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**Y-12 OLD SALVAGE YARD
SCRAP METAL
CHARACTERIZATION STUDY**

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Waste Management and D&D Division
Oak Ridge Y-12 Plant

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Prepared by the
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
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Y-12 OLD SALVAGE YARD SCRAP METAL CHARACTERIZATION STUDY

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ABSTRACT

The purpose of the Y-12 Old Salvage Yard Scrap Metal Characterization Study is to make conservative estimates of the quantities of total uranium and the wt % ^{235}U contained in scrap metal. The original project scope included estimates of thorium, but due to the insignificant quantities found in the yards, thorium was excluded from further analysis. Metal in three of the four Y-12 scrap metal yards were characterized. The scrap metal yard east of the PIDAS fence is managed by the Environmental Restoration Program and therefore was not included in this study. For all Y-12 Plant scrap metal shipments, Waste Transportation, Storage, and Disposal (WTSD) personnel must complete a "Request for Authorization to Ship Nuclear Materials, UCN-16409, which requires the grams of total uranium, the wt % ^{235}U , and the grams of ^{235}U contained in the shipment. This information is necessary to ensure compliance with Department of Transportation regulations, as well as to ensure that the receiving facility is adhering to its operating license. This characterization study was designed to provide a technical basis for determining these necessary radioactive quantities.

1. SAMPLING PLAN

The sampling plan for the Old Salvage Yard Scrap Metal Characterization Study is described in the following section. Figure 1 illustrates the physical layout of the Old Salvage Yard. This layout shows four areas where scrap metal is placed for storage. Areas 1, 2, and 4 are radiological areas, while Area 3 is designated as a clean area. The initial scope of this project included sampling from all four areas.

The sample size used to characterize the Old Salvage Yard was based on documentation from the U.S. Environmental Protection Agency (EPA) Region IV Hazardous Waste Site Field Sampling Workshop (June 1993). The formula used to determine the number of samples is:

$$n = \frac{t_{\alpha}^2 (CV)^2}{p^2} \quad (1)$$

Note: All measurements have been rounded to the nearest 5 feet.

Figure 1. Physical Layout of the Old Salvage Yard.

where

n = number of samples,

t_{α} = confidence level,

CV = coefficient of variation (%), and

p = allowable margin of error (%).

For this sampling plan:

$t_{\alpha} = 1.282$ (for confidence level, $\alpha = 0.90$), (2)

CV = 0.65, and

$p = 0.10$.

The CV is an assumption based on EPA guidelines.

Using the above values, the calculated sample size was 70. To account for any problems that might occur during the sampling, it was decided to add five samples, bringing the sample size to 75. Table 1 shows how the samples were partitioned to each area.

Table 1. Distribution of Samples

<u>Location</u>	<u>Number of samples</u>
Area 1	20
Area 2	20
Area 3	15
Area 4	20
Total	75

To obtain the best estimates of the amount of radiological contamination, more samples were taken from the radiation areas than the clean area. Each area was then gridded into 25-ft by 25-ft squares. The grids were numbered, and a random number generator was used to select which grids would be sampled. On July 16, 1993, Waste Management turned Area 4 over to Environmental Restoration; therefore, the scrap metal in Area 4 was removed from the scope of this study. The samples from Area 4 were redistributed to Areas 1 and 2. Table 2 shows the redistribution of samples.

Table 2. Redistribution of Samples

<u>Location</u>	<u>Number of Samples</u>
Area 1	30
Area 2	30
Area 3	15
Area 4	<u>0</u>
Total	75

Figures 2-4 illustrate the locations where samples were taken once Area 4 was omitted from the scope of the project. The samples were taken by the project engineer, project statistician, the sampling crew supervisor, the sampling crew, and a health physics technician. The health physics technician used alpha detection meters and beta/gamma detection meters to obtain the hottest samples within a gridded area.

Location of Samples Taken SY-H1 -- Area 1

	1	2	3	4	5	6	7	8
A	E931880097	E931880098	E931900070	E931880100				
B	E931880099	E931880101	E931880102 E931900076	E931890000 E931900074	E931890001		E931890002	
C	E931890003	E931890004	E931890005 E931900077	E931890006 E931900079	E931890007 E931900069	E931890008 E931900072	E931890009 E931900081	E931890010
D	E931890011		E931900065	E931900066	E931890012		E931890013

Figure 2. Location of Samples Taken SY-H1 - Area 1.

Grids are 25' by 25'.

Location of Samples Taken SY-H1 -- Area 2

	9	10	11	12	13
E	E931890060		E931900062 E931900030		
F		E931900061	E931900060 E931890061	E931890062	E931900032
G	E931890064*	E931890065 E931900063		E932160000 E931890067	
H	E931900005	E931900003 E932160001			
I	E931900007	E931900008 E931900064*	E931900024		
J	E931900027	E931900058 E931900028	E931900026 E931900059 E931900029		
K	E931900055 E931900031	E931900056 E931890063	E931900057

* Sample taken from scrap metal that had been moved from grids F6, F7, F8, G9, G10, and G11.

Grids are 25' by 25'.

Figure 3. Location of Samples Taken SY-H1 - Area 2.

Location of Samples Taken SY-C3 -- Area 3

● Grids to be sampled.
Grids are 25' by 25'.

Figure 4. Location of Samples Taken SY-C3 - Area 3.

2. SAMPLING OBSERVATIONS

During the course of sampling, some deviations from the original sampling plan occurred. These deviations are as follows:

- Five grids in Area 2 contained no scrap metal, and therefore, samples were taken from other grids within Area 2.
- Two samples from Area 2 could not be pinpointed to a specific grid but were taken from scrap metal that had been moved from grids 6, 7, 8, 11, 12, and 13.
- Only the perimeter grids in Area 3 could be sampled due to telephone and electrical wires located in the interior of the area.

In order to sample the interior grids of the area, a track excavator was used to remove the metal, allowing access to the grids requiring sampling. The wires mentioned above in Area 3 prevented the excavator from digging a path to sample the interior grids. If access to the interior of Area 3 allows future sampling, the four remaining samples could be taken and an addendum issued to this report.

