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OAK RIDGE NATIONAL LABORATORY
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UNION CARBIDE NUCLEAR COMPANY

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

ORNL
CENTRAL FILES NUMBER
CF-56-6-87

NO 8

DATE: June 14, 1956
SUBJECT: Report of Copper Decontamination Work at Federated Metals in St. Louis
TO: J. E. Cunningham
FROM: E. S. Bomar

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Summary

An industrial-scale experiment involving 100-tons of scrap copper has been completed to check the results of laboratory experiments on the use of fire refining as a means of removing uranium contamination. Samples of the refined metal were checked at ORNL for uranium content by activation analyses and found to have on the average less than 0.66-micrograms of uranium per gram of metal sample. The bulk of the activity was found in the slag. The above level of activity was considered acceptable by the ORO of the AEC and the metal has been released for resale.

Purpose of Experiment

Large amounts of contamination scrap are being accumulated at the various atomic energy installations resulting in (1) tying up millions of dollars in nonproductive investments, (2) crowding of storage facilities, and (3) in some cases, withholding of scarce metal from the commercial market. These facts serve as sufficient incentive to examine possible treatments which may be capable of removing the radioactive contaminants. Salvage work done or planned at ORNL concerns recovery of steel and copper being held in the Y-12 scrap yard. The quantities of materials involved are in the hundreds-of-tons of metal.

The immediate problem is to recover scrap containing a high percentage of copper. The purpose of the experiment is to substantiate, on a commercial scale, laboratory experiments conducted jointly by the Research Department of the American Smelting and Refining Co. and the New Burnswich Laboratory of the AEC. Melts, amounting to about 30 pounds of metal prepared with a soda ash flux were found to be essentially free of uranium following treatment. (< 8.5 micrograms of uranium/gram of sample).

An agreement was made with the American Smelting and Refining Co. for the use of a reverberatory furnace at their Federated Metals Plant in St. Louis for a series of five melts. The suitability of these facilities for the proposed experiment was confirmed upon inspection by J. C. Hart of the Health Physics Division and J. L. Gregg, consultant to the Metallurgy Division.

The oil fired furnace to be used has a 20-ton capacity and is equipped with a controlled off-gas system terminating in a 125 ft. Wiederholdt stack. The steel barrels containing the scrap shipped from Oak Ridge will be unloaded from the railroad carrier with a fork lift truck. To obtain proper distribution of the charge within the furnace, hand loading will be employed. The heats will be tapped into a ladle having about a ton capacity and from there into small molds mounted to permit dumping the solidified ingots into a water trough. The reverberatory furnace along with pots used to melt and cast lead base solders is contained in a building measuring about 75 ft x 150 ft. Approximately fifteen people work in this area.

In addition to the extent of decontamination of large scale melts, Health Physics personnel are to monitor the various operations in the handling of the scrap and its melt down to determine whether or not the possibility of an intolerable buildup of radioactive material will occur at some stage of the process. The point of principal concern is any trend indicating long range build-up of contamination but if any part of the operation required for the experiment lead immediately to contamination levels above tolerance, the steps necessary to correct this will be taken.

Outline of Proposed Large Scale Experiment

The Health Physics Division will supply two men to gather information necessary for evaluation of contamination as follows:

1. unloading of contaminated scrap from shipping containers
2. loading scrap into the furnace
3. collecting air-borne contamination samples throughout the plant area, stack gas samples, and fallout samples several stack lengths from the plant area
4. personnel monitoring

The Metallurgy Division will supply one man to work with the health physicists in

1. collecting samples from the monitoring equipment
2. gathering representative samples of slag and the metal product for chemical analysis and activity counts
3. obtaining Orsat analyses of the flue gas for calculations of flue gas volume.

Mr. J. L. Gregg will also be present during the first two days of the setting-up operation at St. Louis.

Arrangements have been made to have a representative of Federated Metals to come to Oak Ridge to supervise loading of 100-tons of scrap copper. This 100-tons of metal will be processed in five batches of 20-tons each. The loading, melt down, and casting operations will require about twenty-four hours per heat, therefore, the proposed series of melts will require one week to prepare and to process.

Actual Work Performed at St. Louis Placing Air and Flue Gas Samplers

The first day and a half was spent placing air sampling equipment, installing a flue gas sampling tube through the wall of the stack about 30 ft from its base, and setting up counting and gas analysis equipment. Filter papers mounted in the sampling equipment removed entrained particles which were checked for radioactivity. Knowing the pumping capacity of the sampler and the time lapse during sample collection it was possible to determine the concentration of air-borne activity.

