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THE FATE OF TRACE METALS IN A FLUIDIZED BED SEWAGE SLUDGE INCINERATOR

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For Presentation at the 74th Annual Meeting of the Air Pollution Control Association

Philadelphia, Pennsylvania June 21-26, 1981

INTRODUCTION

The Marine Protection, Research and Sanctuaries Act of 1972 has established protection for the ocean water from unregulated dumping operations. To accomplish this, under Title II, Section 102 criteria have been established by EPA for the application, issuance and denial of permits for the transportation and dumping of materials into ocean waters.[1] The statute essentially requires the dumping of sewage sludge in the ocean to be terminated by the end of 1981 which will force increased use of land based management and disposal plans.

Land based alternatives for managing sludge are composting, land filling and incineration. This paper is concerned with the last alternative, incineration, and the resultant emissions of trace metals through a scrubber from the combustion of this sludge.

Waste water collection and treatment systems produce sludges, which contain both toxic organic compounds and trace metals. As a result of these organic and metal substances, which in many cases preclude the use of composting and land filling, incineration has become the preferred land based alternative. However, in an effort to ensure that the toxic organic compounds are completely destroyed, state and local environmental officials are investigating, and in some cases requiring, high temperatures of incineration (982°C - 1094°C). While this should in most cases eliminate the toxic organic problem it may drastically increase the stack emissions of some trace metals, especially lead and cadmium.

In an effort to understand the relationship between the temperature of incineration and the emissions of certain trace metals (arsenic, cadmium, chromium, copper, nickel, lead, and zinc), material balance studies were performed on the fluidized bed sludge incinerator at the Port Washington, New York Wastewater Treatment Facility, by GCA Corp under contract to the Regional II office of EPA. These tests were conducted at 3 different bed temperatures of 704°C, 816°C, and 927°C. The results demonstrate that as the temperature of the bed increased, the emissions of trace metals passing through the scrubber increased. This is in agreement with the work of Takeda and Hiraoka.[2] At Port Washington, the emissions of lead and cadmium increased exponentially with an increasing bed temperature. This is most significant because EPA has established an ambient standard for lead (1.5 $\mu g/m^3$ averaged over a calendar quarter) and is anticipated to a establish a standard for cadmium (possibly .1 $\mu g/m^3$) under the authority of the Clean Air Act.

Thus a large sludge incinerator with a substantial quantity of Pb and Cd in the sludge, operating at high temperatures of combustion

could contravene these standards.

FACILITY DESCRIPTION

The Port Washington Waste Water Treatment Plant is located in a primarily residential area on the northern shore of Long Island, New York. The plant is rated at 11.36 $x10^3$ m^3/d (3mgd) and produces primary and secondary sludge. The sludge is blended, conditioned with polymer, centrifuged and fed into a fluidized bed incinerator. During the tests the solids content was 19.2% and the measured heat content of the sludge was measured to be 4162 kJ/kg (8680 BTU/lb). See Figure 1.

The auxiliary fuel, No. 2 fuel oil, is introduced to the reactor by four oil feed guns. Fuel oil feed rate is recorded by plant instrumentation in gallons per minute. The oils measured heat content is 38,506 kJ/l (138,146 BTU/gal).

The Waste Water Treatment Plant does not produce enough sludge to sustain continuous operation of the incinerator. Therefore, the sludge is stored and the incinerator is operated on Mondays, Wednesdays and Fridays until all the stored sludge is combusted (approximately 10 hours operation per operating day).

Fluidized Bed Incinerator

The fluidizing blower delivers air under pressure to the windbox section of the reactor. The upflowing air is evenly distributed to the bottom of the fluid bed of sand by a constriction plate. The entering air is heated to the bed temperature by the hot sand. As the heated air continues its upward flow through the fluidized sand, the oxygen content is reduced by the combustion of the sewage sludge and auxiliary fuel. As the upflowing gas enters the freeboard area of the reactor most of the oxygen originally present in the air has reacted to form a mixture of combustion products.

Scrubber System

Combustion gases and ash solids pass through the reactor exhaust ductwork and enter a venturi scrubber and cooler. The scrubber system at Port Washington, features three cooling stages and two entrainment separation trays for particle removal. The resultant slurry is removed and pumped to a settling tank. Gas leaving the scrubber passes though approximately 6 meters of ductwork before it is emitted to the atmosphere. The gas is saturated with water vapor when it exits the scrubber. The scrubber operates at a pressure drop of 51 cm (20 in.) H_2O.

SAMPLING AND ANALYSIS

Solid, liquid and gas samples were collected from 12 locations during the test. Methods of sampling and measuring flows at each location are presented in Table 1. On each sampling day, a modified Method 5 (MM5), a Andersen impactor and a Source Assessment Sampling System (SASS) run were completed. Every 15 to 20 minutes during each gas sampling run, sludge and water samples were collected and flow rates were measured. All sludge and liquid samples were composited at the end of the day and the composites were analyzed for metals content. Flow rates were also averaged for the entire day. Sampling was conducted for three days at three different bed temperatures. Temperatures the first day were 704°C, the second 816°C and the third 927°C. A complete materials balance was calculated for each sampling day.

Modified Method 5 Train

A modified Method 5 train with absorbing solutions in three impingers was employed. Flue gas passed through a stainless steel probe tip, heated glass-lined probe and through a heated, glass fiber filter. The gas then enters a series of five impingers. The first two impingers contain 100 milliliters of 0.1 N nitric acid. The third impinger held 100 milliliters of 30 percent hydrogen peroxide. The fourth impinger was empty and the fifth impinger contained 250 grams of indicating-type silica gel.

Sampling with the modified Method 5 train was conducted in accordance with EPA Method 5 protocol.

SASS Train

The Source Assessment Sampling System (SASS) was used for particulate sampling. The SASS train collects particles in a series of three cyclones with nominal cut points of 10 μm, 3 μm, and 1 μm.

A 142 mm diameter back-up filter collects particles which are less than 1 um in diameter. The flow gas parameters of velocity and temperature were monitored with a probe attached S-type pitot tube and a type-K thermocouple.

Andersen Impacter Train

Particle size determinations were made by sampling with an Andersen Cascade impactor. The stack was saturated with water vapor at approximately 32°C. Since the parent particle sizes were of interest rather than the size of the associated droplets, the flue gas sample was heated to remove moisture before it

reached the substrate.

Metal Analyses

Analyses of the samples were performed using an Atomic Absorption Spectrophotometer equipped with deuterium arc background correction. The metals to be quantified include arsenic, cadmium, chromium, copper, nickel, lead, and zinc. For all elements except arsenic the samples were intially analyzed using flame methods to determine the concentration levels in the samples. For cadmium, chromium, and lead, the samples which had concentration levels below the flame AA detection limits were also analyzed by flameless AA methods using a Graphite Furnace.

RESULTS AND CONCLUSIONS

Sludge and Metals Input

The sludge charging rate with its metal constituents are presented in table 2.

Table 2

Temp	704°C		816°C		927°C	
Sludge Charging Rate Dry kg/hr.	182.9		212		236.3	
Metal Charging Rate	mg/kg	mg/hr.	mg/kg	mg/hr.	mg/kg	mg/hr.
As	0.39	71	0.23	49	0.27	64
Cd	4.0	732	4.0	849	4.0	945
Cr	3.0	8488	30	6364	30	7089
Cu	920	168,296	840	178,188	960	226,855
Ni	30	5488	20	4242	20	4726
Pb	230	42,074	210	44,546	200	47,261
Zn	660	120,734	650	137,883	620	146,510

The results of the solids material balance performed accross the centrifuge and incenerator/scrubber system are presented in Table 3.