3. SAMPLE PREPARATION AND ANALYSIS

The metal samples were double bagged, identified with Environmental Laboratory Information Management System (ELIMS) numbers, and submitted to the Y-12 Analytical Laboratory using chain of custody procedures. Each sample was analyzed for total uranium concentration ($\mu\text{g/g}$), wt % ^{235}U , and thorium concentration ($\mu\text{g/g}$). Although efforts were made to submit approximately 10-g samples to the laboratory, sample weights range from 7.2 to 751.3 grams. The material composition, limited availability of sampling tools, and the difficulty in retrieving samples in the Old Salvage Yard contributed to the large variation in sample weight. Most samples with the exception of metallic oxides were machined to provide the laboratory with a sample that could be dissolved. The actual sample weights used ranged from 1.2898 to 10.8611 grams, with most samples falling in the 2- to 5-g weight range.

The method used to determine total uranium concentration ($\mu\text{g/g}$) and wt % ^{235}U was thermal ionization mass spectrometry. In preparation for this technique, each metal sample was first dissolved in either nitric acid or a nitric/hydrochloric acid mixture. The solution was then passed through Eichrome U/TEVA*Spec^R uranium tetravalent actinide resin columns that separated uranium from the metal matrix. This separated uranium solution was then dried and placed on a rhenium filament for analysis in a thermal ionization mass spectrometer. This analysis provided the total uranium concentration ($\mu\text{g/g}$) and wt % ^{235}U present for each sample.

The technique used to provide thorium concentration ($\mu\text{g/g}$) was colorimetry. The same metallic dissolutions were used for the thorium ($\mu\text{g/g}$) determinations as were used for the uranium analyses. Each sample was spiked prior to chemical separation using ion exchange resin columns. The separated thorium solution was dried and then mixed with hydrochloric acid. A spectrometer was used to measure the absorbance of this solution, as well as known 10 μg , 20 μg , 40 μg , and blank standards. Spectrometer results were used to calculate the thorium concentration ($\mu\text{g/g}$) in each sample.

4. STATISTICAL ANALYSIS OF DATA

Table 3 provides a summary of all sample identification information, field results, and laboratory results. The sample identification information includes the date each sample was taken, the ELIMS number, and the customer identification number. The ELIMS number is the official unique number assigned to track a sample through the Y-12 Plant laboratory, while the customer identification number is a WTSD number identifying the sample location. The field results were obtained by using hand-held health physics alpha detection and beta/gamma detection meters. Both the alpha and beta/gamma results are in disintegrations per minute (DPM). These readings were used to assure that contaminated samples were obtained. The laboratory results include total uranium ($\mu\text{g/g}$), wt % ^{235}U , a calculated confidence limit on the ^{235}U wt %, and thorium ($\mu\text{g/g}$). The confidence ^{235}U ($\pm$) represents the 95% confidence limit on the isotopic wt % only. The 95% confidence limit is calculated from the standard deviation calculated at one standard deviation by the Finnigan-Mat, Model 251 thermal ionization mass spectrometer. For example, the wt % ^{235}U and confidence limit ^{235}U ($\pm$) for sample E931880097 were reported as 0.22 And 0.05, respectively. This means there is 95% certainty that the actual value for wt % ^{235}U is between 0.17 and 0.27. The total weight (g) is the entire sample of scrap metal submitted to the plant lab, while the sample weight (g) is the amount of metal that laboratory personnel used to obtain the results.

The laboratory results displayed sample-to-sample variation in total uranium and wt % ^{235}U values and very little variation in thorium. Of the 71 thorium results, 37 are detection limit results, and only five of the results are greater than 25 $\mu\text{g/g}$. Including the detection limit results, 66 results have values less than 10 $\mu\text{g/g}$. For this reason, no further analyses were done for thorium. Figures 5 and 6 illustrate the spread of the total uranium and wt % ^{235}U . The total uranium results range from 0.3 to 863,501 $\mu\text{g/g}$ and the wt % ^{235}U ranges from 0.18 to 78. The 78 wt % result is considered a statistical outlier and will be excluded from all subsequent calculations. Although the result is an outlier, it is addressed in the following paragraph. Fifty-seven of the 71 results for weight % ^{235}U are less than 0.54 wt %. Seven of those 57 results are reported as "not applicable" due to the low total uranium concentration values. The laboratory technique for detecting wt % ^{235}U is unreliable for total uranium concentrations less than 1.5 $\mu\text{g/g}$.

Although it is valid statistically to treat the 78 wt % ^{235}U as an outlier, due to the legal implications of shipping and receiving enriched material, the elimination of this data point can easily be misconstrued. The

