JUN 30 1999

STA# 4 4

ENGINEERING DATA TRANSMITTAL

Page 1 of 1

1. EDT

627104

2. To: (Receiving Organization) Distribution		3. From: (Originating Organization) Process Engineering		4. Related EDT No.: N/A	
5. Proj./Prog./Dept./Div.: Spent Nuclear Fuel Project		6. Design Authority/ Design Agent/Cog. Engr.: A.N. Praga		7. Purchase Order No.: N/A	
8. Originator Remarks: For Release				9. Equip./Component No.: N/A	
				10. System/Bldg./Facility: N/A	
11. Receiver Remarks: 11A. Design Baseline Document? ☐ Yes ☒ No				12. Major Assm. Dwg. No.: N/A	
				13. Permit/Permit Application No.: N/A	
				14. Required Response Date:	
15. DATA TRANSMITTED					
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Approval Designator
1	HNF-4465		0	Estimates of Particulate Mass for an MCO Containing Mark 1A Fuel	S ^N , Q
16. KEY					
Approval Designator (F)		Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)		1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)		1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged	
17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)					
(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN
		Design Authority			
		Design Agent			
1	1	Cog.Eng. A.N. Praga	<i>A.N. Praga</i>	6-10-99	
1	1	Cog. Mgr. J.R. Frederickson	<i>J.R. Frederickson</i>	6/30/99	
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18.		19.		20.	
H.A. Wyman <i>H.A. Wyman</i> 6/10/99 Signature of EDT Date Originator		J.R. Frederickson <i>J.R. Frederickson</i> 6/30/99 Authorized Representative Date for Receiving Organization		J.R. Frederickson <i>J.R. Frederickson</i> 6/30/99 Design Authority/ Cognizant Manager Date	
21. DOE APPROVAL (if required) Ctrl. No. ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments					

BD-7400-172-2 (05/96) GEF097

BD-7400-172-1

Estimates of Particulate Mass for an MCO Containing Mark 1A Fuel

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U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: 627104

UC: 510

Org Code: 2T350

Charge Code: LB051

B&R Code: EW7040000

Total Pages: 16

Key Words: Multi-Canister Overpack, MCO, Mark 1A, Particulate, Adhering, Particulate, Canister Particulate, Cladding Film(s), Oxide Film(s)

Abstract: High, best estimate, and low values are given for particulate inventories within an MCO basket containing freshly cleaned Mark 1A fuel. The findings are compared with the estimates of particulate inventories for an MCO basket containing freshly cleaned Mark IV fuel.

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Release Approval 6/30/99 Date

Release Stamp

Approved for Public Release

REVIEW CHECKLIST

Document Reviewed:

HNF-4465, Estimates of Particulate Mass for an MCO Containing Mark 1A Fuel
Rev.0

Scope of Review:

Technical Review of Calculation

Yes No NA

☐	☐	☒	• Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐	Problem completely defined.
☐	☐	☒	Accident scenarios developed in a clear and logical manner.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☐	☐	☒	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☒	☐	☐	Mathematical derivation checked including dimensional consistency of results.
☐	☐	☒	Models appropriate and used within range of validity or use outside range of established validity justified.
☒	☐	☐	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☐	☐	☒	Software input correct and consistent with document reviewed.
☐	☐	☒	Software output consistent with input and with results reported in document reviewed.
☒	☐	☐	Limits/criteria/guidelines applied to analysis results are appropriate and referenced.
☒	☐	☐	Limits/criteria/guidelines checked against references.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.
☒	☐	☐	Format consistent with appropriate NRC Regulatory Guide or other standards.
☒	☐	☐	• Review calculations, comments, and/or notes are attached.
☒	☐	☐	Document approved.

Annamaria N. Praga

Reviewer (Printed Name and Signature)

Annamaria N. Praga

6/10/99

Date

*Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

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1.0 Purpose and Objective

The purpose of this calculation document is to determine the particulate mass associated with Mark 1A fuel. This document will also verify that the estimates for particulate mass for the Mark IV fuel loaded in a Multi-Canister Overpack (MCO) bound the estimates of particulate mass for the Mark 1A fuel. This document follows the form specified in HNF-1613 EP 7.6.

2.0 Summary of Final Results and Conclusions

The calculations show that the particulate inventory of an MCO containing Mark IV fuel bounds an MCO containing Mark 1A fuel. The calculations performed for the Mark 1A fuel use methods and assumptions consistent with those used by Slougher 1998. Table 6-1 summarizes the estimates of particulate mass that were calculated for the Mark 1A fuel. Table 7-1 illustrates the bounding results with a comparison of the total particulate mass for the two fuel types.