TABLE 1. SAMPLE STREAM IDENTIFICATION

Stream No.	Stream description	Stream phase	Phases analyzed	Laboratory analyses/determinations	Sampling method	Flow measurement devices
1A	Sludge feed before centrifugation	Aqueous	Aqueous/ solids	Total Solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Tap/composited daily	Process gauge
1B	Sludge feed after centrifugation	Solid	Solid	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Dipper/composited daily	Calculated
1C	Centrate	Aqueous	Aqueous/ solids	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Dipper/composited daily	Calculated
1D	Coagulant	Aqueous	Aqueous	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Decant from drum/ discrete	In-line flowmeter
1E	Sand	Solid	Solid	Moisture, volatiles Pb, As, Cd, Cu, Cr, Zn, Ni,	Grab/discrete	Calculated
1F	Spent bed material	Solid	Solid	Moisture volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Grab/discrete	Not measured
2	Fuel oil	Organic	Liquid	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Grab/discrete	Process gauge
3	Treated water to scrubber system	Aqueous	Aqueous	Total solids, volatiles Pb, As, Cd, Cu, Cr, Zn, Ni,	Tap/composited daily	Ultrasonic flowmeter in-line flowmeter
4	City water	Aqueous	Aqueous	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Grab	In-line flowmeter
5	Scrubber overflow	Aqueous	Aqueous	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Tap/composited daily	Ultrasonic flowmeter
6	Scrubber effluent	Aqueous	Aqueous	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Grab at discharge composited daily	Ultrasonic flowmeter bucket method
7	Scrubber outlet - stack	Gaseous	Aqueous (Imp) / Solid (filter)	Pb, As, Cd, Cu, Cr, Zn, Ni, / Pb, Cd, Cu, Cr, Zn, Ni, As	M5, SASS, Andersen	S-type pitot/thermocouple

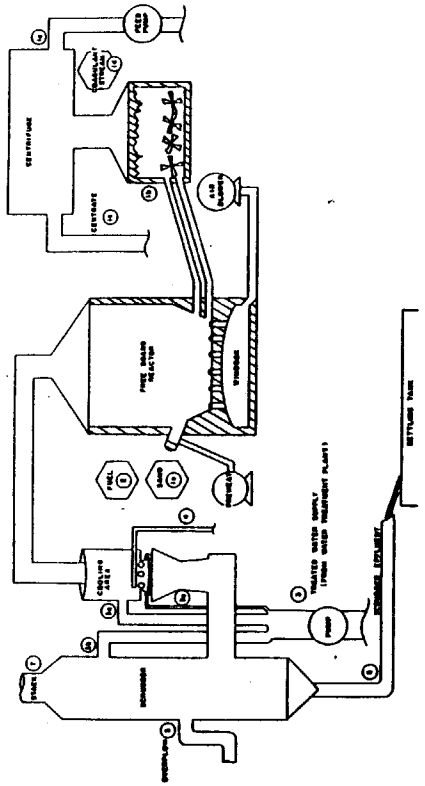

Figure 1. Incinerator-scrubber system.

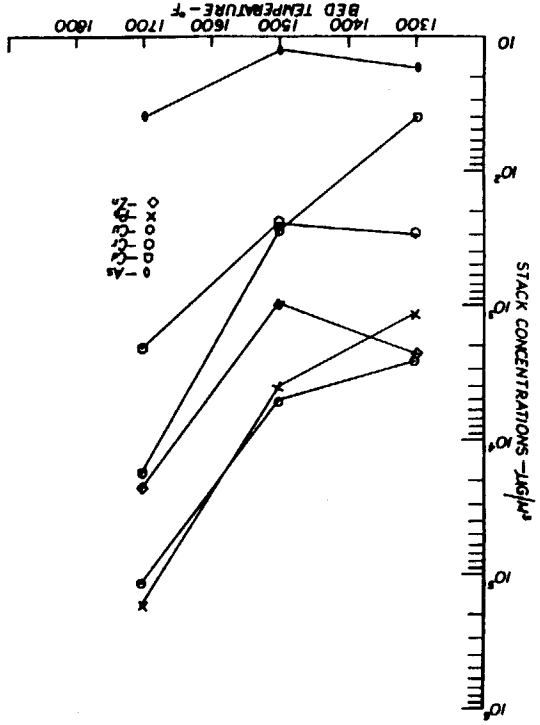

Figure 2

TABLE 1. SAMPLE STREAM IDENTIFICATION

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1A	Sludge feed before centrifugation	Aqueous	Aqueous/ solids	Total Solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Tap/composited daily	Process gauge
1B	Sludge feed after centrifugation	Solid	Solid	Total solids, volatiles, Pb, As, Cd, Cu, Cr, Zn, Ni,	Dipper/composited daily	Calculated

Table 3

Bed Temp °C	704	816	927
% Closure-Centrifuge	101	103	100
% Closure-Incinerator/Scrubber	19	13	11

The balance around the centrifuge indicate that all solids were accounted for. The balance around the incinerator/scrubber shows much of the material missing and is due to the volatile solids that were combusted in the incinerator. While the percent of volatile solids introduced remained fairly constant over the temperature range tested, the amount of material unaccounted for increased with increasing temperatures, as is presented in Table 4.

Table 4

Bed Temp °C	704	816	927
% Volatile solids in sludge	82.1	84.2	82.5
%Unaccounted for across incinerator/scrubber system	81	87	89

This can be explained by a more complete combustion of volatile solids at the higher temperatures and a greater loss of metals through the scrubber as the temperature increased.

Particulate Emissions

The concentrations of particulate matter emitted from the Port Washington sludge incinerator through the scrubber as determined by MM5 and the SASS train are presented in Table 5. All of the emission rates are below the allowable New Source Performance Standard, 0.65 g particulates/kg dry sludge incinerated (40 CFR Part 60 Subpart 0).

316	927
103	100
13	11

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Table 5 - Particulate Emission Results

Date	5/16/80	5/14/80	5/19/80
Bed Temperature °C	704	816	927
Grain loading gr/ dscf MM5	0.0044	0.010	0.012
Grain loading gr/ dscf SASS	0.00127	0.00096	0.00659
Emission Rate g/kg dry sludge MM5	0.17	0.26	0.32
Emission Rate g/kg dry sludge SASS	0.05	0.03	0.19

A comparison of MM5 and SASS train results indicates that the SASS emission rates are less than MM5 emission rates. A possible explanation is that MM5 is transversed across the stack while the SASS train is designed for single point sampling at the point of average velocity in the stack. It appears that the point of average flow is not the point of average particulate concentration at this incinerator, since collection efficiency is essentially identical.

In the development of the material balance for each metal, the SASS train results were used in preference to the MM5 results. The SASS train results while yielding a lower emission rate for total praticulates, sampled approximately ten times as much flow flow as MM5 and as a result yielded detectable samples for metal analysis while MM5 in some cases did not. MM5 did yield significantly higher results for As at all temperatures and slightly higher results for Pb at 816°C and 927°C, however, these differences had little bearing on the total balance. (See Tables 7-13)

Table 6 - Summary of Metal Emissions (mg/hr)

Bed Temperature °C	704		816		927	
Train	MM5	SASS	MM5	SASS	MM5	SASS
Nickel	ND	ND	ND	ND	ND	ND
Copper	94	64	372	139	847	2450
Chromium	ND	7.3	ND	7.0	ND	47
Lead	0.13	28	249	112	3704	3633
Arsenic	0.43	0.36	2.2	0.33	7.4	1.1
Cadmium	0.07	1.0	32.5	7.0	169	382
Zinc	ND	66	ND	58	180	495

Table 7 through 13 present the total mass balance for As, Cd, Cr, Cu, Ni, Pb and Zn across the incinerator/scrubber system. Table 14 summarizes the emissions in terms of µg of metal/g of particulate emitted and µg of metal/m^3 of stack gas.

Table 14 - Summary of Metal Emissions

Bed Temp °C	704		816		927	
Flow tested Sm^3	24.49		27.21		22.16	
	µg/g	µg/m^3	µg/g	µg/m^3	µg/g	µg/m^3
As	39.9	16.71	47.4	12.12	23.9	49.59
Cd	100	40.77	1000	275	8100	17,223
Cr	800	298	1000	275	1000	2,119
Cu	7000	2609	20,000	5106	52,000	110,460
Ni	<200	ND	<200	ND	<200	ND
Pb	3100	1142	16,000	4115	77,000	163,796
Zn	6400	2364	3600	918	10,500	22,317

The concentration in µg/m^3 depicted graphically in figure 2 clearly illustrate that with the exception of Ni, which was not detected in the stack tests, all the metals increased in concentration as the bed temperature was increased to 927°C (1700°F).

In addition the particle size distribution as illustrated in figure 3 shows the following fraction of the total particulate to be less than 1 um as measured in the Andersen Cascade impactors.

Table 15

Bed Temp °C	% Particles less than 1 µm	Mean Mass Diameter µm
704	74	80
816	66	69
927	62	83

All the metals accounted for in the stack have been measured as particulates. However, the material balances indicate that an additional quantity of Cr, Cu, Ni, Pb and Zn is unaccounted for. It is assumed that these quantities were emitted from the stack and accounted for in the following manner.