Table 3: Old Salvage Yard Samples Submitted To Plant Laboratory

Date Taken	ELIMS Number	Customer ID	Field Results		Lab Results					
			Alpha DPM	Beta / Gamma DPM	Total U ug/g	U_235 WT %	Confidence U_235	Thorium ug/g	Sample WT (G)	Total WT (G)
22-Jul-93	E931880097	OSYA1A1	0	300,000 (0.4 mr/hr)	14,502.0	0.22	+/-0.05	2.6	2.9845	24.1
22-Jul-93	E931880098	OSYA1A2	0	36,000	1,028.0	0.21	+/-0.05	133	3.1319	41.9
23-Jul-93	E931900070	OSYA1A3	0	90,000	92,259.0	0.20	+/-0.05	<8.7	2.9090	41.5
22-Jul-93	E931880100	OSYA1A4	0	27,000	1,392.0	0.38	+/-0.10	<1.8	3.0907	22.3
22-Jul-93	E931880099	OSYA1B1	0	75,000 (0.2 mr/hr)	6,250.0	0.20	+/-0.05	<1.6	3.0655	33.4
3-Aug-93	E931880101	OSYA1B2	0	15,000	532.0	0.37	+/-0.10	1.5	4.5117	31.2
2-Aug-93	E931880102	OSYA1B3	0	5,000	101.0	0.35	+/-0.10	<1.3	3.5182	18.9
3-Aug-93	E931900076	OSYA1B3-2	0	150,000	99,978.0	0.20	+/-0.05	6.8	1.9143	33.5
2-Aug-93	E931890000	OSYA1B4	0	9,000	4.3	0.54	+/-0.20	<2.1	2.3413	26.7
2-Aug-93	E931900074	OSYA1B4-2	0	90,000	31,899.0	1.90	+/-0.20	140	3.0758	8.0
23-Jul-93	E931890001	OSYA1B5	0	9,000	253.0	0.21	+/-0.05	<0.7	7.2408	7.2
3-Aug-93	E931890002	OSYA1B7	0	3,000,000	847,771.0	0.20	N/A	<3.3	1.6931	57.5
22-Jul-93	E931890003	OSYA1C1	0	30,000	880.0	0.23	+/-0.05	4.5	2.9280	10.0
3-Aug-93	E931890004	OSYA1C2	0	30,000	120.0	0.54	+/-0.10	<2.2	2.4465	21.8
3-Aug-93	E931890005	OSYA1C3	0	25,000	1,403.0	1.00	+/-0.20	1200	3.6661	28.4
3-Aug-93	E931900077	OSYA1C3-2	0	90,000	39,189.0	0.38	+/-0.10	<1.8	3.0398	13.3
2-Aug-93	E931890006	OSYA1C4	0	12,000	320.0	0.89	+/-0.20	8.2	3.0288	19.2
3-Aug-93	E931900079	OSYA1C4-2	0	25,000	455.0	0.98	+/-0.20	25	3.8587	36.9
22-Jul-93	E931890007	OSYA1C5	0	6,000	262.0	0.20	+/-0.05	<1.6	3.0209	32.3
3-Aug-93	E931900069	OSYA1C5-2	0	9,000	260.0	1.60	+/-0.10	4.1	2.4091	13.2
22-Jul-93	E931890008	OSYA1C6	0	12,000	224.0	0.26	+/-0.05	<1.6	3.2571	60.4
2-Aug-93	E931900072	OSYA1C6-2	0	30,000	755.0	1.30	+/-0.30	<8.5	0.5536	24.6
22-Jul-93	E931890009	OSYA1C7	0	6,000,000 (25 mr/hr)	844,638.0	0.20	N/A	<1.3	4.1024	94.3
3-Aug-93	E931900081	OSYA1C7-2	0	300,000 (>300,000)	734,978.0	0.20	N/A	<1.6	3.2750	43.6
22-Jul-93	E931890010	OSYA1C8	0	5,100,000 (12 mr/hr)	863,501.0	0.20	N/A	<1.9	2.8931	50.3
22-Jul-93	E931890011	OSYA1D1	0	75,000 (0.2 mr/hr)	5,372.0	0.19	+/-0.05	3.1	3.5005	32.5
23-Jul-93	E931900065	OSYA1D3	0	30,000	7,570.0	0.22	+/-0.05	8.6	3.5051	23.3
23-Jul-93	E931900066	OSYA1D4	0	15,000	138.0	0.50	+/-0.10	0.5	10.8611	26.4
22-Jul-93	E931890012	OSYA1D5	0	300,000 (0.7 mr/hr)	21,186.0	0.20	+/-0.05	<1.5	3.4286	42.3
23-Jul-93	E931890013	OSYA1D7	0	30,000	559.0	0.41	+/-0.10	5	5.0809	54.0
16-Jul-93	E931900030	OSYA2E11	400	30,000	528.0	0.18	+/-0.05	1.7	3.0612	247.0
21-Jul-93	E931900062	OSYA2E11-2	0	45,000	203.0	0.21	+/-0.05	3.5	3.3113	128.0
16-Jul-93	E931890060	OSYA2E9	0	30,000	399.0	1.26	+/-0.20	<3.6	1.3118	17.5
21-Jul-93	E931900061	OSYA2F10	0	7,000	653.0	0.28	+/-0.05	6.3	3.7804	26.6
21-Jul-93	E931890061	OSYA2F11	0	9,000	1.9	1.07	N/A	<1.3	1.7758	37.1
21-Jul-93	E931900060	OSYA2F11-2	0	12,000	5.3	1.30	+/-0.30	<1.30	3.8298	44.9
13-Jul-93	E931890062	OSYA2F12	0	7,500	285.0	0.94	+/-0.20	2.2	2.1035	211.6