3.0 Input Data (Parameters)

Cladding surface area, uranium surface area, and particulate density are important parameters for this analysis.

3.1 Cladding Surface Area

The parameter for cladding surface area must be considered for both intact fuel assemblies and for the scrap fuel basket.

3.1.1 Cladding Surface Area of One Intact Fuel Assembly

The cladding surface area of intact fuel is calculated from the dimensions given below (Slougher 1998).

$$\begin{aligned}\text{Maximum Length} &= 53.1 \text{ cm}^1 \\ \text{Outer Diameter of Outer Element} &= 6.10 \text{ cm} \\ \text{Inner Diameter of Outer Element} &= 4.50 \text{ cm} \\ \text{Outer Diameter of Inner Element} &= 3.18 \text{ cm} \\ \text{Inner Diameter of Inner Element} &= 1.11 \text{ cm}\end{aligned}$$

¹ There are 12 Mark 1A assemblies that are 66.3 cm in length which are stored in the K West Basin and are excluded from this analysis.

Table 3-1. Surface Area of Cladding for Mark 1A Fuel Assembly

Area of Outer Element's Outer Diameter	height x (π x diameter) 53.1 cm x (π x 6.10 cm)	1017.6 cm ²
Area of Outer Element's Inner Diameter	53.1 cm x (π x 4.50 cm)	750.7 cm ²
Area of Outer Element's End	$2 \times [(\pi \times r_{OD}^2) - (\pi \times r_{ID}^2)]$ $2 \times [\pi \times (6.10/2)^2 \text{ cm}^2 - \pi \times (4.50/2)^2 \text{ cm}^2]$ $2 \times [29.2 \text{ cm}^2 - 15.9 \text{ cm}^2]$	26.6 cm ²
Area of Inner Element's Outer Diameter	53.1 cm x (π x 3.18 cm)	530.5 cm ²
Area of Inner Element's Inner Diameter	53.1 cm x (π x 1.11 cm)	185.2 cm ²
Area of Inner Element's End	$2 \times [(\pi \times r_{OD}^2) - (\pi \times r_{ID}^2)]$ $2 \times [\pi \times (3.18/2)^2 \text{ cm}^2 - \pi \times (1.11/2)^2 \text{ cm}^2]$ $2 \times [7.9 \text{ cm}^2 - 1.0 \text{ cm}^2]$	13.9 cm ²
Total Cladding Area of One Intact Fuel Assembly		2524.5 cm ²

3.1.2 Cladding Surface Area of One Scrap Basket

The cladding surface area in a scrap basket is calculated based on the number of equivalent assemblies that could be in a scrap basket. The number of equivalent assemblies is calculated by dividing the maximum weight allowed in a scrap basket for criticality purposes by the weight of a full length Mark 1A assembly to arrive at a value of equivalent assemblies.

Calculate total weight of a full length Mark 1A fuel assembly (Slougher 1998):

$$\text{Cladding} = 0.88 \text{ kg (Outer)} + 0.54 \text{ kg (Inner)} = 1.42 \text{ kg}$$

$$\text{Fuel} = 11.1 \text{ kg (Outer)} + 5.49 \text{ kg (Inner)} = 16.59 \text{ kg}$$

$$\text{Total Weight} \text{ -----} = 18.01 \text{ kg}$$

Calculate number of equivalent assemblies in scrap basket:

$$575 \text{ kg (maximum weight; Reilly 1998)} \div 18.01 \text{ kg (weight of assembly)}$$

$$= 31.9 \text{ equivalent assemblies}$$

The analysis above provides for the maximum number of equivalent elements and the maximum cladding surface area that can be loaded into a scrap basket, based on the criticality limits.

3.2 Uranium Surface Area

Uranium surface area estimates are based on bounding estimates for Mark IV fuel and scrap baskets, modified to reflect fuel loading differences. The Mark IV basket data are consistent with Slougher 1998. The modifications to describe Mark 1A baskets are shown below. An upper bound of 26,400 cm² per basket has been estimated for scrap baskets, and 5,600 cm² has been estimated for fuel baskets (Ball 1998).

Note that the Mark IV fuel information has been obtained from Ball 1998 and Slougher 1998.

Calculate surface area of scrap basket:

- High 26,400 cm²/basket $\left(\frac{45,000 \text{ cm}^2}{980 \text{ kg}} \right) (\text{Mark IV}) \times 575 \text{ kg (Mark 1A)}$
- Best Est. 10,000 cm²/basket $\left(\frac{17,000 \text{ cm}^2}{980 \text{ kg}} \right) (\text{Mark IV}) \times 575 \text{ kg (Mark 1A)}$
- Low 5,000 cm²/basket Scrap can consist of damaged assemblies with few
“fine” fragments by its definition. No calculation was
performed for this value, it is just an estimate.

