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Carlsbad, NM 88220

date: December 15, 2021

to: Records Center

from: Seth King (8881) *Signature on File*

subject: Recalculation of iron surface area for iron corrosion in the WIPP PA calculation

Introduction

Gas generation is in important process in the Waste Isolation Pilot Plan (WIPP) Performance Assessment (PA) Salado Flow model. Three gas generation mechanisms are currently modeled in the PA calculation, iron corrosion, microbial bio-degradation of Cellulose, Plastic, and Rubber (CPR), and brine radiolysis. Of these three mechanisms, iron corrosion produces the largest amount of gas (Day, 2019). The iron corrosion reaction consumes solid iron and gaseous or liquid brine (water) and produces solid iron (II) hydroxide and gaseous hydrogen:

$$Fe(s) + 2H_2O(g,l) \rightarrow H_2(g) + Fe(OH)_2(s) \quad (1)$$

Within the PA model, the rate of gas generation in moles of gas per second per cubic meter of repository is currently found by:

$$G_{rate} = \left(R_{ci}S_b + R_{ch}S_g\right)\frac{D_{N,Fe}}{M_{w,Fe}}A_d\frac{n_d}{V_r} \quad (2)$$

Where:

R_{ci} is the sampled inundated iron corrosion rate in m/s.

R_{ch} is the sampled humid iron corrosion rate in m/s.

S_b is the effective brine saturation.

S_g is the effective gas saturation.

$D_{N,Fe}$ is the density of iron (REFCON:DN_FE = 7870 kg/m^3).

$M_{w,Fe}$ is the molecular weight of iron (REFCON:MW_FE = 0.055847 kg/mole).

A_d is the surface area of iron per drum (REFCON:ASDRUM = 6 m^2/drum).

n_d is the number of drums per room assuming optimal loading (REFCON:DRROOM = 6804 drums/room).

V_r is the volume of a room (REFCON:VROOM = 3644.378 m^3).

In equation (2), the surface area of iron per cubic meter of repository (D_s) is found from the terms:

$$D_s = A_d\frac{n_d}{V_r} \quad (3)$$

Which means the total surface area of iron in the repository is a function of an optimal loading of the repository and the total volume of the repository, but not the mass of iron inventory in the repository.

WIPP:4.2.1:PA:QA-L:576427

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Iron corrosion is a zeroth-order reaction in the PA model, meaning that the reaction rate is unchanged by the amount of iron in a grid block as long as some iron exists in the grid block. Additionally, the total surface area of iron is independent of the iron inventory. Therefore, gas generation from iron is independent of iron inventory until complete consumption of the iron inventory in any grid block is realized. This disconnect between iron mass and iron surface area has been questioned several times during compliance recertification application completeness (US EPA, 2015, completeness comment 4-C-4, and US EPA, 2020, completeness comment CC6-GEOCHEM-32).

Conservative Assumptions

The PA calculation is a highly non-linear and complex system where impacts of input parameters can be very complex. In the case of iron corrosion, it is often thought that increasing the amount of iron corrosion, or the rate of iron corrosion, is conservative with respect to releases. While pressure is increased by the gas generated from iron corrosion, this positive correlation between iron corrosion and releases does not always hold true. As iron corrosion consumes brine and can reduce brine availability for releases, an increase in iron corrosion can lead to reduced releases in some cases.

The current approach to calculating iron surface area using an optimal loading strategy and the highest value for the surface area of iron per drum has established that a larger value in the range of estimated surface area should be used. In this analysis, an alternative method of calculating iron surface area will be proposed, and a larger value in the range of iron surface areas will be recommended.

Updated Surface Area Calculation

An alternative approach to calculating iron surface area that ties the estimate of total iron surface area to mass of the iron inventory instead of repository volume is proposed. For this approach a conversion factor from mass of iron to surface area is needed. If the entire inventory of iron was thought of as a single sheet, this conversion factor would be equivalent to the average thickness of that sheet. The conversion factor from mass to surface area of iron will be found using the currently emplaced waste in the WIPP repository as of December 31, 2020 and the surface area estimation techniques put forward by Day (2015).

A query of the WIPP Waste Data System (WDS) was undertaken and data summarized in Table 1. In Table 1, the number, type, and tare weight of emplaced waste and dunnage containers in addition to the average iron-based metal content of emplaced waste for each container type as of December 31, 2020 (Appendix A – WDS data from Steve Offner).