Table 3 (continued): Old Salvage Yard Samples Submitted To Plant Laboratory

Date Taken	ELIMS Number	Customer ID	Field Results		Lab Results					
			Alpha DPM	Beta / Gamma DPM	Total U ug/g	U_235 WT %	Confidence U_235	Thorium ug/g	Sample WT (G)	Total WT (G)
15-Jul-93	E931900032	OSYA2F13	0	1,800	61.0	0.29	+/-0.10	2.7	3.1763	46.0
13-Jul-93	E931890065	OSYA2G10	0	9,000	600.0	0.33	+/-0.10	1.6	3.8706	206.4
21-Jul-93	E931900063	OSYA2G10-2	0	30,000	45.0	0.24	+/-0.10	<1.8	3.0015	145.0
13-Jul-93	E931890067	OSYA2G12	1,600	1,200,000 (Too Large)	-	-	-	-	-	-
4-Aug-93	E932160000	OSYA2G12	4,000	1,500,000	238,262.0	0.18	+/-0.05	140	2.6970	15.2
20-Jul-93	E931890064	OSYA2G9	1,000	300,000	8,070.0	0.98	+/-0.20	<1.6	2.9807	10.6
13-Jul-93	E931900003	OSYA2H10	0	9,000	300.0	0.28	+/-0.10	<1.6	3.1897	148.3
4-Aug-93	E932160001	OSYA2H10-3	0	30,000	938.0	0.76	+/-0.10	3.4	3.0520	16.5
14-Jul-93	E931900005	OSYA2H9	0	30,000	47.0	0.25	+/-0.10	<1.5	3.3252	243.4
14-Jul-93	E931900064	OSYA2I10	0	30,000	940.0	0.37	+/-0.10	2.7	3.5207	96.1
21-Jul-93	E931900008	OSYA2I10-2	0	30,000	875.0	0.21	+/-0.05	<1.9	2.8623	15.0
13-Jul-93	E931900024	OSYA2I11	0	5,000	22.0	0.34	+/-0.10	1.2	6.0551	-
14-Jul-93	E931900007	OSYA2I9	0	5,000	131.0	0.52	+/-0.10	<1.7	2.9743	38.6
14-Jul-93	E931900028	OSYA2J10	10,000	5,000	70.0	78.00	+/-1.00	<1.8	2.9020	50.0
20-Jul-93	E931900058	OSYA2J10-2	0	5,000	216.0	0.33	+/-0.10	<0.9	5.4823	23.8
13-Jul-93	E931900029	OSYA2J11	0	16,000	43.0	0.26	+/-0.10	<1.4	3.0595	664.9
20-Jul-93	E931900059	OSYA2J11-2	0	45,000	3,475.0	0.23	+/-0.05	3.4	5.9326	47.5
14-Jul-93	E931900026	OSYA2J11-3	500	30,000	390.0	0.44	+/-0.10	2.1	2.4063	63.2
15-Jul-93	E931900027	OSYA2J9	0	6,000	84.0	0.47	+/-0.10	6.9	3.2102	50.5
13-Jul-93	E931890063	OSYA2K10	0	9,000	692.0	0.49	+/-0.10	3.1	3.2710	751.3
20-Jul-93	E931900056	OSYA2K10-2	0	9,000	458.0	0.37	+/-0.10	<0.7	6.5195	67.9
20-Jul-93	E931900057	OSYA2K11-2	0	9,000	77.0	0.27	+/-0.10	<2.1	2.5033	21.3
13-Jul-93	E931900031	OSYA2K9	0	12,000	173.0	0.19	+/-0.05	0.6	6.8873	39.7
20-Jul-93	E931900055	OSYA2K9-2	0	10,500	0.8	N/A	N/A	<1.2	3.9340	17.1
9-Aug-93	E931900033	OSYA3L14	0	0	1.1	N/A	N/A	<1.7	3.0700	21.3
9-Aug-93	E931900034	OSYA3L15	0	0	1.4	N/A	N/A	<2.0	2.6109	43.0
5-Aug-93	E931900035	OSYA3L17	0	0	0.4	N/A	N/A	<1.4	3.5931	18.1
5-Aug-93	E931900037	OSYA3M17	0	0	0.6	N/A	N/A	<1.4	3.7916	7.9
9-Aug-93	E931900038	OSYA3N14	0	9,000	447.0	0.23	0.05	1.7	3.2789	13.8
5-Aug-93	E931900040	OSYA3N17	0	0	0.3	N/A	N/A	2.3	3.1966	23.4
9-Aug-93	E931900041	OSYA3O14	0	0	0.4	N/A	N/A	1.7	3.0116	18.3
9-Aug-93	E931900042	OSYA3O17	0	1,500	9.4	0.37	+/-0.10	<3.8	1.2898	21.7
9-Aug-93	E931900045	OSYA3P17	0	15,000	1,923.0	0.22	+/-0.05	<1.3	3.6892	21.2
9-Aug-93	E931900046	OSYA3Q15	0	0	17.0	0.83	+/-0.20	1.5	3.0010	27.2
9-Aug-93	E931900047	OSYA3Q16	0	0	143.0	0.33	+/-0.10	7.2	3.0193	22.0

Figure 5.
Distribution of Total Uranium in ug/g
Old Salvage Yard Characterization Project

Plot excludes 5 values greater than 200,000 ug/g of total uranium.

Figure 6.
Distribution of U₂₃₅ Weight Percent
Old Salvage Yard Characterization Project

A sample with 78% weight percent U₂₃₅ is not shown.

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results from the sampling indicated that the scrap metal yards outside the PIDAS fence have been fairly well segregated and consists mainly of depleted uranium with some lower enriched material. The 78 ^{235}U weight percent data point was not only an outlier as a weight percent, i.e., the second-highest value was at 1.9%, but also had an extremely low average parts per million (ppm) value. The concentration of total uranium contained in this sample is 70 ppm, which is much lower than the average value of 64,597 ppm. This low ppm value is in accordance with the administrative controls placed on enriched material. Scrap metal having an enrichment greater than 20 wt % goes through destructive cleaning to recover as much material as possible prior to release from the processing areas. Although routine cleaning may be performed on equipment contaminated with depleted uranium, the level of intensity of the cleaning process is not the same. This is substantiated by the large concentrations of depleted uranium which may be found on the scrap. These higher concentrations of depleted uranium in the data will bring the overall enrichment of a shipment down below natural even with the addition of some scrap containing high enrichments. As an example, we will assume that a typical 20,000-lb shipment contains an outlier with wt % ^{235}U of 93.3. For the parts per million, we will assume 700 ppm, which is ten times greater than the enriched outlier in this population. Using our model, 4000 pounds of scrap out of a 20,000-lb shipment at 93.3 ^{235}U wt % with the remaining 16,000 assumed to be our enrichment of 0.58 wt % still gives an overall enrichment for the shipment less than natural uranium (0.711 ^{235}U wt %). Since this amount of highly enriched contaminated scrap from these yards is unlikely, it is reasonable to assume that all shipments will have an overall enrichment which is depleted.

Because the "Request for Authorization to Ship Nuclear Materials" requires the total uranium (g), the weight % ^{235}U and the grams ^{235}U contained in a shipment, these sample results will be used to estimate total uranium and wt % ^{235}U for the metal in Area 1 and 2 of the Old Salvage Yard. Once estimates of total uranium and wt % ^{235}U are provided, grams of ^{235}U can be calculated. The sixty samples taken in the radiological areas will be used to estimate total uranium and wt % ^{235}U .