Calculate surface area of fuel basket:

- High 5,600 cm²/basket $\left(\frac{48 \text{ assem.} \times 2524 \text{ cm}^2 (\text{Mk 1A})}{54 \text{ assem.} \times 3156 \text{ cm}^2 (\text{Mk IV})} \right) \times 7,900 \text{ cm}^2 (\text{Mk IV})$
- Best Est. 300 cm²/basket $\left(\frac{48 \text{ assem.} \times 2524 \text{ cm}^2 (\text{Mk 1A})}{54 \text{ assem.} \times 3156 \text{ cm}^2 (\text{Mk IV})} \right) \times 425 \text{ cm}^2 (\text{Mk IV})$
- Low 110 cm²/basket $\left(\frac{48 \text{ assem.} \times 2524 \text{ cm}^2 (\text{Mk 1A})}{54 \text{ assem.} \times 3156 \text{ cm}^2 (\text{Mk IV})} \right) \times 160 \text{ cm}^2 (\text{Mk IV})$

3.3 Particulate Density

Consistent with the calculations in Slougher 1998,

- The adhering particulate mass is based on the density of Uranium Dioxide, 10 g/cm³.
- The canister particulate mass is based on the bulk density of KW Basin canister particulate, 2.7 g/cm³ (Pearce 1998).

4.0 Assumptions

4.1 Particulate Locations

Particulate locations, as discussed in Slougher 1998, are summarized in Table 4-1.

Table 4-1. Particulate Locations

MCO Location	Films	Adhering Particulates	Canister Particulate
Scrap Basket	On cladding and exposed uranium surfaces	On uranium surfaces within/around damage areas	N/A - See Slougher 1998, section 5.2.3.1
Fuel Baskets	On cladding and exposed uranium surfaces	On uranium surfaces within/around damage areas	Within flow channels

4.2 MCO Loading Configurations

Three MCO loading configurations are considered by this calculation. These are discussed in Slougher 1998. The difference between MCOs containing Mark IV fuel and MCOs containing Mark 1A fuel is that they hold a maximum of five baskets and six baskets, respectively. For the Mark 1A MCO, case 1 considers zero scrap baskets and six fuel baskets. Case 2 considers one scrap basket and five fuel baskets. Case 3 considers two scrap baskets and four fuel baskets.

4.3 Estimates for Parameters

The estimated parameters are listed in Table 4-2.

Table 4-2. Estimated Parameters

		High	Best Estimate	Low	Reference
Cladding Surface Film		12.5 mg/cm ²	3.54 mg/cm ²	0.55 mg/cm ²	Sloughter 1998
Uranium Surface Film	Thickness	10 μm	3 μm	3 μm	Sloughter 1998
Uranium Surface Area	Scrap	26,400 cm ² /basket	10,000 cm ² /basket	5,000 cm ² /basket	Section 3.1.2
	Fuel	5,600 cm ² /basket	300 cm ² /basket	110 cm ² /basket	Section 3.1.2
Adhering Particulate	Scrap	200 g	20 g	6 g	Sloughter 1998
	Fuel	20 g	7.6 g	1.3 g	Sloughter 1998
Canister Particulate	Scrap	0	0	0	Sloughter 1998
	Fuel ¹	310 g/basket	140 g/basket	0	Sloughter 1998

¹ The methodology for calculating canister particulate for the fuel baskets follows Sloughter 1998 with modifications for Mark 1A fuel loading:

Calculate volume of canister particulate:

$$V_{\text{tot}} = V_{\text{inner}} + V_{\text{annulus}} = (h \times \pi \times r_{\text{inner}}^2) + (h \times \pi \times (r_{\text{outer}}^2 - r_{\text{inner}}^2))$$

$$= (7.6 \text{ cm} \times \pi \times (1.11/2)^2 \text{ cm}^2) + (7.6 \text{ cm} \times \pi \times ((4.50/2)^2 \text{ cm}^2 - (3.18/2)^2 \text{ cm}^2)) = 68 \text{ cm}^3$$

Calculate the volume of canister particulate:

$$1.3 \text{ cm}^3 \text{ (volume of canister particulate)} \times 406 \text{ assemblies per batch} = 528 \text{ cm}^3 \text{ canister particulate;}$$

$$0.15 \times 29 \text{ canisters per batch} \times 68 \text{ cm}^3 \text{ per assembly} = 296 \text{ cm}^3 \text{ canister particulate;}$$

$$2 \text{ assemblies} \times 68 \text{ cm}^3 \text{ per assembly} = 136 \text{ cm}^3 \text{ canister particulate.}$$

$$528 \text{ cm}^3 + 296 \text{ cm}^3 + 136 \text{ cm}^3 = 960 \text{ cm}^3 \text{ canister particulate per batch.}$$