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Table 1 Waste containers emplaced as of December 2020 (WDS data in Appendix A)

Container Type	Number of Emplaced Containers plus Dunnage $n_{emplaced}$ (#)	Average Iron-Based Metal Waste per Container Type W_{wstl} (kgf)	Container Tare Weight W_{tare} (kgf)[1]
55-gallon drum (DL)	107,498	6.18	28.20
12-in Standard Pipe Overpack (DL)	27,062	2.57	109.77
S100 Pip Overpack (DL)	852	0.00	67.74
S300 Pip Overpack (DL)	61	0.00	107.69
85-gallon drum (OP one drum)	5	27.76	38.85
85-gallon tall drum (DL)	2	0.00	38.85
100-gallon drum (DL of compacted pucks)	34,408	170.52	56.69
Standard Waste Box (DL)	7,004	230.48	295.83
Standard Waste Box (OP four drums)	6,346	19.64	315.42
Standard Large Box 2 (DL)	235	487.62	1224.70
Ten Drum Overpack (OP ten drums)	6,898	26.18	729.09
Ten Drum Overpack (DL)	26	903.18	816.90
Shielded Container (OP one drum)	57	16.30	783.46
RH FL Waste Canister (DL)	18	2.20	931.59
RH RL Waste Canister (DL)	1	0.00	517.00
RH RL Waste Canister (OP 3 drums)	700	33.04	521.37

The inner and outer steel surface area of each emplaced container is conservatively obtained by doubling the surface area determined from the bounding external payload container dimensions provided in Section DATA-B-1.3, Attachment B, of CRA 2014 Appendix DATA-2014. The container inside and outside surface area, A_c, is calculated for each container geometry as follows, depending upon whether the bounding geometry is cylinder (d = outside diameter, h = outside height) or a rectangular prism (l = outside length, w = outside width, h = outside height):

$$A_c = \begin{cases} \pi(d^2 + 2dh) & \text{for a cylinder} \\ 4(lw + wh + lh) & \text{for a retangular prism} \end{cases}$$

[1] Container Tare Weight calculated as average steel packing weight per container instead of current WDS container weight to account for changing container weight over time.

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As applicable, the inside and outside surface areas of all authorized containers shipped in an overpacked configuration, n_{op}, are summed to determine the total payload container surface area that includes the surface area of the outer and all overpacked inner payload containers, A_{ct}, as follows:

$$A_{ct} = A_c + \sum_{i=1}^{n_{op}} A_{c,i} \tag{4}$$

Both the overpacked and direct load configurations employ two comparative methods to estimate the surface area of the iron-based metal waste contents. An estimate of the average iron-based metal waste surface area per container is required because only the weight of iron-based metal waste is explicitly known whereas the steel surface area of containers can be calculated directly. The first method uses a spherical waste surrogate assumption to determine the total surface area, A_{wsph}, of the number of 1 cm spheres required to achieve the average iron-based metal waste weight, W_{wstl}, for each container type. The surface area of spherical waste is found using the volume of the spherical weight V_{wsph}, and the density of iron ρ_{Fe}.

$$A_{wsph} = \frac{3\,V_{wsph}}{r} = \frac{6\,W_{wstl}}{2\,r\,\rho_{Fe}} = \frac{W_{wstl}}{\left(\frac{1}{6}\right)(0.01\text{ m})\left(7{,}817\ \frac{kgf}{m^3}\right)} \tag{5}$$

The second method uses a sheet waste surrogate assumption to determine the total steel surface area of the waste, A_{wsht}, as the product of the waste weight and the payload container's surface area to tare weight, W_{tare}, ratio. Equations used to calculate the surface area of iron-based metal waste are provided below:

$$A_{wsht} = W_{wstl}\left(\frac{A_{ct}}{W_{tare}}\right) \tag{6}$$

The container dimensions, container surface areas, and the estimated waste surface areas using both the spherical and sheet assumptions are presented in Table 2.

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Table 2 Container dimensions, container surface area, and estimated waste surface areas

Container Type	h (m)	d/w (m)	l (m)	A_{ct} (m^2)	A_{wsph} (m^2)	A_{wsht} (m^2)
55-gallon drum (DL)	0.889	0.610	-	4.58	0.47	1.00
12-in Standard Pipe Overpack (DL)	0.699	0.325	-	6.34	0.20	0.15
S100 Pip Overpack (DL)	0.699	0.325	-	6.34	0.00	0.00
S300 Pip Overpack (DL)	0.699	0.325	-	6.34	0.00	0.00
85-gallon drum (OP one drum)	1.022	0.728	-	10.92	2.13	7.80
85-gallon tall drum (DL)	1.022	0.728	-	0.00	0.00	0.00
100-gallon drum (DL of compacted pucks)	0.889	0.813	-	6.62	13.09	19.91
Standard Waste Box (DL)	0.937	1.384	1.803	21.93	17.69	17.08
Standard Waste Box (OP four drums)	0.937	1.384	1.803	40.23	1.51	2.51
Standard Large Box 2 (DL)	1.854	1.753	2.743	52.58	37.43	20.93
Ten Drum Overpack (OP ten drums)	1.858	1.810	-	31.42	69.32	38.93
Ten Drum Overpack (DL)	1.858	1.810	-	77.19	2.01	2.47
Shielded Container (OP one drum)	0.908	0.584	-	8.98	1.25	0.19
RH FL Waste Canister (DL)	3.061	0.660	-	14.06	0.17	0.03
RH RL Waste Canister (DL)	3.061	0.660	-	14.06	0.00	0.00
RH RL Waste Canister (OP 3 drums)	3.061	0.660	-	27.79	2.54	1.76

With the number of containers emplaced, the total weight of the containers, the surface area per container, and the approximations of waste surface area per container the total weight and total surface area can be calculated. These values are presented in Table 3.