The samples analyzed from Area 3 vary significantly from those analyzed in Areas 1 and 2. The average of eleven Area 3 samples for total uranium is 231 $\mu\text{g/g}$, as compared with 645,974 $\mu\text{g/g}$ for the Area 1 and 2 samples. Only four results out of eleven were reportable for wt % ^{235}U in Area 3 because the values were below the detection limits of the instrument. Therefore, the eleven samples from Area 3 are being excluded from all calculations. For a conservative estimate, the values calculated from Area 1 and 2 could be used for Area 3, realizing the obtained data indicate much lower values.

Since the data for total uranium and wt % ^{235}U are not normally distributed for Areas 1 and 2, approximate upper confidence limits for the means will be calculated. Chapter 11, Sect. 7 of Statistical Methods for Environmental Pollution Monitoring¹ states that if the distribution is not normal or you are unwilling to assume a normal distribution and the sample size is sufficiently large, an approximate, one-sided upper 100 (1 - α)% confidence limit is:

$$\bar{X} + z_{1-\alpha} (s)/(n)^{1/2} \quad (3)$$

where

$\bar{X}$ = sample average,

1 - α = confidence level,

$z_{1-\alpha}$ is the 1 - α quantile of the standard normal distribution,

s = sample standard deviation, and

n = sample size.

There is no standard rule for determining how large the sample size should be in the above equation to be used. If the distribution is highly skewed, a sample size of 50 or more may be required. Because there are 60 sample results for total uranium and 58 for wt % ^{235}U (78% was omitted and one total uranium value was 1.5 $\mu\text{g/g}$ so no wt % ^{235}U was reported), the sample sizes are large enough to use the approximate one-sided upper 100 (1 - α)% confidence limit. Table 4 contains the approximate 97.5% one-sided upper confidence limit for total uranium and wt % ^{235}U .

Table 4. 97.5% Upper Confidence Limits for Total Uranium and wt % ^{235}U

	n	$\bar{X}$	s	$z_{0.975}$	$\bar{X} + z_{0.975} (s)/(n)^{1/2}$
Weight % ^{235}U	58	0.4745	0.3957	1.96	0.58
Total uranium ($\mu\text{g/g}$)	60	64,597	207,744	1.96	117,163

The values for the upper confidence limits given in Table 4 will be used in the following sections to estimate the grams of total uranium and wt % ^{235}U in a shipment of scrap metal.

5. ESTIMATION OF TOTAL URANIUM IN SCRAP METAL SHIPMENTS

This section will describe the method used in estimating total uranium in a shipment of scrap metal. Due to the obvious heterogeneity of a scrap metal yard, results from sampling of contaminated areas cannot simply be multiplied by either the total weight or volume of the shipment. Contamination, in practice, does not occur uniformly but rather is concentrated in limited areas or "hot spots." It was these "hot spots" that were sampled and analyzed for uranium concentration. Uranium concentration is given in micrograms of uranium per gram of matrix or parts per million (ppm). To calculate the total grams of uranium for a sample, the uranium concentration is multiplied by the grams of matrix which for a sample is the sample mass.

$$U_{\text{tot}} [\text{g}] = \text{ppm} [\text{ug/g}] * 10^{-6} [\text{g/ug}] * \text{Mass} [\text{g}] \quad (4)$$

A total of 60 samples were collected and analyzed from Areas 1 and 2 to derive a distribution of uranium concentration. Based on the sample results, an uranium concentration value of 0.117 g U_{tot} /g matrix was used as a conservative estimate of the total uranium concentration for "hot spots" on all metal contained in a shipment. To calculate the total quantity of uranium in a shipment, both the uranium concentration and the mass of all the "hot spots" contained in the shipment are needed. The following sections outline the logical steps necessary to calculate the number of grams of uranium in a shipment of scrap metal from Areas 1 and 2. The discussion will start with a calculation of uranium contained in a typical "hot spot" and progress to the method used to estimate the uranium grams contained in an entire shipment. Assumptions needed to perform this estimate and comparisons to similar work are discussed in the section entitled Method Discussion.

5.1 Total Uranium Calculation for a Scrap Metal Piece

Since scrap metal contamination is surface contamination, very little of the overall volume of a shipment is actually contaminated material. If for example, we look at one piece of sheet metal measuring 100 cm x 100 cm x 2.54 cm that contains only one "hot spot" with a surface area of 100 cm² (the area measured with a typical survey instrument) and a depth of contamination of 0.01 millimeters, then the volume of this "hot spot" is given by:

$$\begin{aligned}\text{Vol}_{\text{cont}} [\text{cm}^3] &= \text{Surface Area} [\text{cm}^2] * \text{Depth} [\text{mm}] * 0.1 [\text{cm/mm}] \\ &= 100 \text{ cm}^2 * 0.01 \text{ mm} * 0.1 \text{ cm/mm} = 0.1 \text{ cm}^3\end{aligned}\quad (5)$$

while the volume of the entire piece is given by:

$$\begin{aligned}\text{Vol}_{\text{tot}} [\text{cm}^3] &= \text{Surface Area} [\text{cm}^2] * \text{Thickness} [\text{cm}] \\ &= (100 * 100) \text{ cm}^2 * 2.54 \text{ cm} \\ &= 25,400 \text{ cm}^3\end{aligned}\quad (6)$$

Obviously for this scenario, the ratio of the volume contaminated to total volume is an extremely small number, i.e., $4\text{E-}6$. To be conservative, we assume the entire surface area is contaminated, then the volume of contaminated metal is given by:

$$\begin{aligned}\text{Vol}_{\text{cont}} [\text{cm}^3] &= \text{Total Surface Area} [\text{cm}^2] * \text{Depth} [\text{cm}] \\ &= [(2 * 100 * 100) + (4 * 100 * 2.54)] * 10^{-3} [\text{cm}^3] \\ &= 21 \text{ cm}^3\end{aligned}\quad (7)$$

Thus the volume of contaminated metal to total metal assuming all surface areas are equally contaminated is $8.3\text{E-}4$ or about two orders of magnitude greater than the one hot spot case.