Tables 7-13 - Mass Balances Analyses

Arsenic Balance ug/hr

Bed Temperatures °F	1300	1500	1700
Stream			
1. Sludge	71	49	64
2. Coagulant	*ND	ND	ND
3. Sand	33	33	33
4. #2 Oil	ND	ND	ND
5. Treated Water	ND	ND	ND
6. City Water	ND	ND	ND
7. Scrubber Overflow	ND	ND	ND
8. Scrubber Effluent	151	196	234
9. Stack	0.41	0.33	1.1
% Closure	145	238	320

Lead Balance ug/hr

Bed Temperatures °F	1300	1500	1700
Stream			
1. Sludge	42,074	44,546	47,261
2. Coagulant	*ND	ND	ND
3. Sand	ND	ND	ND
4. #2 Oil	3.6	5.1	6.1
5. Treated Water	367	438	408
6. City Water	ND	ND	ND
7. Scrubber Overflow	668	538	537
8. Scrubber Effluent	40,570	34,425	37,737
9. Stack	28	112	3633
%Closure	97	78	88

Cadmium Balance ug/hr

Bed Temperatures °F	1300	1500	1700
Stream			
1. Sludge	732	849	945
2. Coagulant	*ND	ND	ND
3. Sand	7.0	7.0	7.0
4. #2 Oil	ND	ND	ND
5. Treated Water	63	54	88
6. City Water	0.9	1.0	1.7
7. Scrubber Overflow	64	53	202
8. Scrubber Effluent	554	762	990
9. Stack	1.0	7.0	382
% Closure	72	91	131

Nickel Balance ug/hr

Bed Temperatures °F	1300	1500	1700
Stream			
1. Sludge	5488	4242	4726
2. Coagulant	*ND	ND	ND
3. Sand	ND	ND	ND
4. #2 Oil	ND	ND	ND
5. Treated Water	ND	ND	ND
6. City Water	ND	ND	ND
7. Scrubber Overflow	ND	ND	ND
8. Scrubber Effluent	3845	3150	3150
9. Stack	ND	ND	ND
% Closure	70	74	67

Chromium Balance ug/hr

Bed Temperatures °F	1300	1500	1700
Stream			
1. Sludge	8488	364	7089
2. Coagulant	ND	ND	ND
3. Sand	ND	ND	ND
4. #2 Oil	ND	ND	ND
5. Treated Water	ND	ND	ND
6. City Water	ND	ND	ND
7. Scrubber Overflow	ND	ND	ND
8. Scrubber Effluent	6088	5726	5726
9. Stack	7.3	7.0	47.1
% Closure	10 9	89.97	81.43

Zinc Balance ug/hr

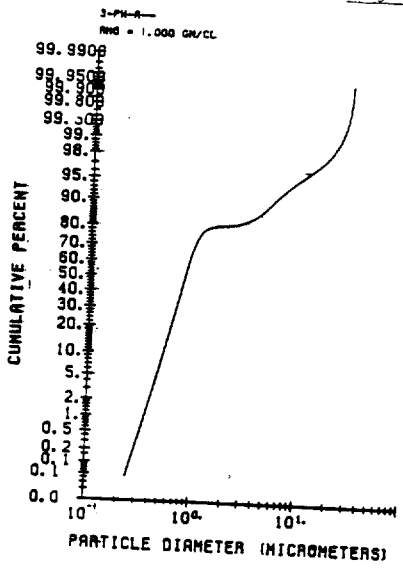
Bed Temperatures °F	1300	1500	1700
Stream			
1. Sludge	120,734	137,883	146,510
2. Coagulant	*ND	ND	ND
3. Sand	ND	ND	ND
4. #2 Oil	ND	ND	ND
5. Treated Water	7,120	5,761	6,108
6. City Water	ND	ND	ND
7. Scrubber Overflow	14,296	11,453	10,103
8. Scrubber Effluent	118,482	109,624	91,554
9. Stack	58	25	495
% Closure	102	83	64

*ND - not detected

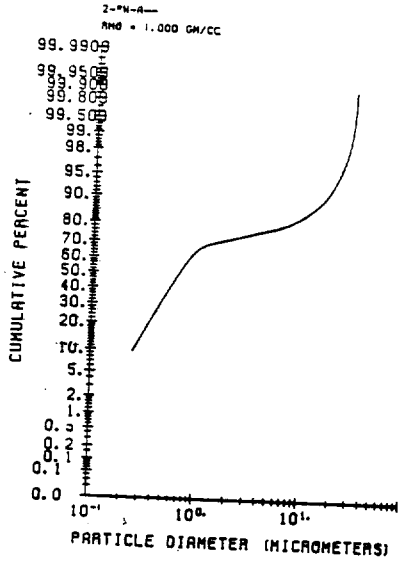
Copper Balance ug/hr

Bed Temperatures °F	1300	1500	1700
Stream			
1. Sludge	168,296	178,188	226,855
2. Coagulant	*ND	ND	ND
3. Sand	ND	ND	ND
4. #2 Oil	ND	ND	ND
5. Treated Water	ND	ND	ND
6. City Water	ND	ND	ND
7. Scrubber Overflow	15,877	17,180	10,635
8. Scrubber Effluent	129,112	237,130	144,840
9. Stack	64	139	2450
% Closure	86	143	68.9

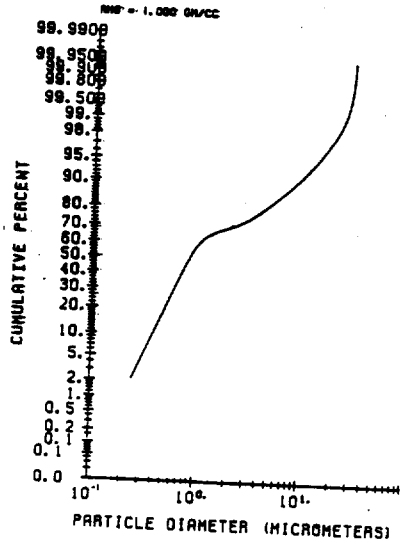
Figure 3



1300 °F



1500 °F



1700 °F

During the combustion process portions of the metals contained in the sludge evaporated either by vaporization, sublimation or both. Upon contact of the incinerator gases with the scrubber system the metals condensed with a portion being removed by the scrubber and the rest exiting the stack. Those particles that were large enough, 0.1 μm and larger, were captured and accounted for by the stack gas test methods that were employed. That portion that condensed to an extremly small particle (a fume, < .01 μm) will exhibit similar behavior to the surrounding gas molecules and pass through the stack sampling collection devices as other gas molecules.

The mechanisms involved in the vaporization of solids have not been fully explored for all substances. However, some work in this field reported by Somorjai and Lester [4] indicate that substances such as Zinc Oxide dissociate upon vaporization to Zn vapor and O_2 gas between 982 and 1204°C. Arsenic by comparison may startout as, As_2O_3 and end up as both As_2O_3 and As_4O_6. This work was reported from observations in a vacuum while in an incinerator environment As_2O_3 may undergo different associations. It does seem highly possible that regardless of the vaporization mechanism, association or dissociation, the vaporized metal will be on the order of molecular size. These vaporized/ condensed forms would find their way through and out of a stack scrubber system and a particulate stack sampling apparatus.

INDIVIDUAL DISCUSSION OF METALS

Arsenic (As):

There was a higher emission rate of As found in the scrubber effluent than in the incinerator input for all three runs. Thus the balance for all three runs exceeded 100%. An explanation is that As was found in the sand (2.9 μg/g) and that the estimated flow rate of sand was inaccurate. It is also unknown if the As associated with the sand had a higher concentrations of the light ends and was emitted easier or was associated with the heavier parts and stayed in the bed.

Arsenic associated with the particulate emissions increased by a factor of 3 from 704°C to 927°C. Because the balance was greater than 100% on all three runs, it is not evident if some portion of the As was emitted in the form of a fume.

However, As sublimes at 613°C and AS_2O_3 sublimes at 139°C which suggest that some As would evaporate and exit through the scrubber as a fume.

Cadmium (Cd):

The balances through the incinerator/scrubber system varied for Cd. More Cd was accounted for in the scrubber effluent then in the sludge input at 927°C. The quantities of Cd in the scrubber increased in a linear fashion as the bed temperature increased with ten times as much Cd found in the aqueous portion of the effluent then in the settleable solids fraction. However, the stack emissions of Cd increased exponentially and can be expressed by:

(1) $C_{cd} = 9.74 \times 10^{-5} e^{.0197T}$

C_{cd} = µg of Cd/g Particulate emitted, T = °C

This equation was arrived at by the use of a Hewlett-Packard 34C programmable calculator and a regression technique program that transforms the general equation Y = a Exp bx (a > 0) into Y = A + bx where the regression coefficients a & b and the coefficient of determination, r^2 are calculated. The closer r^2 is to one the better the fit of the curve to the data points.

For equation 1 the coefficient of determination was found to be .999.

Since the closure at 927°C was greater that 100%, it was not possible to estimate if any Cd was lost as fumes. However, the temperature of vaporization of Cd, 766°C and the dissociation temperature of CdO, 884°C suggest a substantial amount of Cd should vaporize at 927°C and be emitted as fumes. The stack tests indicated 40% of the total Cd input was accounted for in the particulate stack emissions at 927°C.

Chromium (Cr):

The material balance for the low and medium temperatures runs were within 10 percent of closure with more than 99% of the mass being accounted for in the scrubber effluent. However, the stack emissions for Cr increased almost seven times between the 816°C and 927°C runs. Concurrently, the closure for the material balance widened to 19%. Thus there was an increase with the Cr emissions associated with the particulates and that as a fume, so that the total emissions at 927°C could be written as:

(2) E_{cr} = 47.1 μg/hr. + 19% of Cr input

Copper (Cu):

The closure at the 816°C run was 143% and may be attributable to the scrubber effluent which was on the order of 10^5 μg/hr greater than the 704°C or 927°C runs.