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Table 3 Total iron weight and estimated surface areas

Container Type	Total Weight (Tare + Waste) (kgf)	Spherical Surrogate Total Iron Surface Area (m^2)	Sheet Surrogate Total Iron Surface Area (m^2)
55-gallon drum (DL)	3,695,337	542,899	599,676
12-in Standard Pipe Overpack (DL)	3,039,978	176,780	175,459
S100 Pip Overpack (DL)	57,718	5,398	5,398
S300 Pip Overpack (DL)	6,569	386	386
85-gallon drum (OP one drum)	333	65	94
85-gallon tall drum (DL)	0	0	0
100-gallon drum (DL of compacted pucks)	7,818,042	678,059	912,617
Standard Waste Box (DL)	3,686,301	277,477	273,218
Standard Waste Box (OP four drums)	2,126,348	264,878	271,209
Standard Large Box 2 (DL)	402,395	21,151	17,275
Ten Drum Overpack (OP ten drums)	42,439	2,619	1,829
Ten Drum Overpack (DL)	5,815,577	546,286	549,487
Shielded Container (OP one drum)	45,586	583	522
RH FL Waste Canister (DL)	16,808	256	254
RH RL Waste Canister (DL)	517	14	14
RH RL Waste Canister (OP 3 drums)	388,090	21,229	20,687
Total	**27,142,039**	**2,545,398**	**2,835,442**
Total without SCAs	**27,096,531**	**2,544,815**	**2,834,919**
Surface Area per kg Waste (m^2/kg)		**0.094**	**0.105**

Shielded Container Exclusion

In the WDS data, the steel packaging weight per container is equal to the tare weight of each container. For most containers this is reasonable, however for shielded containers a significant portion of the tare weight would be the 1 inch thick lead liner on the side of the container. Including the lead mass as iron mass would lower the iron surface area per kg. With the 3 inch thick steel top and bottom cap, it is expected that the iron surface area per kg for shielded containers will be lower than the average for other containers and waste. With the assumption that higher iron surface areas per kg will be conservative, the emplaced shielded containers will be omitted from the calculation of the iron surface area per kg factor.

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Conclusions

After omitting the shielded containers, the iron surface area per kg of emplaced waste as of December 31, 2020 was 0.094 m^2/kg with a spherical waste assumption and 0.105 m^2/kg with a sheet waste assumption. With the conservative assumption made, the larger value of 0.105 m^2/kg is recommended for use in WIPP PA.

Table 4 Calculated iron surface area per kilogram

Spherical Surface Area per kg Waste (m^2/kg)	Sheet Surface Area per kg Waste (m^2/kg)
0.094	0.105

It is suggested this value be placed in the REFCON material as a new property FESAPKG (Fe Surface Area Per kg). In the ALGEBRACDB step before the Salado Flow calculation, this new property can be multiplied by the total mass of iron in the inventory to get the total surface area. Dividing by the volume of the repository (V_R) gives a new calculation for D_s to replace Equation 3:

$$D_s = \frac{FESAPKG * WTFETOT}{V_R} \quad (7)$$

And the rate of gas generation in moles of gas per second per cubic meter of repository will be found by:

$$G_{rate} = \left(R_{ci}S_b + R_{ch}S_g\right)\frac{D_{N,Fe}}{M_{w,Fe}}\frac{FESAPKG * WTFETOT}{V_R} \quad (8)$$

With this change, the values for REFCON:ASDRUM, REFCON:DRROOM, and REFCON:VROOM previously used to calculate the surface area of iron per cubic meter of repository are no longer needed.

Table 5 Proposed PA parameter

Material	Property	Distribution	Value	Units	Property Description
REFCON	FESAPKG	Constant	0.105	m^2 per kg	Iron (Fe) surface area (m^2) per kilogram (kg) of iron inventory.

The impact on total iron surface area using the proposed methodology versus the current methodology is shown in

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Table 6.