Once the contaminated volume has been estimated, the total grams of uranium can be calculated using the uranium concentration value of 0.117 g U_{tot} /g matrix. If we assume the contaminated material is a mixture of iron and uranium metal only, then the contaminated volume would be equal to the volume of uranium and the volume of iron.

$$\text{Vol}_{\text{cont}} = \text{Vol}_{\text{U}} + \text{Vol}_{\text{Fe}}\quad (8)$$

The weight ratio inherent in the sample measurements, i.e., 0.117 grams of uranium and 0.883 grams of iron, can then be used with the respective metal densities to calculate volume ratios.

$$\begin{aligned}\text{Density of Uranium} &= 18.9 \text{ g/cm}^3 \\ \text{Density of Iron} &= 7.9 \text{ g/cm}^3\end{aligned}$$

$$\begin{aligned}\text{Vol}_{\text{U}} &= 0.117 \text{ g U} / 18.9 \text{ g/cm}^3 = 6.191\text{E-}3 \text{ cm}^3 \\ \text{Vol}_{\text{Fe}} &= 0.883 \text{ g Fe} / 7.9 \text{ g/cm}^3 = 1.118\text{E-}1 \text{ cm}^3\end{aligned}$$

$$\text{Vol}_{\text{U}} / \text{Vol}_{\text{Fe}} = 6.191\text{E-}3 / 1.118\text{E-}1 = 5.54\text{E-}2\quad (9)$$

This volume ratio can be used to determine the portion of the contaminated volume that is comprised of uranium. Rearranging Eq. (9),

$$\text{Vol}_U = 5.54\text{E-}2 \text{ Vol}_{Fe}$$

and using Eq. (8) and the value for the contaminated volume calculated in Eq. (7), we can solve for Vol_{Fe} and Vol_U :

$$5.54\text{E-}2 \text{ Vol}_{Fe} + \text{Vol}_{Fe} = \text{Vol}_{cont} \quad (10)$$

$$\begin{aligned} 1.0554 \text{ Vol}_{Fe} &= 21 \text{ cm}^3 \\ \text{Vol}_{Fe} &= 19.9 \text{ cm}^3 \end{aligned}$$

$$\begin{aligned} \text{Vol}_U &= \text{Vol}_{cont} - \text{Vol}_{Fe} \\ \text{Vol}_U &= 1.1 \text{ cm}^3 \end{aligned}$$

The mass of total uranium in the contaminated volume can then be calculated using the volume calculated from Eq. (10) and uranium metal density:

$$\begin{aligned} U_{tot} [\text{g}] &= \text{Density}_U * \text{Vol}_U \\ &= 18.9 \text{ g/cm}^3 * 1.1 \text{ cm}^3 \\ &= 20.8 \text{ g } U_{tot} \end{aligned} \quad (11)$$

The total weight of the iron metal piece is given by:

$$\begin{aligned} \text{Mass}_{tot} [\text{lb}] &= \text{Vol}_{tot} [\text{cm}^3] * \text{Density}_{Fe} [\text{g/cm}^3] * 2.203\text{E-}3 [\text{lb/g}] \\ &= 25,400 \text{ cm}^3 * 7.9 \text{ g/cm}^3 * 2.203\text{E-}3 \text{ lb/g} \\ &= 442 \text{ lb} \end{aligned} \quad (12)$$

Thus, assuming the entire surface is contaminated, 20.8 grams of total uranium would be present in this piece of iron scrap weighing 442 pounds. On a mass basis this is about 100 ppm.

5.2 Total Uranium Calculation for a Shipment

To calculate the total grams of uranium in all the scrap metal pieces contained in a shipment, an estimate must be made of the contaminated volume for that shipment. Using Eq. (7) and assuming the depth of contamination is 0.01 millimeters to calculate the contaminated volume, an estimate of the total surface area of all the pieces is needed. Since it is impossible to measure the total surface area for all the various scrap shapes, a model was

needed that could provide an estimate of the total surface area for a given weight of scrap metal. In addition to providing a reasonable estimate for the surface area, the model also needs to be one that can easily be visualized. In constructing a model for the determination of the surface area for a randomly selected volume of scrap metal, an approach was taken that would maximize the total surface area-to-volume ratio and also provide an easily visualized scenario of contamination. Since both the total surface area of the scrap metal contained in a shipment and the percentage of that surface area that is contaminated cannot be measured, a situation will be presented that is easily recognized as a gross overestimation of the contaminated volume. This will ensure that the final quantity of uranium estimated by this method represents not an average but an upper bound on the amount that is actually present.

All shipments of scrap metal are weighed with a typical shipment weighing approximately 20,000 pounds. For this model, we have assumed that the scrap metal is iron. If we assume that the entire shipment is comprised of one-pound cubes, then the volume and surface area of each cube is given by the following equations:

$$\begin{aligned}\text{Vol}_{\text{cube}} &= \text{Mass}_{\text{cube}} [\text{g}] / \text{Density}_{\text{Fe}} [\text{g}/\text{cm}^3] \\ &= (1 \text{ lb} * 454 \text{ g/lb}) / 7.9 \text{ g}/\text{cm}^3 \\ &= 57.47 \text{ cm}^3\end{aligned}\tag{13}$$

$$\begin{aligned}\text{Vol}_{\text{cube}} &= \text{length} [\text{cm}] * \text{width} [\text{cm}] * \text{depth} [\text{cm}] \\ &= \text{length}^3 [\text{cm}^3]\end{aligned}\tag{14}$$

Therefore, the length of a cube side is 3.86 cm (or about 1.5 inches), and the total surface area is the sum of the surface areas of each of the six faces which is given by:

$$\begin{aligned}\text{Surface Area}_{\text{cube}} &= 6 * \text{length} [\text{cm}] * \text{length} [\text{cm}] \\ &= 6 * 3.86 \text{ cm} * 3.86 \text{ cm} \\ &= 89.4 \text{ cm}^2\end{aligned}\tag{15}$$