The copper emission rate increased twice from 704°C to 816°C and 18 times from 816°C to 927°C and can be expressed by the following exponential equation:

(3) $Ccu = 12.64\ e^{.009T}$

where Ccu = μg of Cu/g of Particulate emitted, T = °C

and

$r^2 = .999$

At 927°C up to 31% of the Cu input was unaccounted for and could have been emitted from the stack as a fume.

Thus, the maximum emission of Cu at 927°C is expressed as:

(4) $Ecu = (12.64\ e^{.009T})\ G$ + 31% of total Cu input

Ecu = Total Emission of Cu, G = Grams of particulates emissions

Nickel

There was little change in any of the nickel emission rates despite changing bed temperature. Nickel was not detected in the stack for any of the runs. Approximately 30 percent of the nickel was unaccounted for in all three of the material balances.

Lead (Pb)

The 704°C run had a 97% closure with most of the lead found in the scrubber effluent. At 816°C the lead emissions increased by a factor of 4 and by a factor of 32 at 927°C. The increase in lead emissions indicated an exponential trend as the temperature increased as expressed in equation 5 below:

(5) $C_{Pb} = 0.123\ e^{.0144T}$

C = μgPb/g of Particulate, T= °C

The portion of Pb not accounted for at 927°C and assumed to be emitted as a fume is 12% of the total lead input.

Thus, the maximum Pb emission rate at 927°C is:

(6) $E_{Pb} = (.123\ e^{.0144T})\ G$ + 12% of total Pb input

E_{Pb} = Total lead emission in grams , T = °C

G = grams of particulate emissions

Zinc (Zn)

At the 704°C run the material balance was within 2% of closure. As the bed temperature increased to 816°C and 927°C, 38% of the zinc was unaccountable, with 19% unaccounted for between each bed temperature rise. This is probably because of the low volatilization temperature and possible sublimation activities. The vaporization temperature of zinc is 906°C. The maximum emission of Zinc at 927°C then becomes:

(7) E_{Zn} = (10,500 μgZn/g pt) G + 36% of total zinc input

E_{Zn} = Total zinc emission

G = Grams of particulates emissions

The test results from the Port Washington sludge incinerator demonstrates a similar trend to the work of Takeda and Hiraoka in Japan. Though the incinerator tested in Japan is of a different type (combined pyrolysis and combustion), both studies clearly show an increase of metals emissions with an increase in incineration temperature.

There have been other studies that demonstrate that most of the trace metals, with the exception of Hg, are retained in the ash and/or captured by the venturi scrubber, i.e., Dewling et al,[5] Greenburg et al [6] and Wall and Farrell.[7] However, these studies were performed on incinerators that operated at conventional temperatures (704°C to 816°C) and when compared with the Port Washington study for the 704°C to 816°C temperature range demonstrates similar results.

It appears from this study that substantial quantities of trace metals are emitted as the temperature in the combustion chamber increases above 816°C particularly for Cd, Cr, Cu, Pb and Zn. For an incinerator of this size with this much trace metal input and output it may not seem substantial. However, when the emission trends of this study are applied to EPA funded sludge proposed incinerators that are designed to burn 300-400 dry tons of sludge per day with high metal content at 982°C - 1094°C, the metal emissions may then become substantial and necessitate that for those emissions not regulated by the Clean Air Act

environmental assessment, as directed under the National Environmental Policy Act be completed. Part of that assessment is to determine if any adverse health impacts are caused by these projected trace metal emissions.

CONCLUSION

1. The SASS test results found no particulates captured in the cyclones. All particulates were captured on the filter. In addition, the Andersen Impactor demonstrated that most particulates being emitted were between .1 μm and 1 μm diameter. This is significant since particulates of this size are too large to be influenced by Brownian motion and too small to be trapped in the upper portion of the lung. Thus all metal emissions associated with particulates emissions are between .1 μm and 1 μm diameter and are capable of retention in the lower respiratory tract.[3]

2. The emissions of trace metals from a fluidized bed incinerator through a medium pressure drop scrubber substantially increase as the bed temperature increases from 704°C to 927°C (1300°F to 1700°F).

3. As the bed temperature of a fluidize bed incinerator increases the quantity of metal unaccounted for in the material balance increases and is assumed to be emitted through the scrubber as fumes.

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GCA-TR-80-91-G

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Division of Stationary Source Enforcement
Washington, D.C.

Contract No. 68-01-4143
Technical Service Area 3
Task Order No. 83

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PERFORMANCE OF EMISSIONS TESTS AND MATERIAL BALANCE FOR A FLUIDIZED-BED SLUDGE INCINERATOR

Final Report

November 1980

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SECTION 1

INTRODUCTION

STATEMENT OF THE PROBLEM

The extent to which sewage sludge incinerators can comply with Federal and State regulations needs further documentation. Of special concern are emissions of particulates and trace metals, and the extent to which these emissions may vary with incinerator operating variables.

OBJECTIVES OF THIS STUDY

Region II of the U.S. Environmental Protection Agency identified a fluidized-bed sewage sludge incinerator in Port Washington, New York which was a suitable test site for a compliance evaluation. Testing at this sludge incinerator was conducted at three different bed temperatures (1300°F, 1500°F, and 1700°F) so that the EPA may better determine the variance of the total particulate and heavy metals emissions. This testing will also provide data to the Air Facilities Branch for heavy metals emissions modeling.

Testing was performed at the Port Washington sewage sludge incinerator by GCA personnel on May 14, 16 and 19. Flue gas samples were taken from the scrubber outlet stack using three different types of sampling trains; a modified Method 5 train, a Source Assessment Sampling System train and an Andersen impactor train. The modified Method 5 train was used to collect particulate on the filter and volatile metals in the impinger solutions. The SASS train was used to collect a size-classified sample of particulate. The samples collected from both of these trains were analyzed for seven metals of interest. Those metals are: lead, cadmium, copper, chromium, zinc, nickel and arsenic. The Andersen impactor train was used for determining particle size distribution in the flue gas stream.

The fundamental objective of this study was to provide data to perform a material balance across the incinerator/scrubber system. To do this, samples were procured from seven process streams bihourly during the stack sampling. Samples were composited on a daily basis at the conclusion of each day of sampling. Four additional discrete samples were obtained during the week of testing. The discrete samples were; bed sand, fuel oil and polymer. These and the other process streams were analyzed for the seven metals of interest plus mercury.

SECTION 2

FACILITY DESCRIPTION

The fluidized-bed sewage sludge incinerator in Port Washington, New York, operates on each Monday, Wednesday and Friday for approximately 10 hours during which roughly 10,000 pounds of wet sludge is incinerated. The incinerator was manufactured by Dorr-Oliver and is 10 years old.

A diagram of the incinerator and scrubber is given in Figure 1.

SLUDGE AND FUEL FEED

Raw sludge exits the primary treatment plant to a thickening tank. Thickened sludge then passes through a separator to a disintegrator where any fiberous trash is shredded into small pieces to avoid equipment plugging. After the disintegrator, a conditioning polymer is added to aggregate and precipitate additional solids from the solution. This polymer produces heavier and more consolidated solids and therefore a cleaner centrate. Two parallel centrifuge feed pumps then deliver the concentrated sludge to two centrifuges where dewatering occurs. The heavy sludge solids are ejected from the centrifuges and enter the sludge feed chutes, the remaining water, or centrate, being returned to the treatment plant. Two reactor feed pumps then force the dewatered sludge through the feed hose to the reactor. The sludge finally enters the bed of hot fluidized sand where it is burned.

The auxiliary fuel, No. 2 fuel oil, is introduced to the reactor by four oil feed guns. Fuel oil feed rate is recorded by plant instrumentation in gallons per minute. Actual sludge feed rate is estimated by plant personnel.

FLUIDIZED BED INCINERATOR

The fluidizing blower delivers air under pressure to the windbox section of the reactor. The upflowing air is evenly distributed to the bottom of the fluid bed of silica sand by the constriction plate. The entering air is heated to the bed temperature instantly by the hot sand. As the heated air continues its upward flow through the fluidized sand, the oxygen content is reduced by the combustion of the sewage sludge and auxiliary fuel. By the time the upflowing gas enters the freeboard area of the reactor most of the oxygen originally present in the air has been converted to a mixture of combustion products.

Bed material, the silica sand, is added to the reactor every 2 weeks. An average of fifteen 100-pound bags are added every 60 hours of operation.

