 Figure 7.5.1-1

B →	Minimum	B2		Total	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
C →	Limit	7.75		Limit		C6	180	180	180	9	1.8	900	900	900
D →	Meets Criteria?	D2		Meets Criteria?	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14
						E →	Filled out by:					E1		

10. Enter the minimum active fuel height in Cell B2.
11. Sum the total uranium mass in Cell B5.
12. Sum the total thermal power in Cell B6.
13. For Cells B7 – B14, sum the dose rate contributions.
14. Row D, confirm that the criteria established in Row C is not exceeded by the shipment values listed in Row B.
15. Enter the name of the person filling out the Irradiated Fuel Rod Table in Cell E1

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Clarification Information from February 5, 2019 Meeting with the NRC [ML19025A013]

Chapter 3 Amendment

- Amended for completeness.
- The term "irradiated fuel rod" will be added to NEDO-33866 Rev. 3 Section 3.1.2.
  - *"The derivations of the decay heats for the different contents of the Model 2000 Transport Package are presented in Chapter 5. The decay heat for irradiated hardware and by-product, ~~and~~ cobalt-60 isotope rod, and irradiated fuel rod contents is determined using watt-per-Curie conversion factors listed in Section 5.5.4 and the radionuclide inventory of the contents."*
- No amendment to the thermal limit.
- No amendment to the thermal analysis.

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Justification for Not Crediting Fuel Rod Cladding

- Conservatively treated as a point source for shielding.
- The optimal Hydrogen-to-Uranium (H/U) criticality studies using fuel columns bound credible NCT and HAC.
  - The GE2000 is only flooded during loading and unloading operations.
  - The containment analysis in NEDO-33866 Rev. 3 Chapter 4 demonstrates that water ingress is not possible during accident conditions (maintains Type-B helium leak rate).
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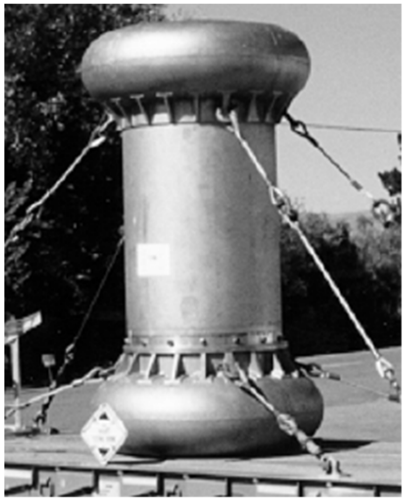
- Optimal pitch and pellet diameter criticality evaluations conservatively assess fuel relocation.
- No credit for fuel depletion or absorbers.

Summary

- Shielding evaluation for irradiated fuel rods provides for a wide range of application flexibility.
  - Reduces the total number of MCNP6 shielding calculations.
- Current assumptions for not crediting fuel cladding are adequately justified.
- Chapter 3 Amendment is for completeness purposes only.



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