If we assume that the entire surface area of this cube is contaminated to a depth of 0.01 millimeters, using Eq. (4), the volume of contaminated metal in the cube is given by:

$$\begin{aligned}\text{Vol}_{\text{cont}} [\text{cm}^3] &= \text{Total Surface Area} [\text{cm}^2] * \text{Depth} [\text{cm}] \\ &= 89.4 \text{ cm}^2 * 10^{-3} \text{ cm} \\ &= 8.94\text{E-}2 \text{ cm}^3\end{aligned}\tag{16}$$

Using Eq. (7) and this contaminated volume, we can calculate the portion of the contaminated volume of the cube that is due to iron and uranium:

$$\begin{aligned}
 1.0554 \text{ Vol}_{Fe} &= 8.94E-2 \text{ cm}^3 & (17) \\
 \text{Vol}_{Fe} &= 8.47E-2 \text{ cm}^3 \\
 \text{Vol}_U &= \text{Vol}_{cont} - \text{Vol}_{Fe} \\
 &= 4.7E-3 \text{ cm}^3
 \end{aligned}$$

and using Eq. (8), calculate the total uranium contained in the cube:

$$\begin{aligned}
 U_{tot} \text{ [g]} &= \text{Uranium Density} * \text{Vol}_U & (18) \\
 &= 18.9 \text{ g/cm}^3 * 4.7E-3 \text{ cm}^3 \\
 &= 8.883E-2 \text{ g / cube}
 \end{aligned}$$

Since by definition each cube weighs one pound, this relationship is also given by:

$$U_{tot} \text{ [g]} = 8.883E-2 \text{ g U / lb. scrap} \quad (19)$$

Thus, the total grams of uranium in a shipment can be calculated by multiplying the weight by U_{tot} g / lb scrap. For a typical shipment of 20,000 pounds, the total uranium in the shipment would be given by:

$$\begin{aligned}
 U_{tot} \text{ [g]} &= 8.883E-2 \text{ g U / lb scrap} * 20,000 \text{ lb scrap} & (20) \\
 &= 1777 \text{ g U}
 \end{aligned}$$

The grams of ^{235}U contained in this shipment can be calculated using the sampling results for weight percent ^{235}U . A weight percent of 0.58 corresponds to 0.0058 g ^{235}U for every gram of total uranium.

$$\begin{aligned}
 ^{235}\text{U} \text{ [g]} &= 0.0058 \text{ [g } ^{235}\text{U} / \text{g } U_{tot}] * U_{tot} \text{ [g]} & (21) \\
 &= 0.0058 * 1777 \text{ g } ^{235}\text{U} \\
 &= 10.3 \text{ g } ^{235}\text{U}
 \end{aligned}$$

5.3 Method Discussion

Although using one-pound cubes is a convenient way to estimate surface area, the results obtained by this model also compare well with measurements that were performed during a remedial action project in Weldon Springs, Missouri². This project included demolition of overhead piping and supports

in a building that had processed both thorium and depleted uranium. Since the goal of the Weldon Springs project was to release scrap to commercial salvage companies, all surface areas were surveyed. Extensive logs were kept which correlated surface areas of the scrap to weight. From their log books, approximately 4,300 square meters of pipe and structural material weighed about 200,000 kilograms. This corresponds to about 102 pounds of scrap metal per square meter. For a 20,000-pound shipment and using our model, the total surface area for this shipment can be calculated by:

$$\begin{aligned}\text{Surface Area} &= 20,000 \text{ cubes} * \text{Surface Area}_{\text{cube}} [\text{cm}^2] * 1\text{E-}4 [\text{m}^2/\text{cm}^2] \quad (22) \\ &= 20,000 * 89.4 \text{ cm}^2 * 1\text{E-}4 \text{ m}^2/\text{cm}^2 \\ &= 179 \text{ m}^2\end{aligned}$$

which results in about 110 pounds of scrap metal per square meter. The agreement with the Weldon Springs figure gives confidence in our model.

The results of this model were also compared to calculations in a report on decision levels for surface contamination issued by Los Alamos National Laboratory³. This report included rough calculations of pounds of iron scrap metal to total surface area. A low value of 22 lb/m² was used to estimate small pieces of scrap, while a high value of 220 lb/m² was used for larger scrap pieces. The 110 lb/m² value from our model falls in the middle of these two values as it should since our model represents a random mixture of both small and large pieces of scrap.

In addition to the uncertainty surrounding the surface area, the overall approach included two other assumptions that were necessary to calculate total uranium. The most crucial of these assumptions concerns the depth of contamination since it, along with the total surface area, define the contaminated volume. Just as the surface area model does not depict reality, i.e., the scrap metal yard does not actually contain 20,000 iron cubes, the assumption of uniformly contaminated surface area is meant to represent a situation that is easily recognized as an upper limit.

This same conservative approach was used to determine the depth of contamination. Data concerning uranium contamination on process equipment from holdup measurements performed by Los Alamos National Laboratory personnel was used to determine an upper bound for the depth of contamination.⁴ The term "holdup" refers to the accumulation of nuclear material inside processing equipment of nuclear facilities.

The values that are listed below were measured from typical regions of high holdup:

- Gloveboxes after destructive cleaning $2 \text{ g } U_{\text{tot}} / \text{m}^2$
- * Equipment interiors after routine cleaning:
 - Low value $10 \text{ g } U_{\text{tot}} / \text{m}^2$
 - High value $50 \text{ g } U_{\text{tot}} / \text{m}^2$

Destructive cleaning refers to abrasive blasting, electrochemical polishing, and various other techniques that actually remove layers of the matrix material. Routine cleaning refers to washing the surface which is obviously not as effective as destructive cleaning and therefore gives a higher value for uranium mass density. If we use the highest mass density value listed above, the thickness of the contaminated area would be calculated as:

$$\begin{aligned}
 \text{Thickness[cm]} &= \text{Density Thickness[g/m}^2\text{]} * 1\text{E-4[m}^2\text{/cm}^2\text{]}/\text{Density}_U \text{ [g/cm}^3\text{]} \quad (23) \\
 &= 50 \text{ g } U_{\text{tot}}/\text{m}^2 * 1\text{E-4 m}^2/\text{cm}^2 / 18.9 \text{ g/cm}^3 \\
 &= 2.7\text{E-4 cm} \\
 &= 0.0027 \text{ mm}
 \end{aligned}$$

The depth of contamination used in our model, i.e., 0.01 millimeter is over three times as large as the calculated value for highly contaminated process equipment and therefore represents a conservative value.