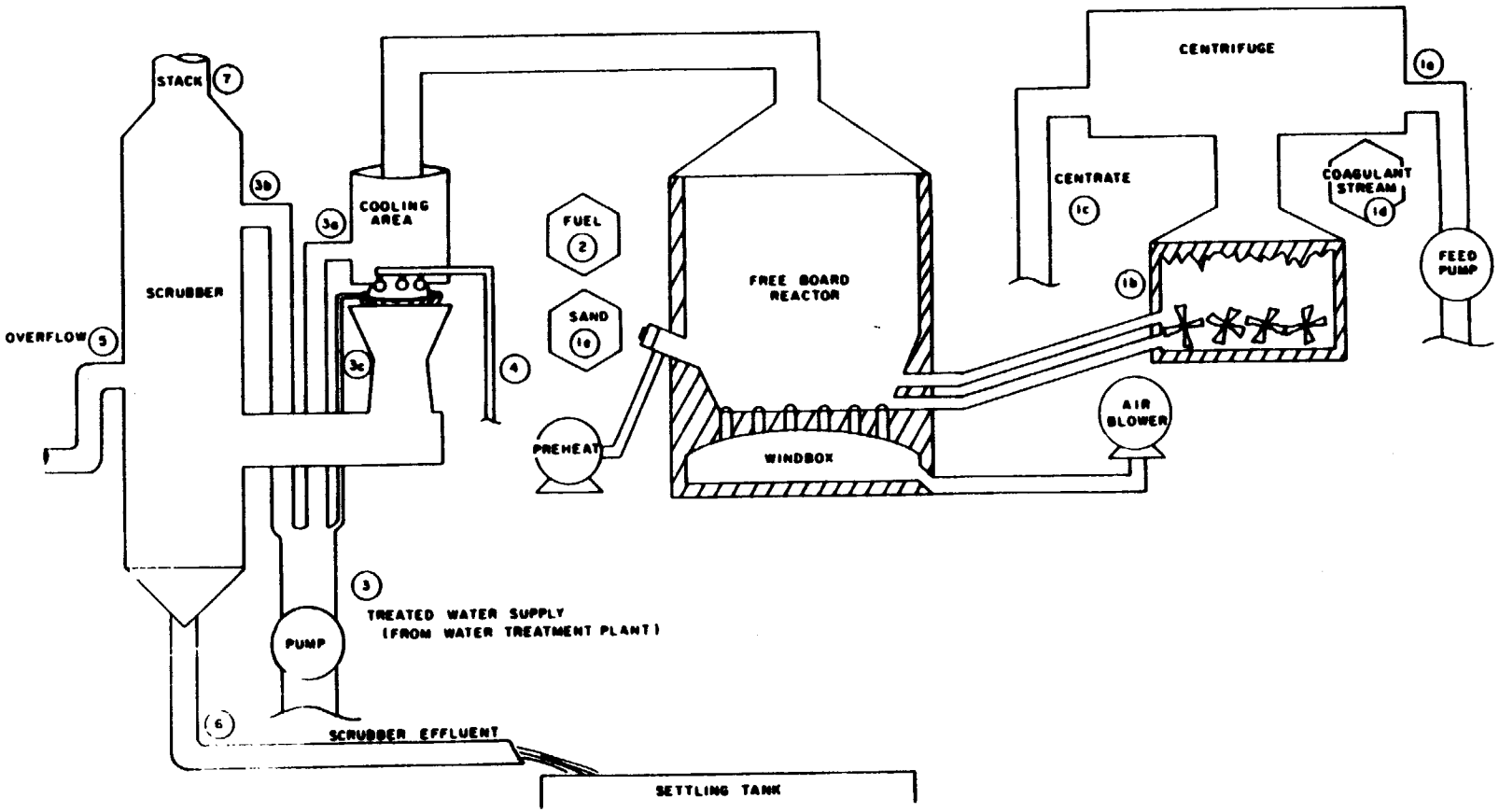


Figure 1. Incinerator-scrubber system.

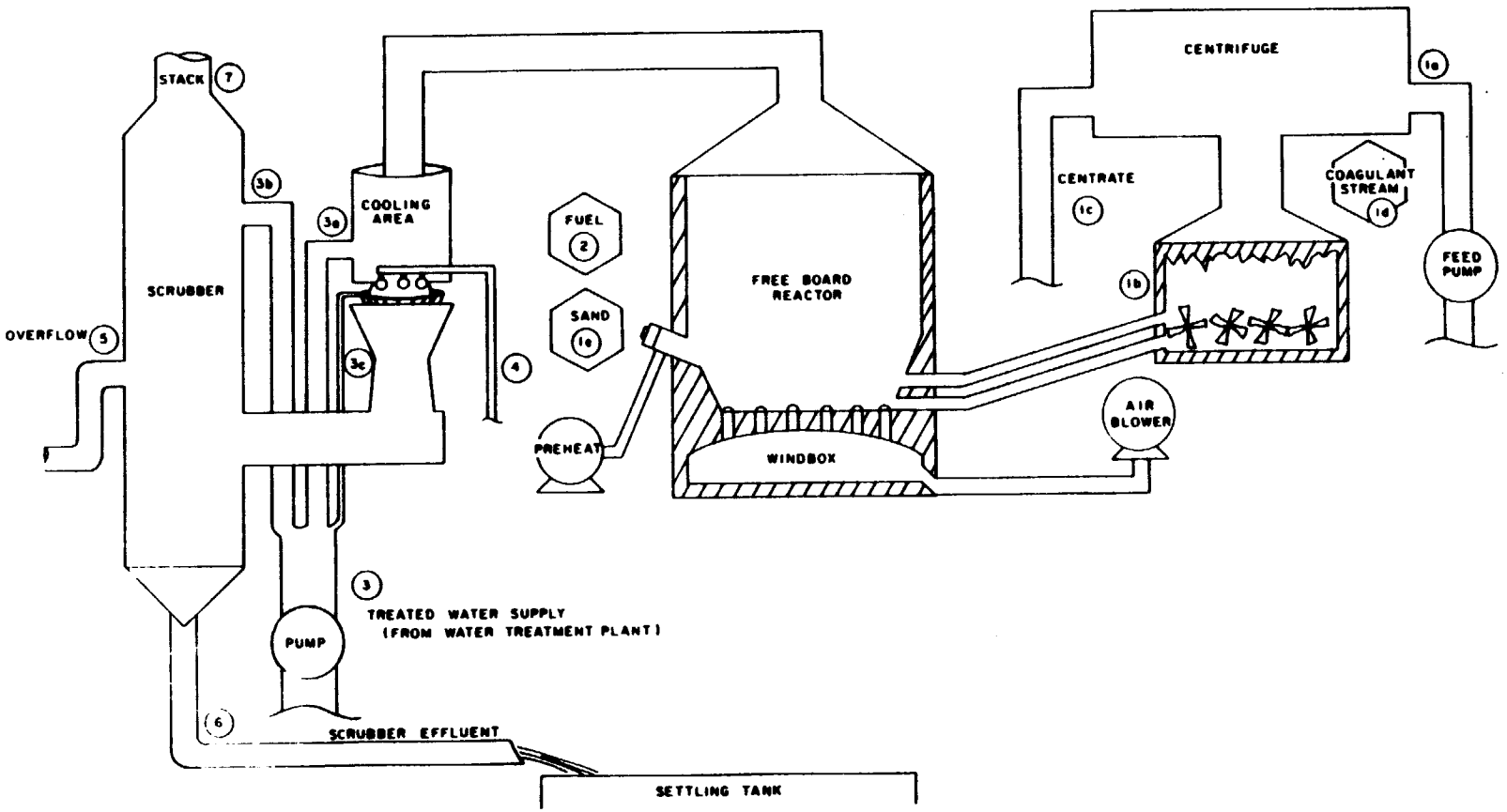


Figure 1. Incinerator-scrubber system.

The uncontrolled off gases from the reactor, are a mixture of sewage sludge combustion products, fuel oil combustion products, water vapor, small amounts of very fine sand and ash (uncombustible portions of the sewage sludge).

SCRUBBER SYSTEM

The mixture of combustion gases and ash solids pass through the reactor exhaust ductwork and enter a venturi scrubber and cooler. This scrubber system features three cooling stages and two entrainment separation trays to remove solid particles. The resultant slurry is removed from the scrubber and pumped to a settling basin. The gas leaving the scrubber passes through approximately 20 feet of ductwork before it is emitted to the atmosphere. The gas is saturated with water vapor when it exits the scrubber. The scrubber operates at a pressure drop of 20 in. H_2O.

SECTION 3

SAMPLING AND ANALYSIS PROCEDURES

PRESAMPLING PREPARATION

All glassware, HDLP sample bottles, probe tips, SASS train sampling components, sample buckets and containers utilized in this program were cleaned with an Alconox solution, rinsed with tap water, soaked in 15 percent nitric acid and finally rinsed with distilled deionized water. All components were air-dried and capped off for transport.

All filters were desiccated to a constant weight. Sample handling procedures included quality control of all solvents, sample bottles and recovery procedures to assure sample integrity.

Calibration of field equipment, including pitot tubes, probe nozzles, dry gas meters and orifices were completed prior to any sampling. All calibration data is listed in Appendix A.

SAMPLING LOCATIONS

Described below are the sampling locations that were used throughout the sampling period. Various sampling and flow measurement methodologies were employed and are discussed in this section. Table 1 is a list of sampling locations and flow measurement techniques used.