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Table 6 Impact of using surface area per kilogram factor

Analysis	CRA14	CRA19	APPA
Iron Inventory (kg)	4.91E+07	6.31E+07	6.31E+07
D_s (m^2/m^3)	11.2	11.2	11.2
VREPOS (m^3)	438,406.08	438,406.08	819,834.21
Total Surface Area (m^2)	4.91E+06	4.91E+06	9.18E+06
Calculated Surface Area from sheet waste assumption (m^2)	5.14E+06	6.60E+06	6.60E+06

References

Day, B. 2015. Review of the Technical Basis for REFCON: ASDRUM, DRROOM, and VROOM Performance Assessment Analysis Parameters with Comparison to the Currently Emplaced Steel Surface Area per Unit Volume in the WIPP Repository. Sandia National Laboratories. Carlsbad, MN. ERMS 564670.

Day, B. 2019. Analysis Package for Salado Flow in the 2019 Compliance Recertification Application Performance Assessment (CRA-2019 PA). Carlsbad, NM: Sandia national Laboratories. ERMS 571368.

U.S. EPA, 2015. Letter from J. Edwards, USEPA to J. Franco, DOE, Transmitting Fourth Set of Completeness Comments Related to The 2014 WIPP Compliance Recertification Application. July 30, 2015. EPA-HQ-OAR-2014-0609-0024.

U.S. EPA, 2020. Letter to DOE/M. Brown - EPA Completeness Comments #6 on the CRA-2019 (11/13/20). November 13, 2020. EPA-HQ-OAR-2019-0534-0010.

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Appendix A – WDS data from Steve Offner

From: Offner, Steve - NWP <Steve.Offner@wipp.ws>
Sent: Friday, August 27, 2021 11:11 AM
To: Kirkes, G Ross <grkirke@sandia.gov>
Cc: Wagner, Steve <swagner@sandia.gov>
Subject: [EXTERNAL] RE: WDS Data for iron surface area calculation

Hi Ross,

The attached spreadsheet is an update to the original spreadsheet I sent Brad six years ago. (The "day25_calculations.xlsx" spreadsheet attached to your email had been modified by someone else to include additional information.)

Note that the nominal "Container Weights" for most of the container types were recently increased by 5% at the request of the Packaging group. This resulted in increases in the weights of the associated dunnage container types – both directly emplaced and overpacked.

Let me know if you have any questions.

Steve Offner
Government Contractor
WWIS/WDS Database Administrator
offners@wipp.ws
575-200-5326 (cell: call or text)

From: Kirkes, G Ross <grkirke@sandia.gov>
Sent: Thursday, August 26, 2021 2:53 PM
To: Offner, Steve - NWP <Steve.Offner@wipp.ws>
Cc: Wagner, Steve - SNL <SWAGNER@sandia.gov>
Subject: [EXTERNAL]WDS Data for iron surface area calculation

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****
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Use caution if this message contains attachments, links or requests
for information.
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Steve:

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I hope all is well with you.

You performed a WDS data query for Brad Day a few years ago that allowed him to do an iron surface area calculation to determine the gas generating potential due to the corrosion of iron within the repository. I am attaching the spreadsheet you provided to Brad for reference.

We have been asked to update this calculation using more recent disposal information.

Is it possible that you could re-run this query using a data-cutoff date of 12/31/2020? Also, if there are new container types that have been approved (and disposed) since your initial data report for Brad, please add these as well.

Thanks, and feel free to call if you need any further clarification or information to document this request.

G. Ross Kirkes

Piru Associates, Inc.

WIPP FEPs and Regulatory Analyses

Carlsbad Programs Group

Sandia National Laboratories

575 302-6921

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Table 7 Attachment 'day25_2020-12-31.xlsx' sheet 'day25

All Payload Containers and Dunnage Emplaced at WIPP as of 12/31/2020:								
Handling Code	Container Type	Waste Container Count	Dunnage Container Count	Iron-Based Metal Waste (kg)	Steel Packaging (kg)	Steel Liners (kg)	Dunnage Weight (kg)	Total Iron-Based Metal (kg)
CH	100GD	34,407	1	5,867,404.48	1,950,577.70		59.54	**7,818,041.72**
	55GD	101,254	6,244	663,877.46	2,843,952.35	487.80	187,507.32	**3,695,824.93**
	85GD OP	5		138.82	194.25			**333.07**
	85GD Tall		2				77.70	**77.70**
	POP 12-in	27,062		55,013.23	2,970,551.14	14,413.70		**3,039,978.07**
	POP S100	852			57,718.06			**57,718.06**
	POP S300	61			6,569.30			**6,569.30**
	SLB2	235		114,590.80	287,804.50			**402,395.30**
	SWB	6,989	15	1,614,283.73	2,067,445.52		4,572.23	**3,686,301.48**
	SWB OP	6,346		840,497.19	2,001,683.25			**2,842,180.44**
	TDOP	6,898		2,125,833.55	5,634,989.47			**7,760,823.02**
	TDOP DL	26		19,618.80	18,956.36	3,864.00		**42,439.16**
	Totals:	**184,135**	**6,262**	**11,301,258.06**	**17,840,441.90**	**18,765.50**	**192,216.78**	**29,352,682.24**
RH	72-B Fixed DL	18		39.60	16,768.59			**16,808.19**
	72-B Rem DL	1			517.00			**517.00**
	72-B Rem OP	700		82,348.81	364,961.33			**447,310.14**
	SCA	56	1	0.00	43,835.12	929.30	821.90	**45,586.32**
	Totals:	**775**	**1**	**82,388.41**	**426,082.04**	**929.30**	**821.90**	**510,221.66**
Grand	**Totals:**	**184,910**	**6,263**	**11,383,646.47**	**18,266,523.94**	**19,694.80**	**193,038.68**	**29,862,903.90**