The final assumption required to develop the estimation method concerned the type of metal in the scrap yard. We assumed the entire yard is comprised of iron. Rough estimates of the types and volumes of the various metals sent to the scrap yards indicated that the majority metal was indeed iron at 65%, while the remainder consisted of a mixture of aluminum, stainless steel, copper, brass, tungsten, and nickel. With the exception of aluminum, all these metals have a higher density than iron and thus would result in a lower total surface area for a given weight. A lower surface area would seem to infer a much lower total uranium quantity for the same shipment weight. In our model, the higher density also results in a higher proportion of the contaminated volume to be comprised of uranium which tends to offset the lower surface area. The opposite is true of a density lower than iron, such as aluminum. The total surface area would increase, but the proportion of contaminated volume containing uranium would decrease. Of the metals listed above contained in the scrap yard, tungsten has the highest density at 19.2 g/cm^3 , while aluminum has the lowest at 2.7 g/cm^3 . If we assume the metal in the yard is only tungsten, then the total uranium in a typical 20,000 pound shipment would be 1650 grams. For an assumption of aluminum, the same size shipment would contain 1950 grams of total uranium. These two quantities

bracket the value given for iron at 1777 grams. Since the majority of metal in the yard is iron, with the remainder consisting of a mixture of metals primarily with higher densities, the assumption of iron does not bias the results and therefore is a reasonable assumption.

6. SUMMARY

To estimate the total grams of uranium in a shipment of scrap metal from Areas 1, 2, and 3 using the results from the method described above:

$$U_{\text{tot}} [\text{g}] = \text{Net Weight of shipment} [\text{lb}] * 0.08883 [\text{g } U_{\text{tot}}/\text{lb}] \quad (24)$$

To calculate the grams of ^{235}U for the shipment, we use the weight percent ^{235}U and the total grams of uranium, U_{tot} , which is calculated above. A 0.58 wt % corresponds to 0.0058 g ^{235}U for every gram of total uranium.

$$^{235}\text{U} [\text{g}] = U_{\text{tot}} [\text{g}] * 0.0058 [\text{g } ^{235}\text{U} / \text{g } U_{\text{tot}}]. \quad (25)$$

7. DEFINITIONS

Alpha Decay - the spontaneous emission of doubly charged helium ions from the nucleus. Naturally occurring alpha emitters are prevalent among elements with atomic numbers greater than 82. ^{234}U , ^{235}U , and ^{238}U are all alpha emitters.

Beta Decay - the spontaneous emission of electrons from a nucleus. All the short-lived daughters of the uranium isotopes decay by beta emission.

Curie (Ci) - unit of measure for the activity of a source. A curie is equal to 3.7×10^{10} disintegrations per second. A disintegration is the transformation of one isotope into another and may result in the emission of more than one radiation entity. Submultiples of the curie are listed below:

1 milliCurie (mCi) = 10^{-3} Ci

1 microCurie (uCi) = 10^{-6} Ci

1 nanoCurie (nCi) = 10^{-9} Ci

1 picoCurie (pCi) = 10^{-12} Ci

Daughter - a nuclide, stable or radioactive, formed by radioactive decay. ^{234}Th and ^{234}Pa are both daughters of ^{238}U , while ^{231}Th is a daughter of ^{235}U .

Depleted Uranium - uranium with the ^{235}U weight percent less than 0.711 %.

DPM - disintegrations per minute. A disintegration is the transformation of one isotope into another and may result in the emission of more than one radiation entity.

Enriched Uranium - uranium with a ^{235}U weight percent greater than 0.711 %.

Isotope - atom that contains the same number of positive nuclear charges and have the same extra-nuclear electronic structure but differ in the number of neutrons. Isotopes cannot be distinguished chemically since they have the same electronic structure and therefore undergo the same chemical reactions. ^{234}U , ^{235}U , and ^{238}U are all isotopes of uranium.

Isotopic composition - the relative amounts, expressed in atom or weight fraction of the various isotopes of an element in a sample.

Weight percent - composition term which gives the percentage of a substance in a solution. For this application, weight percent is ratio of the grams of ^{235}U to the grams of total uranium.

Natural uranium - uranium whose isotopic composition, as it occurs in nature, has not been altered.

Parts per Million (ppm) - concentration term which indicates that one gram of the substance of interest is present per million grams of total solution or mixture. In this application expressed as micrograms of total uranium to grams of matrix.

Radioactivity - spontaneous nuclear changes that result in the formation of new elements. These changes can occur by several mechanisms such as alpha particle emission, beta and positron emission, and orbital electron capture. Gamma radiation may also be present.

Specific Activity - concentration of radioactivity or relationship between mass of radioactive material and the activity. It is the number of curies per unit mass or volume, e.g., pCi/gm.

Total Uranium - refers to the total grams of all isotopes of uranium contained in a sample.

Transuranium element - an element above uranium in the periodic table, i.e., with an atomic number greater than 92.

8. REFERENCES

1. R. O. Gilbert, **Statistical Methods for Environmental Pollution Monitoring**, Chapter 11, Section 7, Van Nostrand Reinhold Publishing, 1987.
2. "Radiological and Chemical Completion Report for Overhead Piping Removal for the Weldon Springs Site Remedial Action Project, Weldon Springs Missouri," Department of Energy report DOE/OR/21548-112.
3. J. W. Healy, "Surface Contamination: Decision Levels," Los Alamos National Laboratory, University of California, Los Alamos, LA-4558-MS, September 1971.
4. D. Reilly, N. Ensslin, and H. Smith, Jr., **Passive Nondestructive Assay of Nuclear Materials**, Chapter 20, Section 5, NUREG/CR-5550, March 1991.

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