Process Sequence

Unloading of the first railroad car was begun on the afternoon of Sunday, Jan. 29. A fork-left truck moved the 55-gal drums containing the scrap in groups of four and placed them near the charging area of the furnace. Charging of the furnace, which had been brought up to temperature slowly during the preceeding week, was begun at 4:15 PM Jan. 29. As with the remaining runs, the charging period lasted about 10 to 12 hours. Some difficulty was encountered during the first run due to a large quantity of slag produced. This appeared to be due to cleaning out of the furnace rather than material contained in the scrap; since subsequent heats produced about half as much slag. Following slagging, the oxygen content was adjusted to an acceptable level as indicated by test castings. This adjustment was done by introducing a green log (poling) directly into the melt. Poling was continued until the resulting gases combined with enough copper oxide to give satisfactory shrinkage in casting. The melt was then covered with a protective covering of charcoal and the casting operation begun. The amount of metal charged to the furnace averaged more than 20-tons per heat with the result that the 100-tons of scrap was treated in four heats. The original plan had been to prepare slags which would be insoluble, therefore, a high silica plus borax slag was made in the first melt. However, difficulty with the resulting high viscosity of this type of slag made it necessary to reduce the silica addition to obtain more fluidity of the expense of low solubility. The material balances for the various runs

4

listed in Appendix 2 show this adjustment. Metal samples were taken for activity checks after the melt down also at the time of tapping. A sample of the slag was taken from the first and last pots of slag removed from each heat.

Knowledge of the chemical make-up of the fuel oil and the stack gases plus rate of oil consumption data make it possible to calculate the mass or volume of the stack gases. This is needed by the health physicist in order that he may determine total activity carried out the stack in the flue gases. To obtain a sample of flue gas for analysis, the exhaust from the stock sampler pump was coupled to the Orsat manifold. After a thorough purging, a gas sample was drawn into the burette by lowering the mercury reservoir. The original plan had been to relate flue gas volume to activity samples collected during specific periods of the process cycle, however, the activity associated with the flue gases proved to be so low that extended collection periods became necessary. During these intervals, a considerable variation in the rate of oil consumption occurred with accompanying fuel-to-air ratio changes making it necessary to average the stack gas analyses. Stack gas analyses and calculations using them are presented in Appendix 1. These computations show that 40,000,000 + 13% cubic-ft of gas under standard conditions passed up the stack during the four runs. Water froze causing a stoppage in a portion of the flue-gas sample line which passed out of the building to the stack. The line was moved inside of the building and flue-gas samples were taken from the base of the stack without further trouble.

Personnel Monitoring

Only those individuals coming in immediate contact with the melting or casting operations were issued special clothing and were monitored for radioactive pickup. Coveralls, a hat, and gloves were issued to each man. Those actually placing the metal in the furnace were provided with dust masks. There were about eight men on the day shift and four on each of the other shifts that received protective clothing. Each man's clothing was checked with a portable alpha counter for excessive alpha pick-up at the end of each shift. After the sampling schedule was established and the necessary health controls determined, one representative from ORNL was present at the plant during each shift.

Preliminary Counts on Samples

As filter samples, sections cut from ingots, and slag became available they were checked for activity. Activity above background was detected only in (1) the slag, (2) the solid from the flue gas, and (3) the liquid condensate from the flue gas samples. None of the metal samples gave activity responses greater than background. Samples were prepared for more sensitive testing at ORNL.

Additional Activity-Check Samples

In addition to the above radioactivity checks, samples were collected from floor-sweepings around the furnace loading area and from the trough used to cool the ingots. One week after the furnace was secured, samples were collected from the top and bottom of the furnace, various locations along the tunnel leading to the stack, and from ashes at the base of the stack. All of these were returned to Oak Ridge for uranium analyses.

Metal Analyses Obtained at Federated Metals

The analytical laboratory at Federated Metals obtained chemical analyses on the metal product of each heat. In each of the four heats, the copper content of the product analysed close to 99%. This represents a satisfactory product of a salvage operation. Tin occurred as the principal impurity. The complete analyses appear in Appendix 2.