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Table 8 Attachment 'day25_2020-12-31.xlsx' sheet 'Container Weights'

WDS Container Weights:		
Type Code	Description	Container Weight (kg)
1	55GD	30.03
2	SWB	304.82
5	12-in POP	115.82
6	6-in POP	72.87
10	72-B Rem	517.01
13	S100 POP	74.03
20	TDOP	809.53
21	85GD Tall	38.85
22	85GD Short	38.85
23	100GD	59.54
24	S200A POP	193.83
25	S200B POP	193.83
26	S300 POP	115.29
35	30GD	16.36
36	72-B Fixed	799.09
41	15GD	8.62
43	NS15 NSC	938.78
45	NS30 NSC	752.83
47	SLB2	1,224.49
48	SCA	821.90
49	CCO	109.52

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Appendix B – Surface Area per kilogram calculation

Table 9 Containers emplaced and average iron-based metal

Handling Code	Container Type	Average Iron-Based Metal Waste per Container Type (kg)	Average Iron-Based Metal Waste per Container Type (lbf)	Average Steel Packaging Weight (kg)	Container Type	No. Containers Emplaced (#)	No. Containers plus Dunnage Emplaced (#)	Average Iron-Based Metal Waste per Container Type (kg)	Container Weight (kg)
CH	100GD	170.52	375.94	56.69	100GD	34,407	34,408	170.52	59.54
	55GD	6.18	13.63	28.20	55GD	101,254	107,498	6.18	30.03
	85GD OP	27.76	61.21	38.85	85GD OP	5	5	27.76	38.85
	85GD Tall	0.00	0.00	38.85	85GD Tall	0	2	0.00	38.85
	POP 12-in	2.57	5.66	109.77	POP 12-in	27,062	27,062	2.57	115.82
	POP S100	0.00	0.00	67.74	POP S100	852	852	0.00	74.03
	POP S300	0.00	0.00	107.69	POP S300	61	61	0.00	115.29
	SLB2	487.62	1075.02	1224.70	SLB2	235	235	487.62	1,224.49
	SWB	230.48	508.12	295.83	SWB	6,989	7,004	230.48	304.82
	SWB OP	19.64	43.31	315.42	SWB OP	6,346	6,346	19.64	304.82
	TDOP	26.18	57.72	816.90	TDOP	6,898	6,898	26.18	809.53
	TDOP DL	903.18	1991.18	729.09	TDOP DL	26	26	903.18	809.53
					72-B Fixed DL	18	18	2.20	799.09
					72-B Rem DL	1	1	0.00	517.01
RH	72-B Fixed DL	2.20	4.85	931.59	72-B Rem OP	700	700	33.04	517.01
	72-B Rem DL	0.00	0.00	517.00	SCA	56	57	16.30	821.90
	72-B Rem OP	33.04	72.84	521.37					
	SCA	16.30	35.94	783.46					
55GD Container Weight (kg)	28.20	Note that nominal container tare weights have been changed through time. This has a noticable impact on the iron-based metal waste without overpack calculation. Using the Average Steel Packaging Weight, should capture an average overpack container weight closely.							

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Table 10 Surface Area per kilogram calculation (with SCAs)

Calculations:														
Spherical Surrogate Waste A/V/W Relationship:														
Sphere Diameter (m)	0.010													
Sphere Area (m^2)	3.142E-04													
Sphere Volume (m^3)	5.236E-07													
Sphere Weight (kgf)	4.093E-03													

Calculation of Emplaced Container A/V Ratio Based on Payload Container Type Comparing Two Waste Surrogates (spherical surrogate as 1" cm spheres, sheet surrogate scaled by the waste to payload container weight fraction)