Calculate the maximum volume of canister particulate loaded into one fuel basket, based on 48 assemblies per basket (Smith 1998):

$$960 \text{ cm}^3 \times (48 \text{ assemblies per fuel basket} \div 406 \text{ assemblies per batch}) = 114 \text{ cm}^3/\text{basket.}$$

$$2.7 \text{ g/cm}^3 \times 114 \text{ cm}^3/\text{basket} = 310 \text{ g canister particulate per fuel basket.}$$

Calculate the best estimate volume of canister particulate loaded into one fuel basket.

$$296 \text{ cm}^3 + 136 \text{ cm}^3 = 432 \text{ cm}^3 \text{ canister particulate per 406 assembly validation batch.}$$

$$(48 \text{ assemblies per basket} \div 406 \text{ assemblies per batch}) \times 432 \text{ cm}^3 \text{ per batch} = 51 \text{ cm}^3 \text{ per basket.}$$

$$2.7 \text{ g/cm}^3 \times 51 \text{ cm}^3/\text{basket} = 140 \text{ g canister particulate per fuel basket.}$$

4.4 Other Assumptions

Other key assumptions used in this analysis, from Sloughter 1998, are restated below:

- Fuel elements described as “bad” are assumed to be placed in scrap baskets (Pitner 1998).
- Formation of white layers in local spots and the presence of local reddish spots are considered to be included in the high estimates.
- While no credit is taken for the cleaning equipment’s ability to remove any of the white layer that was measured on fuel element samples, the estimate does assume that the cleaning process will be at least as effective as the limited cleaning obtained from transporting the fuel elements to the laboratory.
- The above statement should not be taken to imply that “adhering particulate” would be readily available for release from an MCO. What it does imply is that the adhering particulate estimate is both reasonable (in that it does not include the particulate that was found on the bottom of the transfer cask) and conservative (in that it does include all of the particulate that was recovered from the sample, even though the sample had not been cleaned). The adhering particulate category is intended to represent only those materials that are very difficult to remove.

5.0 Calculation

5.1 Scope of Calculation

The calculation, consistent with Slougher 1998, considers materials that may be loaded into an MCO that are literally not cladding and fuel in their original form.

5.2 Mass Calculation Equations

Particulate masses are calculated for cladding and uranium surface area films, adhering particulates, and canister particulate deposits loaded into the MCO. The mass values are calculated for scrap and fuel.

5.2.1 Cladding Surface Films (Scrap)

The associated mass is given by:

$$M_{\text{layer}} = A_{\text{assy}} \times N_{\text{assy}} \times (m/A)_{\text{layer}} \quad (\text{Equation 1})$$

where,

$$\begin{aligned} M_{\text{layer}} &= \text{Layer mass} && (\text{kg}) \\ A_{\text{assy}} &= \text{Assembly area} && (\text{cm}^2) \\ N_{\text{assy}} &= \text{Number of assemblies} && (\text{fuel plus scrap}) \\ (m/A)_{\text{layer}} &= \text{Mass per unit area of layer} && (\text{kg/cm}^2) \end{aligned}$$

The area of an assembly is from section 3.1.1:

$$A_{\text{assy}} = 2524.5 \text{ cm}^2$$

The number of equivalent assemblies in a scrap basket is from section 3.1.2:

$$N_{\text{assy, scrap}} = (575 \text{ kg/scrap basket}) \div (18.01 \text{ kg/assembly}) = 31.9$$

Mass per unit area of the layer values are defined in section 4.3.

5.2.2 Cladding Surface Film (Fuel)

The associated mass is given by Equation 1, with the exception that the number of fuel assemblies is taken as the sum of fuel assemblies for an MCO with four, five, or six fuel baskets:

$$\begin{aligned} N_{\text{assy, fuel}} &= 4 \text{ fuel baskets} \times 48 \text{ fuel assemblies per basket} && = 192 \\ N_{\text{assy, fuel}} &= 5 \text{ fuel baskets} \times 48 \text{ fuel assemblies per basket} && = 240 \\ N_{\text{assy, fuel}} &= 6 \text{ fuel baskets} \times 48 \text{ fuel assemblies per basket} && = 288 \end{aligned}$$

5.2.3 Uranium Surface Film (Scrap)

All exposed uranium metal should have some oxide film because some corrosion must have occurred. Scrap is considered separately from fuel because the area for scrap is deduced differently than the area for fuel. The mass of an oxide layer is given by:

$$M_{\text{ox, scrap}} = A_{\text{ox, scrap}} \times (m/A)_{\text{ox}} \quad (\text{Equation 2})$$

where,

$$\begin{aligned} M_{\text{ox, scrap}} &= \text{Oxide mass on scrap} && (\text{kg}) \\ A_{\text{ox, scrap}} &= \text{Oxidation area of scrap} && (\text{m}^2) \\ (m/A)_{\text{ox}} &= \text{Mass per unit area oxide layer} && (\text{kg/m}^2) \end{aligned}$$

The area $A_{\text{ox, scrap}}$ is chosen as discussed in section 4.3.