Sampling Location No. 1

Sampling location No. 1 is the sludge feed area of the process. This location included three separate sampling points. The main sludge feed line diverges to travel to two Merco Bowl centrifuges. Separate samples were taken from a tap before each centrifuge and composited to form Sample 1A. The dewatered sludge exiting each centrifuge was sampled at the hopper of each paddle feed box with a dipper shovel (1B). This sample was representative of the material that was fed into the incinerator. The centrate stream exiting each centrifuge was sampled at the point of discharge beneath the basement floor with a dipper shovel (1C). A representative sample of the coagulant that was mixed with the sludge before the centrifuge was obtained from the chemical mix tank (1D). A sample of the sand, before (1E) and after (1F) addition to the bed was also taken.

TABLE 1. SAMPLE STREAM IDENTIFICATION

Stream No.	Stream description	Stream phase	Phases analyzed	Laboratory analyses/determinations	Sampling method	Flow measurement devices
1A	Sludge feed before centrifugation	Aqueous	Aqueous/ solids	Total Solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Tap/composited daily	Process gauge
1B	Sludge feed after centrifugation	Solid	Solid	Total solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Dipper/composited daily	Calculated
1C	Centrate	Aqueous	Aqueous/ solids	Total solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Dipper/composited daily	Calculated
1D	Coagulant	Aqueous	Aqueous	Total solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Decant from drum/ discrete	In-line flowmeter
1E	Sand	Solid	Solid	Moisture, volatiles Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Grab/discrete	Calculated
1F	Spent bed material	Solid	Solid	Moisture volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Grab/discrete	Not measured
2	Fuel oil	Organic	Liquid	Total solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Grab/discrete	Process gauge
3	Treated water to scrubber system	Aqueous	Aqueous	Total solids, volatiles Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Tap/composited daily	Ultrasonic flowmeter in-line flowmeter
4	City water	Aqueous	Aqueous	Total solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Grab	In-line flowmeter
5	Scrubber overflow	Aqueous	Aqueous	Total solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Tap/composited daily	Ultrasonic flowmeter
6	Scrubber effluent	Aqueous	Aqueous/ Solids	Total solids, volatiles, Pb, Hg, Cd, Cu, Cr, Zn, Ni, As	Grab at discharge composited daily	Ultrasonic flowmeter bucket method
7	Scrubber outlet - stack	Gaseous	Aqueous (Imp) / Solid (filter)	Pb, Cd, Cu, Cr, Zn, Ni, As / Pb, Cd, Cu, Cr, Zn, Ni, As	M5, SASS, Andersen	S-type pitot/thermocouple

Sampling Location No. 2

Sampling location No. 2 was the auxiliary fuel feed line. During sample procurement the fuel feed line was disengaged near the incinerator port and the sample of No. 2 fuel oil was collected.

Sampling Location No. 3

Sampling location No. 3 was an effluent from the secondary treatment plant. A 4-inch steel pipe splits into three streams above the main water pump. Two of the streams (3A and 3C) were 1-1/2 inch steel pipe that were routed to the cooling unit before the scrubber. The third stream, 3B, was a 4-inch steel pipe that introduced water into the scrubber. A sample of this water was obtained from a tap at location 3B.

Sampling Location No. 4

Sampling location No. 4 was a city water stream. This 1-inch PVC pipe provided water at the cooling unit via several independent jets or ports. A sample of this water was taken from a side stream that discharged city water into a basin.

Sampling Location No. 5

Sampling location No. 5 was a scrubber overflow pipe. This was a 6-inch steel pipe that led from the scrubber into an underground storage tank. A sample from this location was obtained from a tap in the pipe.

Sampling Location No. 6

Sampling location No. 6 is the scrubber effluent stream. Scrubber effluent drains through the bottom of the scrubber and is pumped through a 2-inch PVC pipe to a settling tank. Samples were collected at the point of discharge into the settling tank.

Sampling Location No. 7

The scrubber outlet stack is 13-1/2 inches in diameter. Two 3-inch ports at 90° intervals are located 5 feet from the roof. A third port, 4 inches in diameter, is located 12 inches above the other ports. A drawing of sample location No. 7 is given in Figure 2.

MODIFIED METHOD 5 TRAIN

On each sampling day, one modified Method 5, one Andersen impactor and one SASS run were completed.

The modified Method 5 train was a RAC train with absorbing solutions in three impingers. A schematic of the Method 5 train is shown in Figure 3. Flue gas passed through a stainless steel probe tip, heated glass-lined probe and into a heated, glass fiber filter. The gas then enters a series of five impingers. The first two impingers contain 100 millimeters of 0.1 N nitric

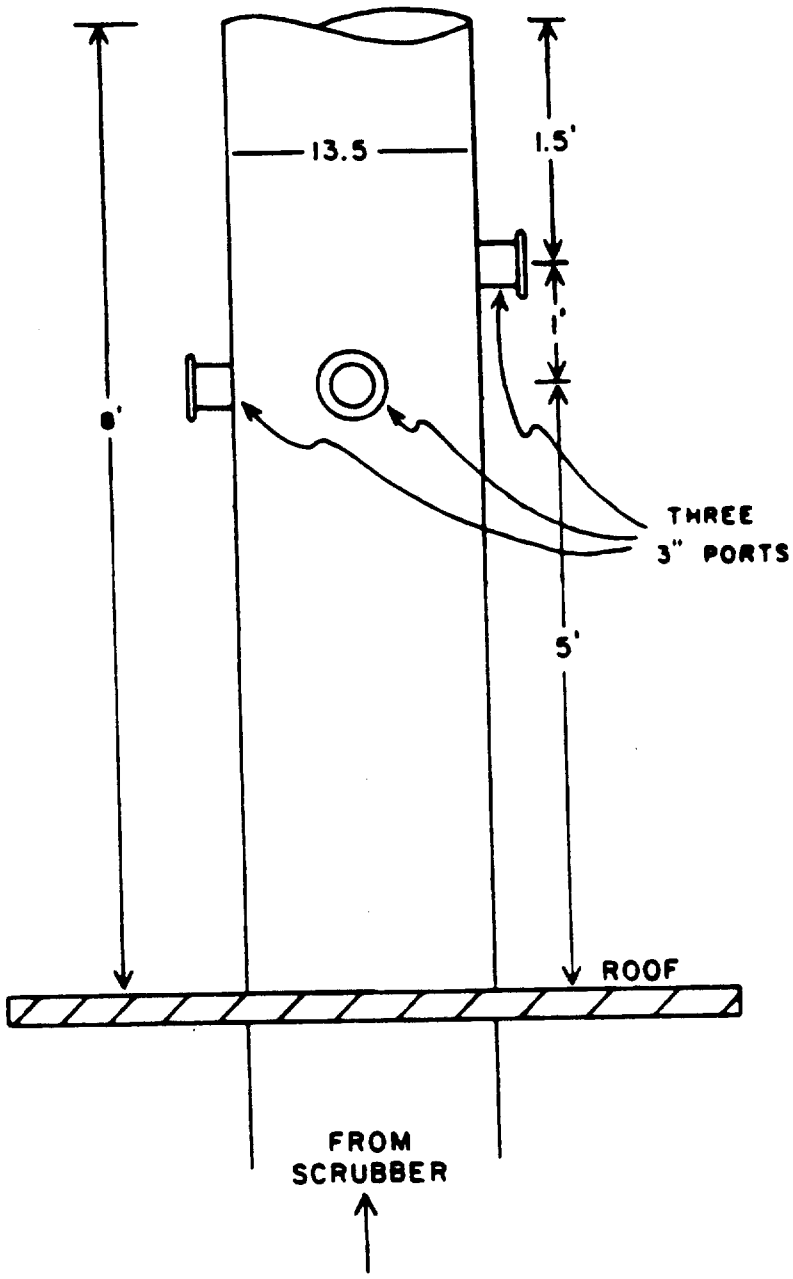


Figure 2. Fluidized-bed incinerator stack.