	Container Dimensions and Weight				WDS Emplacement Data		Container + Waste Steel Surface Area			Spherical Waste Surrogate	Sheet Waste Surrogate	Total Weights		
Container Type	Height (m)	Diameter or Width (m)	Length (m)	Tare Weight (kgf)	No. of Waste and Dunnage Containers Emplaced (#)	Average Steel Waste Weight per Container (kgf)	Outer and Overpacked Container(s) (m^2)	Spherical Surrogate Waste Equivalent (m^2)	Sheet Surrogate Waste Equivalent (m^2)	Total Steel Surface Area (m^2)	Total Steel Surface Area(m^2)	Total Tare Weight (kgf)	Total Waste Weight (kgf)	Total Weight
55GD	0.889	0.610		28.20	107,498	6.18	4.58	0.47	1.00	542,899	599,676	3,031,459.67	663,877.46	3,695,337
POP 12-in	0.699	0.325		109.77	27,062	2.57	6.34	0.20	0.15	176,780	175,459	2,970,551.14	69,426.93	3,039,978
POP S100	0.699	0.325		67.74	852	0.00	6.34	0.00	0.00	5,398	5,398	57,718.06	0.00	57,718
POP S300	0.699	0.325		107.69	61	0.00	6.34	0.00	0.00	386	386	6,569.30	0.00	6,569
85GD OP	1.022	0.728		38.85	5	27.76	10.92	2.13	7.80	65	94	194.25	138.82	333
85GD Tall	1.022	0.728		38.85	0	0.00	0.00	0.00	0.00	0	0	0.00	0.00	0
100GD	0.889	0.813		56.69	34,408	170.52	6.62	13.09	19.91	678,059	912,617	1,950,637.24	5,867,404.48	7,818,042
SWB DL	0.937	1.384	1.803	295.83	7,004	230.48	21.93	17.69	17.08	277,477	273,218	2,072,017.75	1,614,283.73	3,686,301
SWB OP	0.937	1.384	1.803	315.42	6,346	19.64	40.23	1.51	2.51	264,878	271,209	2,001,683.25	124,664.60	2,126,348
SLB2	1.854	1.753	2.743	1224.70	235	487.62	52.58	37.43	20.93	21,151	17,275	287,804.50	114,590.80	402,395
TDOP DL	1.858	1.810		729.09	26	903.18	31.42	69.32	38.93	2,619	1,829	18,956.36	23,482.80	42,439
TDOP OP	1.858	1.810		816.90	6,898	26.18	77.19	2.01	2.47	546,286	549,487	5,634,989.47	180,587.24	5,815,577
SCA	0.908	0.584		783.46	57	16.30	8.98	1.25	0.19	583	522	44,657.02	929.30	45,586
FLC DL	3.061	0.660		931.59	18	2.20	14.06	0.17	0.03	256	254	16,768.59	39.60	16,808
RLC DL	3.061	0.660		517.00	1	0.00	14.06	0.00	0.00	14	14	517.00	0.00	517
RLC OP	3.061	0.660		521.37	700	33.04	27.79	2.54	1.76	21,229	20,687	364,961.33	23,128.50	388,090
SHIELD PLUG	1.829	0.737			719		10.18			7,317	7,317	0.00	0.00	0
Total										2,545,398	2,835,442	18,459,485	8,682,554	27,142,039
													Spherical Surface Area per kg Waste (m^2/kg)	Sheet Surface Area per kg Waste (m^2/kg)
													0.094	0.104

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Table 11 Surface Area per kilogram calculation (without SCAs)

Calculations:														
Spherical Surrogate Waste A/V/W Relationship:														
Sphere Diameter (m)	0.010													
Sphere Area (m^2)	3.142E-04													
Sphere Volume (m^3)	5.236E-07													
Sphere Weight (kgf)	4.093E-03													

Calculation of Emplaced Container A/V Ratio Based on Payload Container Type Comparing Two Waste Surrogates (spherical surrogate as 1" cm spheres, sheet surrogate scaled by the waste to payload container weight fraction)