Results of Activation Analyses Made at ORNL

Since the uranium present in the product was expected to be present in very low concentration, an analytical method had to be selected which had a high degree of sensitivity. Prior to the work at St. Louis, J. L. Gregg and the writer met with Dr. Kelly of the Analytical Chemistry Division. The problem was outlined and he was asked for a recommendation as to the analytical procedure to be used. He selected activation analysis which is the method that was used in checking the product of melting experiments with contaminated-steel scrap (the analytical work at the New Brunswick Laboratory used a fluometric technique).

Metal samples were selected from two stages in the refining sequence. A sample was taken from the molten bath after melt down in each of three heats and from one of the cast billets of each of the four heats. The purpose of two samples from each heat was to detect any dependence of the decontamination process on time held in the molten condition. These samples were identified as "metal bath after melt down" and "final product metal". Duplicate samples from the metal product were submitted. Single samples of the molten metal bath were analysed. Material for analysis was prepared by making a cut through the cast ingot then combining turnings drilled from several points across the cut surface. The first set of metal product samples contained no detectable uranium. Samples of wire bar and blister-anode copper analysed along with the first set of metal product sample also contained no detectable uranium.¹ The analytical results for the second set included uranium concentration as high as 3.10 micrograms of uranium per gram of sample. An arithmetic average content for the two sets was 0.65 micrograms of uranium per gram of sample. This is about three times higher than the value found for the uranium content of reference copper samples analysed by the National Bureau of Standards.² Samples of the metal bath after melting contained less than 0.50 micrograms of uranium/gram of sample. It was not established whether the higher values for uranium concentration in the second set of samples from the final product metal were due to the presence of segregation or to some other cause. The degree of decontamination was considered acceptable by the local AEC office and the metal has been released to commercial channels.

The results of analyses on all of the materials submitted are given in Appendix 3.

Conclusions

Fire refining is capable of reducing uranium contamination in copper to levels low enough to permit resale on the open market. Orsat gas analysis equipment has sufficient accuracy for calculation of flue-gas volume for this type of work. Some inconsistency in the results of activation analyses indicate the need for additional work on the reliability of this analytical method and the sampling methods used for detecting low uranium concentrations.

¹ Supplied by the Central Research Laboratory, American Smelting and Refining Company

² "Decontamination of Radioactivity from Non-Ferrous Metals by Resmelting", Klevin and Harris

APPENDIX 1

CALCULATIONS BASED ON ORSAT ANALYSES OF FLUE GASES

The fuel used in the furnace at Federated Metals for the copper salvage work was number 5 fuel oil. A chemical composition analysis of this oil was not available. Since there is not an appreciable variation in the makeup of fuel oils,³ it was assumed that a typical analysis for a medium-weight-fuel oil would be applicable. The data³ given below serves as a basis for the following calculations.

% composition by weight ----	C	H	S	O	N	H ₂ O
	85	12	0.8	1.0	0.2	1.0
API° -----	22					
Specific gravity 60°/60° ----	0.92					
Density lb/gal. -----	7.7					

The composition of the flue gas will be a combination of the analysis of the oil and the air fed to sustain combustion. A check of the climatological data for the St. Louis area was made to find how much water would be contained in the air. Since the experiment was to be performed in January, information for that month in the last five years was checked. The following was reported for the St. Louis area by the U. S. Weather Bureau:

Jan	Avg. dew point °F	Avg. Relative Humidity %	Avg. Temp. °F	Saturated Vapor Pressure H ₂ O mm
1955	23	67	33.0	4.74
1954	23	70	32.7	4.71
1953	--	--	---	---
1952	27	73	32.6	4.48
1951	23	73	32.6	4.48

A vapor pressure of 4 mm of water vapor represents about $\frac{1}{2}$ % change in the volume of air required for stoichiometric burning. The moisture contribution of the air will be neglected and calculations of the quantity of air required will be based on dry air.

³ Chemical Engineers' Handbook, John H. Perry, Editor, 1950
Liquid Fuels, p. 1572

7

7

APPENDIX 1 (continued)

Calculate quantity of air at STP (0°C and 760 mm of Hg) required for stoichiometric combustion of fuel oil of given analysis.