The mass per unit area is further decomposed as the product of layer thickness and density:

$$(m/A)_{\text{ox}} = \rho_{\text{layer}} \times \delta_{\text{layer}} \quad (\text{Equation 3})$$

where,

$$\begin{aligned} \rho_{\text{layer}} &= \text{Layer density} && (\text{kg/m}^3) \\ \delta_{\text{layer}} &= \text{Layer thickness} && (\text{cm}) \end{aligned}$$

5.2.4 Uranium Surface Film (Fuel)

Fuel in fuel baskets has areas with cladding failure and the exposed metal must have some oxide layer. The mass of this oxide is given by the same formula as for the scrap basket oxide:

$$M_{\text{ox, fuel}} = A_{\text{ox, fuel}} \times (m/A)_{\text{ox}} \quad (\text{Equation 4})$$

The exposed area is defined in section 4.3 and the mass per unit area is chosen the same way as for that in the scrap basket.

5.2.5 Particulate on Scrap

Particulate is found to be associated with failed areas, both on the failed area and underneath the adjacent cladding that has become unbonded from the fuel. Particulates associated with fuel and scrap are considered separately because the damage in scrap is more extensive than it is in fuel. The mass of particulate associated with scrap is given by:

$$M_{\text{par, scrap}} = N_{\text{assy, scrap}} \times m_{\text{par, assy}} \quad (\text{Equation 5})$$

where,

$$\begin{aligned} M_{\text{par, scrap}} &= \text{Particulate mass on scrap} && (\text{kg}) \\ m_{\text{par, assy}} &= \text{Mass of particulate per assembly} && (\text{kg}) \end{aligned}$$

The mass of particulate per assembly in a scrap basket is given in section 4.3.

5.2.6 Particulate on Fuel

Similarly, particulate may be found on the failed area and locally underneath adjacent cladding on fuel assemblies in fuel baskets, and the total mass is:

$$M_{\text{par, fuel}} = N_{\text{assy, fuel}} \times m_{\text{par, assy}} \quad (\text{Equation 6})$$

The mass of particulate per assembly in a fuel basket is given in section 4.3.

5.3 Resulting Particulate Mass Values

Calculations of particulate values (on an MCO basis) are shown below for three cases. Results are rounded to yield the overall values summarized in Table 6-1.

5.3.1 Case 1: Zero Scrap Baskets – Six Fuel Baskets

5.3.1.1 Cladding Surface Film (Fuel) [Equation 1]

$$\begin{aligned}\text{High:} & 2524.5 \text{ cm}^2/\text{assy} \times 288 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2 &= 9.088 \text{ kg} \\ \text{Best Est.:} & 2524.5 \text{ cm}^2/\text{assy} \times 288 \text{ assy} \times 3.54\text{E-}6 \text{ kg/cm}^2 &= 2.574 \text{ kg}\end{aligned}$$

Best Estimate Calculation for Break Down by Film Type Reported in Table 6.1

$$\begin{aligned}\text{Al(OH)}_3: & 2524.5 \text{ cm}^2/\text{assy} \times 0.25 \times 288 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2 &= 2.272 \text{ kg} \\ \text{UO}_x: & 2524.5 \text{ cm}^2/\text{assy} \times 0.75 \times 288 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2 &= 0.300 \text{ kg} \\ \text{Low:} & 2524.5 \text{ cm}^2/\text{assy} \times 288 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2 &= 0.400 \text{ kg}\end{aligned}$$

5.3.1.2 Uranium Surface Film (Fuel) [Equation 4]

$$\begin{aligned}\text{High:} & 5600 \text{ cm}^2/\text{basket} \times 6 \text{ baskets} \times 10\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3 &= 0.336 \text{ kg} \\ \text{Best Est.:} & 300 \text{ cm}^2/\text{basket} \times 6 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3 &= 0.005 \text{ kg} \\ \text{Low:} & 110 \text{ cm}^2/\text{basket} \times 6 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3 &= 0.002 \text{ kg}\end{aligned}$$