	Container Dimensions and Weight				WDS Emplacement Data		Container + Waste Steel Surface Area			Spherical Waste Surrogate	Sheet Waste Surrogate	Total Weights		
Container Type	Height (m)	Diameter or Width (m)	Length (m)	Tare Weight (kgf)	No. of Waste and Dunnage Containers Emplaced (#)	Average Steel Waste Weight per Container (kgf)	Outer and Overpacked Container(s) (m^2)	Spherical Surrogate Waste Equivalent (m^2)	Sheet Surrogate Waste Equivalent (m^2)	Total Steel Surface Area (m^2)	Total Steel Surface Area(m^2)	Total Tare Weight (kgf)	Total Waste Weight (kgf)	Total Weight
55GD	0.889	0.610		28.20	107,498	6.18	4.58	0.47	1.00	542,899	599,676	3,031,459.67	663,877.46	3,695,337.13
POP 12-in	0.699	0.325		109.77	27,062	2.57	6.34	0.20	0.15	176,780	175,459	2,970,551.14	69,426.93	3,039,978.07
POP S100	0.699	0.325		67.74	852	0.00	6.34	0.00	0.00	5,398	5,398	57,718.06	0.00	57,718.06
POP S300	0.699	0.325		107.69	61	0.00	6.34	0.00	0.00	386	386	6,569.30	0.00	6,569.30
85GD OP	1.022	0.728		38.85	5	27.76	10.92	2.13	7.80	65	94	194.25	138.82	333.07
85GD Tall	1.022	0.728		38.85	2	0.00	0.00	0.00	0.00	0	0	77.70	0.00	77.70
100GD	0.889	0.813		56.69	34,408	170.52	6.62	13.09	19.91	678,059	912,617	1,950,637.24	5,867,404.48	7,818,041.72
SWB DL	0.937	1.384	1.803	295.83	7,004	230.48	21.93	17.69	17.08	277,477	273,218	2,072,017.75	1,614,283.73	3,686,301.48
SWB OP	0.937	1.384	1.803	315.42	6,346	19.64	40.23	1.51	2.51	264,878	271,209	2,001,683.25	124,664.60	2,126,347.85
SLB2	1.854	1.753	2.743	1224.70	235	487.62	52.58	37.43	20.93	21,151	17,275	287,804.50	114,590.80	402,395.30
TDOP DL	1.858	1.810		729.09	26	903.18	31.42	69.32	38.93	2,619	1,829	18,956.36	23,482.80	42,439.16
TDOP OP	1.858	1.810		816.90	6,898	26.18	77.19	2.01	2.47	546,286	549,487	5,634,989.47	180,587.24	5,815,576.71
SCA	0.908	0.584		783.46	0	16.30	8.98	1.25	0.19	0	0	0.00	0.00	0.00
FLC DL	3.061	0.660		931.59	18	2.20	14.06	0.17	0.03	256	254	16,768.59	39.60	16,808.19
RLC DL	3.061	0.660		517.00	1	0.00	14.06	0.00	0.00	14	14	517.00	0.00	517.00
RLC OP	3.061	0.660		521.37	700	33.04	27.79	2.54	1.76	21,229	20,687	364,961.33	23,128.50	388,089.83
SHIELD PLUG	1.829	0.737			719		10.18			7,317	7,317	0.00	0.00	0.00
Total										2,544,815	2,834,919	18,414,906	8,681,625	27,096,531
													Spherical Surface Area per kg Waste (m^2/kg)	Sheet Surface Area per kg Waste (m^2/kg)
													9.39E-02	1.05E-01

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Table 12 Surface Area per kilogram calculation (formulas shown)

Calculations:

Spherical Surrogate Waste A/V/W Relationship:

Sphere Diameter (m)	0.01
Sphere Area (m^2)	=4*PI()*(B22/2)^2
Sphere Volume (m^3)	=(4/3)*PI()*(B22/2)^3
Sphere Weight (kgf)	=B24*7817

Calculation of Emplaced Container A/V Ratio Based on Payload Container Type Comparing Two Waste Surrogates (spherical surrogate as 1" cm spheres, sheet surrogate scaled by the waste to payload container weight fraction)