$$\frac{0.85}{12} \text{ moles of } CO_2 / \phi \text{ fuel} = 0.071$$

$$\text{moles of } O_2 \text{ required} / \phi \text{ fuel} = 0.071$$

$$\frac{0.12}{2} \text{ moles of } H_2O / \phi \text{ fuel} = 0.060$$

$$\text{moles of } O_2 \text{ required} / \phi \text{ fuel} = 0.030$$

$$\frac{0.008}{32} \text{ moles of } SO_2 / \phi \text{ fuel} = 0.00025$$

$$\text{moles of } O_2 \text{ required} / \phi \text{ fuel} = 0.00025$$

$$\text{Moles of } O_2 \text{ from fuel} / \phi \text{ fuel} = \frac{0.01}{32} = 0.00031$$

$$\text{Moles of } N_2 \text{ from fuel} / \phi \text{ fuel} = \frac{0.002}{28} = 0.00007$$

$$\text{Moles of } H_2O \text{ from fuel} / \phi \text{ fuel} = \frac{0.01}{18} = 0.0006$$

$$\begin{aligned} \text{Total moles of } O_2 \text{ required} / \phi \text{ fuel} &= 0.071 + 0.030 \\ &= 0.101 \end{aligned}$$

Oxygen supply from air, therefore, accompanying N_2 appears in the gases.

$$\begin{aligned} \text{Moles of } N_2 \text{ from air} &= \frac{(79)}{(21)} (0.101) \\ &= 0.380 \end{aligned}$$

Total moles of the gas/ ϕ of fuel - neglect SO_2 and N_2 from fuel

0.071	CO_2
0.060	H_2O (combustion of hydrogen in fuel)
0.380	N_2
<u>0.001</u>	H_2O (mechanically entrained in fuel)
0.512	

8
APPENDIX 1 (continued)

8

Since at STP, 1 mole of gas occupies 359 ft^3 , the volume of flue gases/ ϕ fuel = $(359) (0.512)$
 $= 183 \text{ ft}^3$

For a density of $7.7 \phi/\text{gal}$, the volume of flue gases/gal fuel = $(183) (7.7)$
 $= 1410 \text{ ft}^3$

The values necessary to show in graphical form the volume of flue gas at STP per gal. of fuel burned are calculated next. These values are based on an assumed variation in the amount of excess air supplied to the fuel. Correction is made for the fact that an Orsat analysis gives the equivalent of an analysis of the dry gas.

% Excess Air	Moles of Excess Air	Total moles of dry gas/ ϕ fuel	Dry Gas % CO_2 % O_2		Total moles of wet gas/ ϕ fuel	Ft^3 of the gas at STP gal. fuel
0	0	0.451	15.7	0	0.512	1410
20	0.095	0.546	13.0	3.7	0.607	1680
40	0.190	0.641	11.1	6.2	0.702	1930
60	0.291	0.742	9.6	8.2	0.803	2220
80	0.386	0.837	8.5	9.7	0.898	2470
100	0.481	0.932	7.6	10.8	0.993	2740
200	0.962	1.413	4.8	14.3	1.474	4070
300	1.443	1.894	3.7	16.0	1.955	5400
400	1.964	2.375	2.9	17.0	2.436	6740
500	2.405	2.856	2.4	17.7	2.917	8050
600	2.886	3.337	2.1	18.2	3.398	9370
700	3.367	3.818	1.8	18.5	3.879	10,700
800	3.848	4.299	1.6	18.8	4.360	12,050
900	4.329	4.780	1.5	19.0	4.841	13,370
1000	4.810	5.261	1.3	19.2	5.322	14,700

9

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10
APPENDIX 1 (continued)

9

DATA ON USE OF # 5 FUEL OIL

<u>Time</u>	<u>Oil Meter Reading gal. used</u>	<u>Rate of oil used gal/hr</u>	<u>Time</u>	<u>Oil Meter Reading gal. used</u>	<u>Rate of oil used gal/hr</u>	<u>Time</u>	<u>Oil Meter Reading gal. used</u>	<u>Rate of oil use gal/hr</u>
Jan 29								
1730	3130	30			63			93
2030	3220	110	1600	6047	13	0330	8898	82
2130	3330	60	1700	6060	50	0430	8980	100
2230	3390	60	1800	6110	70	0530	9080	108
2330	3450		1900	6180		0630	9188	68
Jan 30					70	1800	9875	
0030	3490	40	2100	6320	42			
0130	3550	60				Total oil used 6845 gal.		
0230	3613	63	2300	6404	121			
0330	3706	93	2400	6525				
0430	3776	70	Feb. 1		100			
0530	3846	70	0100	6625	88			
0630	3928	82	0200	6713	87			
1000	4158	66	0300	6800	97			
1700	4600	63	0400	6897	78			
1800	4640	40	0500	6975	89			
1900	4720	80	0600	7064				
2100	4810	45			56			
2200	4880	70	0900	7233	91			
2300	4940	60	1800	8050	110			
2400	5012	72	1900	8160	70			
Jan. 31			2000	8230	80			
0100	5072	60	2100	8310	70			
0200	5143	71	2200	8380	83			
0300	5215	72	2330	8504				
0400	5286	71	Feb. 2		116			
0500	5356	70	0030	8620	79			
0600	5418	62	0130	8699	106			
0700	5479	61	0230	8805				