5.3.1.3 Particulate on Fuel [Equation 6]

$$\begin{aligned}\text{High:} & 0.0200 \text{ kg/assy} \times 288 \text{ assy} &= 5.760 \text{ kg} \\ \text{Best Est.:} & 0.0076 \text{ kg/assy} \times 288 \text{ assy} &= 2.189 \text{ kg} \\ \text{Low:} & 0.0013 \text{ kg/assy} \times 288 \text{ assy} &= 0.374 \text{ kg}\end{aligned}$$

5.3.1.4 Canister Particulate [Equation 6]

$$\begin{aligned}\text{High:} & 6 \text{ baskets} \times 0.310 \text{ kg/basket} &= 1.860 \text{ kg} \\ \text{Best Est.:} & 6 \text{ baskets} \times 0.140 \text{ kg/basket} &= 0.840 \text{ kg} \\ \text{Low:} & 6 \text{ baskets} \times 0 \text{ kg/basket} &= 0 \text{ kg}\end{aligned}$$

5.3.2 Case 2: One Scrap Basket – Five Fuel Baskets

5.3.2.1 Cladding Surface Film (Scrap) [Equation 1]

$$\begin{aligned}\text{High:} & 2524.5 \text{ cm}^2/\text{assy} \times 31.9 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2 &= 1.007 \text{ kg} \\ \text{Best Est.:} & 2524.5 \text{ cm}^2/\text{assy} \times 31.9 \text{ assy} \times 3.54\text{E-}6 \text{ kg/cm}^2 &= 0.285 \text{ kg}\end{aligned}$$

Best Estimate Calculation for Break Down by Film Type Reported in Table 6.1

$$\begin{aligned}\text{Al(OH)}_3: & 2524.5 \text{ cm}^2/\text{assy} \times 0.25 \times 31.9 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2 &= 0.252 \text{ kg} \\ \text{UO}_x: & 2524.5 \text{ cm}^2/\text{assy} \times 0.75 \times 31.9 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2 &= 0.033 \text{ kg} \\ \text{Low:} & 2524.5 \text{ cm}^2/\text{assy} \times 31.9 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2 &= 0.044 \text{ kg}\end{aligned}$$

5.3.2.2 Cladding Surface Film (Fuel)

[Equation 1]

High:	$2524.5 \text{ cm}^2/\text{assy} \times 240 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2$	= 7.573 kg
Best Est.:	$2524.5 \text{ cm}^2/\text{assy} \times 240 \text{ assy} \times 3.54\text{E-}6 \text{ kg/cm}^2$	= 2.145 kg

Best Estimate Calculation for Break Down by Film Type Reported in Table 6.1

Al(OH) ₃ :	$2524.5 \text{ cm}^2/\text{assy} \times 0.25 \times 240 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2$	= 1.893 kg
UO _x :	$2524.5 \text{ cm}^2/\text{assy} \times 0.75 \times 240 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2$	= 0.250 kg
Low:	$2524.5 \text{ cm}^2/\text{assy} \times 240 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2$	= 0.333 kg

5.3.2.3 Uranium Surface Film (Scrap)

[Equation 2]

High:	$26400 \text{ cm}^2/\text{basket} \times 1 \text{ baskets} \times 10\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.264 kg
Best Est.:	$10000 \text{ cm}^2/\text{basket} \times 1 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.030 kg
Low:	$5000 \text{ cm}^2/\text{basket} \times 1 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.015 kg

5.3.2.4 Uranium Surface Film (Fuel)

[Equation 4]

High:	$5600 \text{ cm}^2/\text{basket} \times 5 \text{ baskets} \times 10\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.280 kg
Best Est.:	$300 \text{ cm}^2/\text{basket} \times 5 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.005 kg
Low:	$110 \text{ cm}^2/\text{basket} \times 5 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.002 kg

5.3.2.5 Particulate on Scrap

[Equation 5]

High:	$0.200 \text{ kg/assy} \times 31.9 \text{ assy}$	= 6.380 kg
Best Est.:	$0.020 \text{ kg/assy} \times 31.9 \text{ assy}$	= 0.638 kg
Low:	$0.006 \text{ kg/assy} \times 31.9 \text{ assy}$	= 0.191 kg

5.3.2.6 Particulate on Fuel

[Equation 6]

High:	$0.0200 \text{ kg/assy} \times 240 \text{ assy}$	= 4.800 kg
Best Est.:	$0.0076 \text{ kg/assy} \times 240 \text{ assy}$	= 1.824 kg
Low:	$0.0013 \text{ kg/assy} \times 240 \text{ assy}$	= 0.312 kg

5.3.2.7 Canister Particulate

[Equation 6]