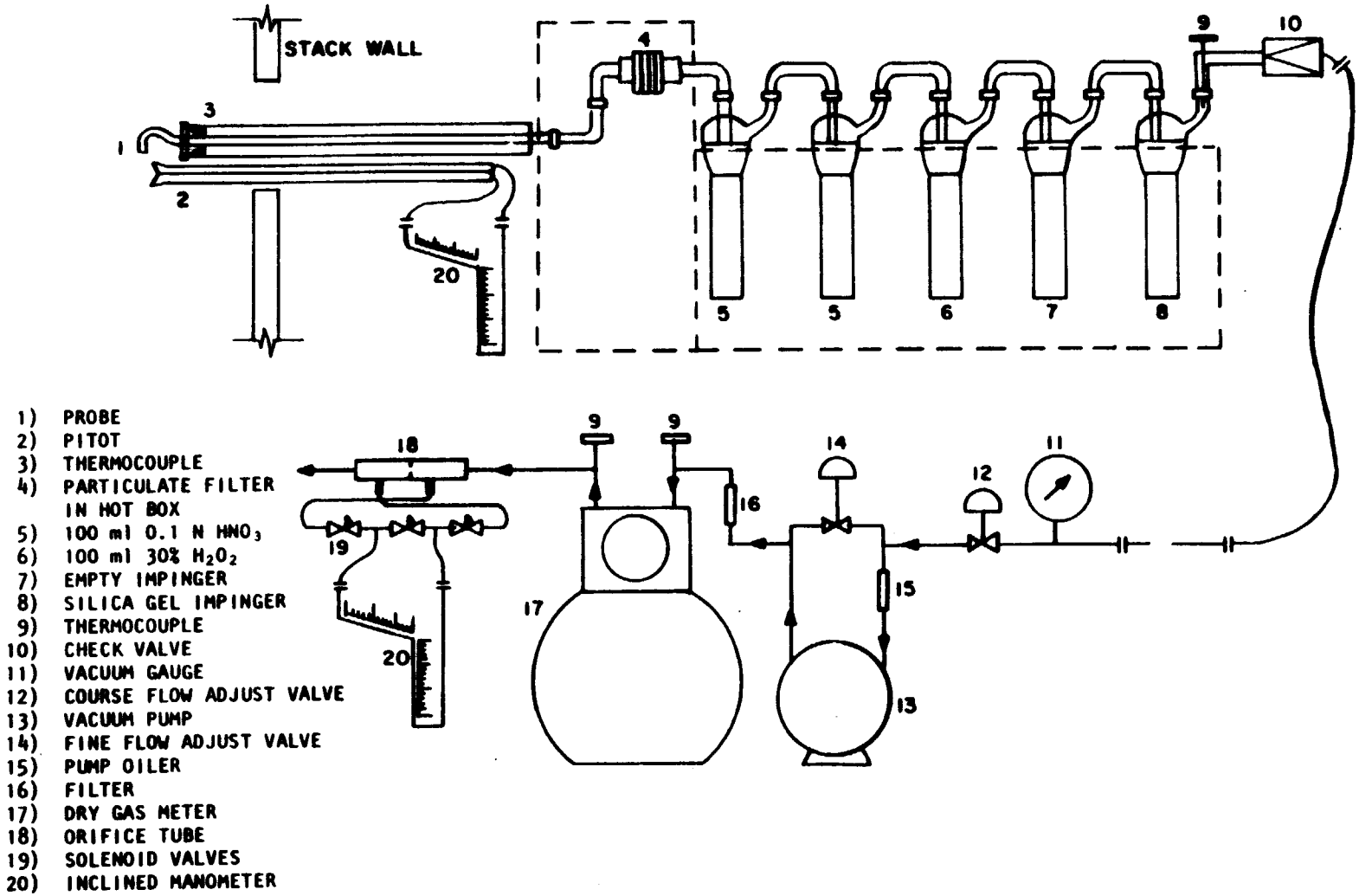


Figure 3. Schematic of RAC Staksamplr™ used for Modified Method 5 sampling.

acid. The third impinger held 100 milliliters of 30 percent hydrogen peroxide. The fourth impinger was empty and the fifth impinger contained 250 grams of indicating-type silica gel.

Sampling with the modified Method 5 train was conducted in accordance with EPA Method 5 protocol. A total of 20 points, at 5 minutes per point, were sampled along two diameters of the stack. Physical parameters of the stack gas were monitored with an S-type pitot tube and a type K thermocouple that were attached to the sample probe.

Upon completion of each test, the sample train was leak checked, capped off and carried to the sample recovery area. The impingers were first measured for moisture gain and then each of the first four impingers and connecting glassware were rinsed with distilled deionized water into precleaned (15 percent HNO_3 washed) HDLP containers. The glass fiber filter was transferred to a petri dish. All adhered particulate in the sample probe and the front half of the filter holder was rinsed with acetone. Prior to each run, the entire sampling train was cleaned with 15 percent nitric acid and rinsed with DDI water. The particulate samples, impinger solutions and appropriate blanks were returned to the GCA laboratory facility for analysis.

SASS TRAIN

The Source Assessment Sampling System (SASS) was used for particulate sampling. A schematic of the SASS train is shown in Figure 4. The SASS train collects particles in a series of three cyclones with nominal cut points of 10 μm, 3 μm and 1 μm. A 142 mm back-up filter collects particles which are less than 1 μm in diameter. The probe, cyclones and filter housing were prewashed with 15 percent nitric acid before each run to remove any contaminants prior to the sampling.

For the first two (1300°F and 1500°F) of the three SASS runs, the filter was followed by an organic module. The organic module features a double wall heat exchanger to reduce gas temperature from 400°F at the cyclones to 68°F. Organic materials are collected in a XAD-2 resin sorbent cartridge. Organic condensate is collected in a reservoir at the base of the module. Gas exits the organic module to an impinger system.

For the third of the three SASS runs, the organic module was not used. Sample gas went from the filter housing exit to the first in a series of four impingers. The first two impingers contained 500 milliliters of DDI each. The third impinger was empty and the fourth impinger contained 750 grams of silica gel.

The physical parameters of the flue gas were monitored with an attached S-type pitot tube and a type-K thermocouple. Readings of all sample train operations and flue gas parameters were recorded every 15 minutes. Sampling was designed to collect 4 dscf per minute for as long as possible.

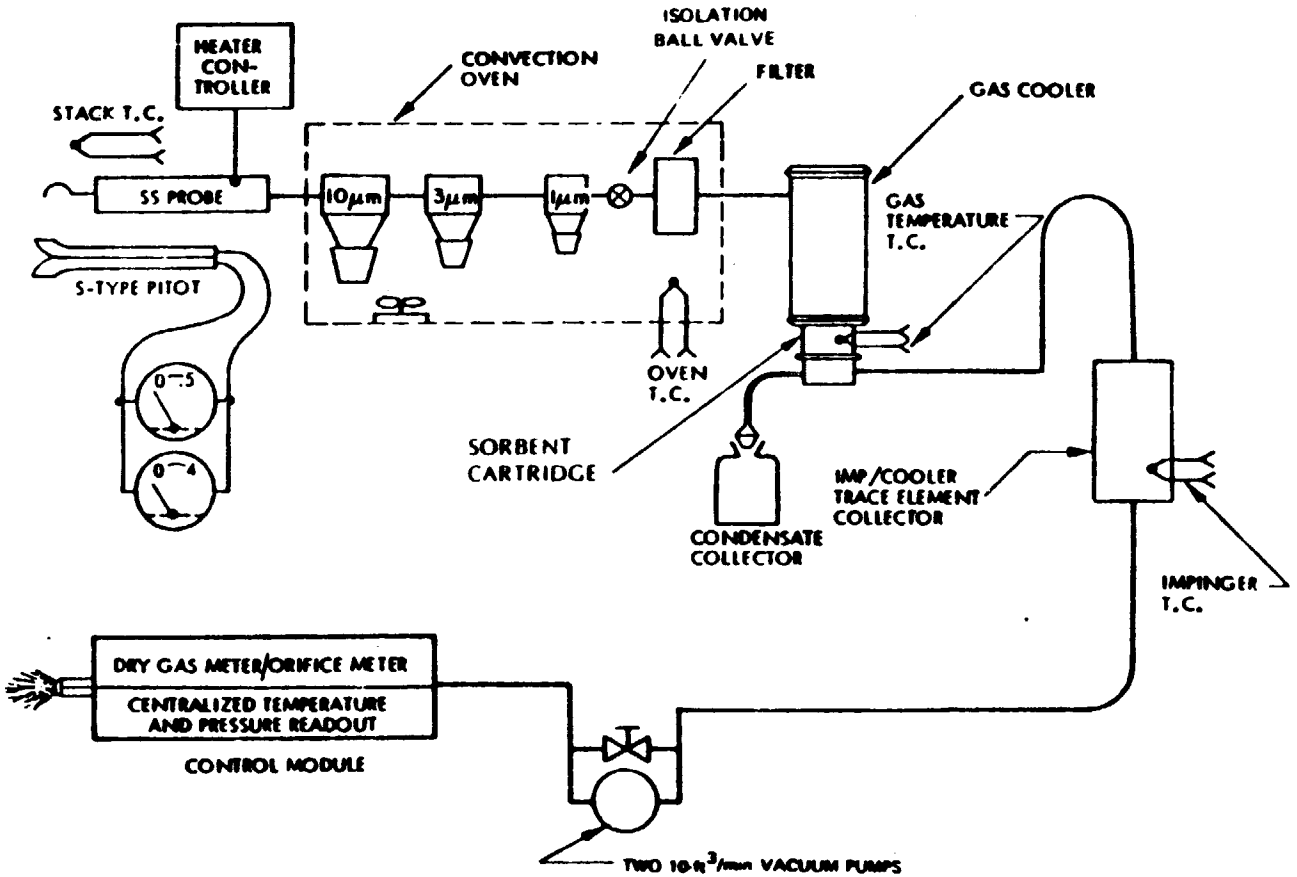


Figure 4. Source assessment sampling train schematic.