11

419 011

RECORD OF ORSAT ANALYSIS

<u>Date and Time</u>	<u>% CO₂</u>	<u>% O₂</u>	<u>Oil meter reading at start of sampling</u>	<u>Oil meter reading at end of sampling</u>	<u>Operation</u>
Jan. 29					
1730	*3.0	16.5	3130	3170	
2122-2153	*3.6	17.4	3329	3387	charging
Jan. 30					
0330-0400	*4.4	16.6	3693	3803	charging
0815-0922	3.0	17.1	4095	4147	tapping
0510-0531	3.4	16.4	5354	5428	charging
0642-0657	3.4	16.6	5469	5574	blowing melt with air
1902-1926	3.8	15.8	6185	6258	charging
2025-2105	*3.9	16.3	6208	6352	melting charge
Feb. 2					
0033-0048	3.2	16.7	8415	8491	charging
0055-0115	*4.8	14.9	8645	8729	charging
0256-0324	*3.8	15.1	8849	8986	charging
0535-0605	3.9	15.5	9091	9187	charging

* Results considered unreliable because of poor agreement between measured %CO₂ and %O₂ and calculated values. See graph presented in preceding portion of this appendix relating theoretical percentages of CO₂, O₂, and dilution.

	<u>Range of values in analyses</u>	<u>Range in ft³ flue gas per gal of oil</u>	<u>Maximum spread in ft³/gal of oil</u>	<u>Avg. variation ft³/gal from avg</u>
CO ₂	3.0-3.9	6600-5100	-----	--- ----
O ₂	17.1-15.5	5100-6600	-----	--- -----
			5100-6600	5850 ± 13%

VOLUME OF FLUE GAS

The average value found for the ft³ of flue gas generated/gal. of fuel burned is combined with the total volume of fuel consumed to obtain a value for the volume of flue gas generated during the four heats.

$$\begin{array}{rcl}
 \text{total oil consumed, gal} & \times & \text{ft}^3 \text{ of flue gas at STP/gal. of fuel} = \text{ft}^3 \text{ of flue gas} \\
 6845 & \times & 5850 \pm 13\% \\
 & & = 40,000,000 \pm 13\%
 \end{array}$$

WATER CONDENSATION IN FLUE GAS SAMPLE LINE

Water appears in the flue gas as a result of the combustion of hydrogen in the fuel, water in the fuel, and due to the moisture contained in the air entering the furnace. Since the stack gas sample will have to be cooled before passing through the filter, information is needed of the temperature at which condensation of water will happen.

Moisture from combustion

$$\frac{0.12}{2} \text{ moles of H}_2\text{O/lb of fuel} = 0.060$$

Moisture from fuel

$$1\% \text{ or } \frac{0.01}{18} \text{ moles of H}_2\text{O/lb of fuel} = 0.0006$$

Moisture from air

Mole fraction of moisture in air equal to the partial vapor pressure fraction of water in moist air. Moles of moisture/lb of fuel is

$$\frac{4}{760} \frac{(0.481 \text{ moles of dry air/lb of fuel})}{0.99 \text{ volume fraction of dry air}} = 0.0025$$

Total moles of moisture/lb of fuel = 0.064

$$\text{Partial pressure of moisture in flue gas} = \frac{(0.064)}{0.515} (760) = 94.5 \text{ mm}$$

for stoichiometric burning

This corresponds to the saturated vapor pressure of water at 50°C.

If 300% excess air is used, 1.894 moles of dry air is consumed/lb of fuel

$$\text{Partial pressure of moisture in flue gas} = \frac{(0.064)}{1.958} (760) = 25 \text{ mm}$$

This corresponds to the vapor pressure of water at 26°C

The condensation of moisture was therefore expected and provided for in the form of a glass bottle placed in the sample line before the filter.

14

APPENDIX 2

12.