High:	$5 \text{ baskets} \times 0.310 \text{ kg/basket}$	= 1.550 kg
Best Est.:	$5 \text{ baskets} \times 0.140 \text{ kg/basket}$	= 0.700 kg
Low:	$5 \text{ baskets} \times 0 \text{ kg/basket}$	= 0 kg

5.3.3 Case 3: Two Scrap Baskets – Four Fuel Baskets

5.3.3.1 Cladding Surface Film (Scrap) [Equation 1]

High:	$2524.5 \text{ cm}^2/\text{assy} \times 63.8 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2$	= 2.013 kg
Best Est.:	$2524.5 \text{ cm}^2/\text{assy} \times 63.8 \text{ assy} \times 3.54\text{E-}6 \text{ kg/cm}^2$	= 0.570 kg

Best Estimate Calculation for Break Down by Film Type Reported in Table 6.1

Al(OH) ₃ :	$2524.5 \text{ cm}^2/\text{assy} \times 0.25 \times 63.8 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2$	= 0.503 kg
UO _x :	$2524.5 \text{ cm}^2/\text{assy} \times 0.75 \times 63.8 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2$	= 0.066 kg
Low:	$2524.5 \text{ cm}^2/\text{assy} \times 63.8 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2$	= 0.089 kg

5.3.3.2 Cladding Surface Film (Fuel) [Equation 1]

High:	$2524.5 \text{ cm}^2/\text{assy} \times 192 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2$	= 6.059 kg
Best Est.:	$2524.5 \text{ cm}^2/\text{assy} \times 192 \text{ assy} \times 3.54\text{E-}6 \text{ kg/cm}^2$	= 1.716 kg

Best Estimate Calculation for Break Down by Film Type Reported in Table 6.1

Al(OH) ₃ :	$2524.5 \text{ cm}^2/\text{assy} \times 0.25 \times 192 \text{ assy} \times 1.25\text{E-}5 \text{ kg/cm}^2$	= 1.515 kg
UO _x :	$2524.5 \text{ cm}^2/\text{assy} \times 0.75 \times 192 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2$	= 0.200 kg
Low:	$2524.5 \text{ cm}^2/\text{assy} \times 192 \text{ assy} \times 5.5\text{E-}7 \text{ kg/cm}^2$	= 0.267 kg

5.3.3.3 Uranium Surface Film (Scrap) [Equation 2]

High:	$26400 \text{ cm}^2/\text{basket} \times 2 \text{ baskets} \times 10\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.528 kg
Best Est.:	$10000 \text{ cm}^2/\text{basket} \times 2 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.060 kg
Low:	$5000 \text{ cm}^2/\text{basket} \times 2 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.030 kg

5.3.3.4 Uranium Surface Film (Fuel) [Equation 4]

High:	$5600 \text{ cm}^2/\text{basket} \times 4 \text{ baskets} \times 10\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.224 kg
Best Est.:	$300 \text{ cm}^2/\text{basket} \times 4 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.004 kg
Low:	$110 \text{ cm}^2/\text{basket} \times 4 \text{ baskets} \times 3\text{E-}4 \text{ cm} \times 0.01 \text{ kg/cm}^3$	= 0.001 kg

5.3.3.5 Particulate on Scrap [Equation 5]

High:	$0.200 \text{ kg/assy} \times 63.8 \text{ assy}$	= 12.76 kg
Best Est.:	$0.020 \text{ kg/assy} \times 63.8 \text{ assy}$	= 1.276 kg
Low:	$0.006 \text{ kg/assy} \times 63.8 \text{ assy}$	= 0.383 kg

5.3.3.6 Particulate on Fuel [Equation 6]

High:	$0.0200 \text{ kg/assy} \times 192 \text{ assy}$	= 3.840 kg
Best Est.:	$0.0076 \text{ kg/assy} \times 192 \text{ assy}$	= 1.459 kg
Low:	$0.0013 \text{ kg/assy} \times 192 \text{ assy}$	= 0.250 kg

5.3.3.7 Canister Particulate

[Equation 6]

High:	4 baskets x 0.310 kg/basket	= 1.240 kg
Best Est.:	4 baskets x 0.140 kg/basket	= 0.560 kg
Low:	4 baskets x 0 kg/basket	= 0 kg

6.0 Results

The results of the calculations in section 5.0 are summarized in Table 6-1.