	Container Dimensions and Weight				WDS Emplacement Data		Container + Waste Steel Surface Area			Spherical Waste Surrogate	Sheet Waste Surrogate	Total Weights		
Container Type	Height (m)	Diameter or Width (m)	Length (m)	Tare Weight (kgf)	No. of Waste and Dunnage Containers Emplaced (#)	Average Steel Waste Weight per Container (kgf)	Outer and Overpacked Container(s) (m^2)	Spherical Surrogate Waste Equivalent (m^2)	Sheet Surrogate Waste Equivalent (m^2)	Total Steel Surface Area (m^2)	Total Steel Surface Area(m^2)	Total Tare Weight (kgf)	Total Waste Weight (kgf)	Total Weight
55GD	0.889	0.61		='day25'!M5	='day25'!Q5	='day25'!R5	=4*PI()*((B32*(C32/2)+(C32/2)^2))	=(G32/$B$25)*$B$23	=(G32/E32)*H32	=F32*(H32+I32)	=F32*(H32+J32)	=F32*E32	=G32*F32	=M32+N32
POP 12-in	0.699	0.325		='day25'!M8	='day25'!Q8	='day25'!R8	=4*PI()*((B33*(C33/2)+(C33/2)^2))+$H$32	=(G33/$B$25)*$B$23	=(G33/E33)*H33	=F33*(H33+I33)	=F33*(H33+J33)	=F33*E33	=G33*F33	=M33+N33
POP S100	0.699	0.325		='day25'!M9	='day25'!Q9	='day25'!R9	=4*PI()*((B34*(C34/2)+(C34/2)^2))+$H$32	=(G34/$B$25)*$B$23	=(G34/E34)*H34	=F34*(H34+I34)	=F34*(H34+J34)	=F34*E34	=G34*F34	=M34+N34
POP S300	0.699	0.325		='day25'!M10	='day25'!Q10	='day25'!R10	=4*PI()*((B35*(C35/2)+(C35/2)^2))+$H$32	=(G35/$B$25)*$B$23	=(G35/E35)*H35	=F35*(H35+I35)	=F35*(H35+J35)	=F35*E35	=G35*F35	=M35+N35
85GD OP	1.022	0.728		='day25'!M6	='day25'!Q6	='day25'!R6	=4*PI()*((B36*(C36/2)+(C36/2)^2))+$H$32	=(G36/$B$25)*$B$23	=(G36/E36)*H36	=F36*(H36+I36)	=F36*(H36+J36)	=F36*E36	=G36*F36	=M36+N36
85GD Tall	1.022	0.728		='day25'!M6	='day25'!R7	0	0	0	0	=F37*(H37+I37)	=F37*(H37+J37)	=F37*E37	=G37*F37	=M37+N37
100GD	0.889	0.813		='day25'!M7	='day25'!Q4	='day25'!R4	=4*PI()*((B38*(C38/2)+(C38/2)^2))	=(G38/$B$25)*$B$23	=(G38/E38)*H38	=F38*(H38+I38)	=F38*(H38+J38)	=F38*E38	=G38*F38	=M38+N38
SWB DL	0.937	1.384	1.803	='day25'!M12	='day25'!Q12	='day25'!R12	=4*(B39*C39+C39*D39+B39*D39)	=(G39/$B$25)*$B$23	=(G39/E39)*H39	=F39*(H39+I39)	=F39*(H39+J39)	=F39*E39	=G39*F39	=M39+N39
SWB OP	0.937	1.384	1.803	='day25'!M13	='day25'!Q13	='day25'!R13	=4*(B40*C40+C40*D40+B40*D40)+4*$H$32	=(G40/$B$25)*$B$23	=(G40/E40)*H40	=F40*(H40+I40)	=F40*(H40+J40)	=F40*E40	=G40*F40	=M40+N40
SLB2	1.854	1.753	2.743	='day25'!M11	='day25'!Q11	='day25'!R11	=4*(B41*C41+C41*D41+B41*D41)	=(G41/$B$25)*$B$23	=(G41/E41)*H41	=F41*(H41+I41)	=F41*(H41+J41)	=F41*E41	=G41*F41	=M41+N41
TDOP DL	1.858	1.81		='day25'!M15	='day25'!Q15	='day25'!R15	=4*PI()*((B42*(C42/2)+(C42/2)^2))	=(G42/$B$25)*$B$23	=(G42/E42)*H42	=F42*(H42+I42)	=F42*(H42+J42)	=F42*E42	=G42*F42	=M42+N42
TDOP OP	1.858	1.81		='day25'!M14	='day25'!Q14	='day25'!R14	=4*PI()*((B43*(C43/2)+(C43/2)^2))+10*$H$32	=(G43/$B$25)*$B$23	=(G43/E43)*H43	=F43*(H43+I43)	=F43*(H43+J43)	=F43*E43	=G43*F43	=M43+N43
SCA	0.908	0.584		='day25'!M21	='day25'!Q19	='day25'!R19	=4*PI()*((B44*(C44/2)+(C44/2)^2))+$H$32	=(G44/$B$25)*$B$23	=(G44/E44)*H44	=F44*(H44+I44)	=F44*(H44+J44)	=F44*E44	=G44*F44	=M44+N44
FLC DL	3.061	0.66		='day25'!M18	='day25'!Q16	='day25'!R16	=4*PI()*((B45*(C45/2)+(C45/2)^2))	=(G45/$B$25)*$B$23	=(G45/E45)*H45	=F45*(H45+I45)	=F45*(H45+J45)	=F45*E45	=G45*F45	=M45+N45
RLC DL	3.061	0.66		='day25'!M19	='day25'!Q17	='day25'!R17	=4*PI()*((B46*(C46/2)+(C46/2)^2))	=(G46/$B$25)*$B$23	=(G46/E46)*H46	=F46*(H46+I46)	=F46*(H46+J46)	=F46*E46	=G46*F46	=M46+N46
RLC OP	3.061	0.66		='day25'!M20	='day25'!Q18	='day25'!R18	=4*PI()*((B47*(C47/2)+(C47/2)^2))+3*$H$32	=(G47/$B$25)*$B$23	=(G47/E47)*H47	=F47*(H47+I47)	=F47*(H47+J47)	=F47*E47	=G47*F47	=M47+N47
SHIELD PLUG	1.829	0.737			=SUM(F45:F47)		=4*PI()*((B48*(C48/2)+(C48/2)^2))			=F48*(H48)	=F48*(H48)	=F48*E48	=G48*F48	=M48+N48
Total										=SUM(K32:K48)	=SUM(L32:L48)	=SUM(M32:M48)	=SUM(N32:N48)	=SUM(O32:O48)
													Spherical Surface Area per kg Waste (m^2/kg)	Sheet Surface Area per kg Waste (m^2/kg)
													=K49/O49	=L49/O49

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