MAKE-UP OF CHARGE AND ANALYSES OF PRODUCT. RESULTS TAKEN FROM
FEDERATED METALS RECORDS OF RUNS

	Heat # 1	Heat # 2	Heat # 3	Heat # 4
# 1 Scrap - lb	11,662			
# 2 Scrap - lb	29,405			
Total scrap - lb	41,067	53,172	55,035	59,531
Sand - lb	928	420	215	---
Borax - lb	200	300	800	600
Ingot - lb	38,445	49,939	51,783	--
Buttons and Spatters - lb	202	185	80	--
Pot Skims - lb	990	885	703	598
Slag	7,608	2361	4223	1719
Casting time - hr	5 3/4	7	8	8 1/2
Oil used - gal	1565	1447	2003	1925
Cu	99.17	99.59	98.69	98.97
Sn	0.054	0.28	0.85	0.76
Pb	0.08	0.1	0.00	<0.01
Zn	Trace	0.1	Trace	Trace
Fe	0.008	0.013	0.013	0.018
Ni	0.13	0.04	0.42	0.07
S	0.02	0.016	0.014	0.017

APPENDIX 3

RESULTS OF ACTIVATION ANALYSES PERFORMED AT ORNL

Samples were taken from the metal product, slag by-product, and various places within the furnace or off gas system for determination of the uranium content. The method selected by Dr. Kelly of the Analytical Chemistry Division for uranium determination was activation analysis. The work was performed under the direction of G. W. Leddicotte.

The metal samples were prepared by cutting through a cast ingot then drilling to obtain turnings from several points across the cut face. Ingots were cast from metal taken from the bath after melting of the charge and also from the final product. Slag samples were taken from the first and last pots of slag to be removed from each heat and have been designated Pot # 1 and Pot # 2 respectively. The identification of the remaining samples in the following table shows the locations from which they were taken.

A. Copper Metal Samples

<u>Sample</u>	<u>Uranium Concentration, micrograms/gram</u>
Wire Bar ^a	Not Detected ^b
Blister Anode ^a	Not Detected
Final Product Metal, Heat # 1	Not Detected
Final Product Metal, Heat # 2	Not Detected
Final Product Metal, Heat # 3	Not Detected
Final Product Metal, Heat # 4	Not Detected
Metal Bath After Meltdown, Heat # 1	< 0.50 ^c
Metal Bath After Meltdown, Heat # 2	< 0.50 ^c
Metal Bath After Meltdown, Heat # 4	< 0.50 ^c
Final Metal Product, Heat # 1	0.80 (± 0.05)
Final Metal Product, Heat # 2	< 0.50 ^c
Final Metal Product, Heat # 3	< 1.30 ^d (est. 0.80)
Final Metal Product, Heat # 4	3.10 ^e

^a From Central Research Laboratory, Amer. Smelting and Ref. Company

^b Less than 0.022 micrograms/gram.

^c Limit of detection for irradiation conditions used in analysis.

^d Limit of detection for irradiation conditions used in analysis.

^e One analysis only. Uranium (as Np ²³⁹ gamma radiations) determined by single channel gamma spectrometer.

B. Slag Samples

<u>Sample</u>	<u>Uranium Concentration, milligrams/gram</u>
Heat # 1, Pot # 1	1.44, 1.43
Heat # 1, Pot # 2	1.68, 0.45, 0.52
Heat # 2, Pot # 1	1.68, 1.60
Heat # 2, Pot # 2	1.48, 1.68, 1.59
Heat # 3, Pot # 1	0.43, 0.44
Heat # 3, Pot # 2	0.47, 0.53, 0.57
Heat # 4, Pot # 1	1.40, 1.23, 1.23
Heat # 4, Pot # 3	1.73, 0.57, 0.42
Floor sweepings, 1st batch	0.56, 0.54
Floor sweepings, 2nd batch	1.59, 1.63, 1.39
Floor sweepings, 4th batch	0.21, 0.22
Waste from Ingot Cooling Trough	0.0021, 0.0028

C. Siliceous Materials

<u>Sample</u>	<u>Uranium Concentration, milligrams/gram</u>
Top of Furnace	0.19, 0.19
Bottom of Furnace	1.00, 1.02, 0.92
Ashes at Stack Bottom	0.001, 0.001
Start of Tunnel (at furnace side)	0.00041, 0.00037
Sides of Tunnel	0.098, 0.098, 0.110
Tunnel	0.031, 0.035, 0.038