Table 6-1. Summary of Derived Particulate Mass Values for Mark 1A Fuel (kg/MCO) ¹

		Case 1 ²			Case 2 ³			Case 3 ⁴		
		Zero Scrap Baskets Six Fuel Baskets			One Scrap Baskets Five Fuel Baskets			Two Scrap Baskets Four Fuel Baskets		
		High	Best Est.	Low	High	Best Est.	Low	High	Best Est.	Low
Cladding Surface Film (Aluminum Hydroxide) ⁵	Scrap	0	0	0	1.007	0.252	0	2.013	0.503	0
	Fuel	9.088	2.272	0	7.573	1.893	0	6.059	1.515	0
Cladding Surface Film (Uranium Oxides) ⁵	Scrap	0	0	0	0	0.033	0.044	0	0.066	0.089
	Fuel	0	0.300	0.400	0	0.250	0.333	0	0.200	0.267
Cladding Surface Film (TOTAL)	Scrap	0	0	0	1.007	0.285	0.044	2.013	0.569	0.089
	Fuel	9.088	2.572	0.400	7.573	2.143	0.333	6.059	1.715	0.267
Uranium Surface Film (Uranium Oxides)	Scrap	0	0	0	0.264	0.030	0.015	0.528	0.060	0.030
	Fuel	0.336	0.005	0.002	0.280	0.005	0.002	0.224	0.004	0.001
Adhering Particulate (Uranium Oxides)	Scrap	0	0	0	6.380	0.638	0.191	12.760	1.276	0.383
	Fuel	5.760	2.189	0.374	4.800	1.824	0.312	3.840	1.459	0.250
Canister Particulate (Uranium Oxides)	Scrap	0	0	0	0	0	0	0	0	0
	Fuel	1.860	0.840	0	1.550	0.700	0	1.240	0.560	0
Total Particulate Scrap (kg)		0	0	0	7.651	0.953	0.250	15.301	1.905	0.502
Total Particulate Fuel (kg)		17.044	5.606	0.776	14.203	4.672	0.647	11.363	3.738	0.518
Total Particulate Mass (kg)		17.044	5.606	0.776	21.854	5.625	0.897	26.664	5.643	1.020
Rounded Total (kg)		17	6	1	22	6	1	27	6	1

¹ This table includes only those particulates that still remain on fuel and scrap (i.e., "residual" particulates) immediately after it has been cleaned.

² Bounding for Cladding Film and Canister Particulate

³ Nominal MCO Configuration

⁴ Bounding Total Particulate MCO

⁵ The high cladding film values are based on the assumption that all cladding on fuel and/or scrap has a "white coating" and that the white coating is totally composed of aluminum hydroxide compounds. The best estimate values for cladding film are based on the observation that roughly 25% of the fuel canisters at K West Basin are aluminum, and on the subsequent conclusion that up to 25% of the fuel assemblies within a typical MCO will have the white layer, and that 75% have the "gray layer" (i.e., 100% oxides of uranium). The low cladding values are based on the observation that most fuel elements have the gray layer

7.0 Conclusion

When the results from Table 6-1 are compared to those in Slougher 1998, it is concluded that the estimates for particulate mass for the Mark IV fuel do indeed bound the estimates for particulate mass for the Mark 1A fuel. Table 6-2 summarizes these findings.

Table 7-1. Comparison of Results for Mark 1A Fuel and Mark IV Fuel

	<u>Case 1</u> Zero Scrap / Six Fuel Baskets			<u>Case 2</u> One Scrap / Five Fuel Baskets			<u>Case 3</u> Two Scrap / Four Fuel Baskets		
	High	Best Est.	Low	High	Best Est.	Low	High	Best Est.	Low
Mark 1A Fuel	17	6	1	22	6	1	27	6	1
Mark IV Fuel	18	6	1	24	6	1	30	6	1

8.0 References

- Ball, D. E. and D. R. Duncan, 1998, *Fuel Surface Area*, HNF-SD-SNF-CN-017, Rev. 3, Duke Engineering and Services Hanford, Richland, Washington.
- Pearce, K. L., 1998, *105-K Basin Material Design Basis Feed Description for Spent Nuclear Fuel Project Facilities, Volume 2, Sludge*, HNF-SD-SNF-TI-009, Volume 2, Rev. 2, Numatec Hanford Corporation, Richland, Washington.
- Pitner, A. L., 1998, *Summary Assessment of Fuel Damage Distributions in the K Basins*, HNF-2586, Rev. 0, Duke Engineering and Services Hanford, Richland, Washington.
- Reilly, M. A., 1998, *Spent Nuclear Fuel Project Technical Databook*, HNF-SD-SNF-TI-015, Rev. 5, Duke Engineering and Services Hanford, Richland, Washington.
- Slougher, J. P., 1998, *Estimates of Particulate Mass in Multi-Canister Overpacks*, HNF-1527, Rev. 2, Numatec Hanford Corporation, Richland, Washington.
- Smith, K. E., 1998, *Multi-Canister Overpack Design Report*, HNF-SD-SNF-DR-003, Rev. 1, Duke Engineering and Services Hanford, Richland, Washington.

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