Upon completion of each test the sample train was leak-checked, capped off and removed to the recovery area. The impingers were measured for moisture gain and discarded. The filter was transferred to a petri dish. When the cyclones were opened at the end of the run, there were no visible particulates to be transferred to sample containers. Any surface adhered particulate in the probe/cyclone/filter assembly was recovered by rinsing with acetone. The particulate samples were returned to GCA for gravimetric determination and analysis for metal content. Samples obtained from the organic module were recovered as required for Level I. These samples were turned over to an EPA representative.

Andersen Impactor Train

Particle size determinations were made by sampling with an Andersen Cascade impactor. The stack was saturated with water vapor at approximately 90°F. Since the parent particle sizes were of interest rather than the size of the associated droplets, the flue gas sample was heated to remove moisture before it reached the substrates. Heating tape was wrapped around a 10-inch piece of stainless steel tubing between the probe tip and the impactor. The impactor itself was also wrapped with heating tape. The impactor and the associated tubing was maintained at a temperature of 300°F to drive off moisture and maintain constant cut sizes.

Fixed Gases

Grab samples of the flue gas for fixed gas analysis were obtained by continuous withdrawal of flue gas through a stainless steel proble connected with Teflon tubing to an evacuated Tedlar bag. An alternative method, direct withdrawal of flue gas with a squeeze bulb was also employed for one of the samples. Oxygen, carbon dioxide, and carbon monoxide measurements were made with an Orsat analyzer.

Metal Analyses

The atomic absorption analyses of the samples were done on a Perkin-Elmer Model 460 Atomic Absorption Spectrophotometer equipped with deuterium arc background correction. The metals to be quantified included arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc. For all elements except arsenic and mercury, the samples were initially analyzed using flame methods to determine the concentration levels in the samples. For cadmium, chromium, and lead, the samples which had concentration levels below the flame AA detection limits were also analyzed by flameless methods with a Perkin-Elmer HGA-2100 Graphite Furnace.

The operating parameters for each element for the flame and flameless methods are listed in Tables 2 and 3, respectively. For the flameless analyses, the drying, charring, and atomization cycles were optimized for each element. Aliquot volumes of 50 µl were injected into the furnace using a Perkin-Elmer AS-40 Auto Sampler.

TABLE 2. OPERATING PARAMETERS FOR FLAME AA ANALYSES

Metal	Wavelength (nm)	Slit width (nm)	Lamp	Flame type
Cd	228.8	0.7	EDL	Air/C_2H_2
Cr	357.9	0.7	HCL	Air/C_2H_2
Cu	324.8	0.7	HCL	Air/C_2H_2
Ni	232	0.2	HCL	Air/C_2H_2
Pb	283.2	0.7	HCL	Air/C_2H_2
Zn	213.9	0.7	EDL	Air/C_2H_2

For both AA methods, calibration curves were used to quantitate the data and to determine the linear working ranges for the metals. The standard solutions were prepared in the matrix appropriate for each type of sample. The detection limits for the flame and graphite furnace methods are listed in Table 4.

Mercury was analyzed using the cold vapor technique. To determine the total mercury content, potassium persulfate was used to decompose the organo-mercury compounds. The mercury is reduced in acidic solution with stannous chloride. The elemental mercury formed is swept through a quartz cell with argon, and the absorption of the mercury is measured at 253.7 nm.

Arsenic in the samples was determined using the hydride generation method. The arsenic in the samples is converted to the hydride with sodium borohydride. The gaseous arsine is swept into an argon-hydrogen flame and the absorption is monitored at 193.7 nm.

TABLE 3. OPERATING PARAMETERS FOR FLAMELESS AA ANALYSES

Metal	Lamp*	Wavelength (nm)	Slit (nm)	Purge gas	Gas interrupt	Drying temperature/ time	Charring temperature/ time	Atomization temperature/ time
Cd	EDL	228.6	0.7	Ar	No	120°C/30 sec	600°C/30 sec	2500°C/8 sec
Cr	HCL	358	0.7	Ar	No	120°C/30 sec	1100°C/30 sec	2700°C/8 sec
Pb	HCL	217	0.7	Ar	No	120°C/30 sec	600°C/30 sec	2300°C/8 sec

TABLE 4. DETECTION LIMITS FOR ATOMIC ABSORPTION ANALYSES

Metal	Flame (ppm)	Flameless (ppb)
As		2.0[a]
Cd	0.02	0.1
Cr	0.2	1.0
Cu	0.2	
Hg		1.0[b]
Ni	0.2	
Pb	0.3	5.0
Zn	0.02	

[a]Hydride generation method.

[b]Cold vapor method.

SECTION 4

PRESENTATION AND INTERPRETATION OF DATA

The following section is a presentation of data collected during this sampling and analysis program along with an interpretation of the data. The data presented herein includes: process operations, flow rate measurements, particulate emissions, total solids and metals material balances.

PROCESS OPERATIONS

The first sampling run was attempted Monday, May 12, but was aborted due to equipment and weather difficulties. On Wednesday, May 14, designated as run day 2, the incinerator operated with a bed temperature of 1500°F. A minor delay occurred at the beginning of the day requiring that a manometer tap on the freeboard area of the reactor be repaired. Operators estimated 9,800 pounds of dewatered sludge was incinerated on that day. The operators estimated the sludge input based on air rate into the reactor, percent oxygen in the reactor exhaust and the fuel value of the sludge incinerated. The calculations for this estimate can be found in Appendix B. Incineration rate was also calculated using a percent solids method. This calculation is given in the flow rate measurement discussion.

On Friday, May 16, day 3, the incinerator operated for the low temperature run at 1300°F. The incinerator is designed to trip out at temperatures less than 1275°F. Plant operators paid close attention to operation conditions to avoid a trip out and maintain steady operation for the duration of the sampling. Fifteen 100 pound bags of sand were added to the incinerator bed prior to firing the incinerator at the beginning of the day. Operators estimate that 7,600 pounds of sludge was incinerated on this day.

Monday, May 16, was designated as day 4, the high temperature run day. Reactor bed temperatures were 1650°F, while freeboard temperatures ranged as high as 1720°F. Operators estimate that 10,200 pounds of sludge was incinerated.

Table 5 summarizes the operator's log which is presented in Appendix E.

FLOW RATE MEASUREMENTS

Flow rates were measured or calculated several different ways. Since this facility was not instrumented for a direct measurement of sludge feed rate, it was calculated using a percent dry solids method. The percent dry solids method was preferred to the air flow method for two reasons: the air flow

method used by the operators used an estimated fuel value for the sludge, and the oxygen analyzer was not calibrated with certified gases. The oxygen analyzer was calibrated electronically with ambient air, each day. Sample calculations for both methods are given in Appendix B.

TABLE 5. OPERATOR'S LOG SUMMARY

Date	5/14/80	5/16/80	5/19/80
Run	2	3	4
Amount Incinerated	9,800	7,600	10,200
Feed Rate			
Fuel oil gal/min	0.44	0.32	0.51
Temperatures °F			
Reactor bed	1,495	1,295	1,640
Freeboard	1,570	1,375	1,680
Scrubber inlet	250	250	257
Scrubber outlet	90	88	95
Pressures in H_2O			
Windbox	+90	+91	+96
Freeboard	+20.0	+20.0	+20.0
Scrubber outlet[a]	-0.14	-0.18	-0.11
Airflow scfm	2,150	2,150	2,150

[a]Taken from stack testing data sheets - Appendix C.

Prior to any sampling, the centrifuge feed pumps were calibrated to determine the centrifuge feed rates at different pumping rates. The pumps were calibrated at their normal operating rate. Pumping rate was measured on a tachometer in the control room. The percent solids sludge input calculation is:

$$W = \frac{D \times (A-C)}{B-C} \times F.R.$$

$$\frac{\text{lbs dry solids}}{\text{hour}} = W \times 60 \times \frac{B}{100}$$

where W = pounds of wet sludge

D = density of sludge

A = percent solids before centrifuge

B = percent solids after centrifuge

C = percent solids in centrate

F.R. = centrifuge pumps feed rate, gal/min.

Fuel oil feed rate (2) was monitored on a direct read out dial in the control room. Rates were recorded in gallon/minute. The amount of sand used in the incinerator was an estimate based on a refilling frequency. Sand (IE) is continuously removed from the incinerator by blowing it over into the scrubber where it is removed in the scrubber effluent. Fifteen 100 pound bags of sand are added to the incinerator every other Friday (approximately 60 hours of operation time).

The flow rate for the treated water (3) was measured with in-line float meters and with a doppler ultrasonic flow meter. The doppler flow meter has an accuracy of ±10 percent. This meter was field calibrated electronically, by comparison to one of the float meters and by a bucket and stopwatch method each day. Flow rates given by the doppler ultrasonic flow meter were used rather than the float meters because buildup of debris in float chamber caused erratic readings and the ultrasonic meter offered consistent numbers throughout the day of sampling. Treated water flow rate was measured ultrasonically at a point before the pipe split into three streams.

City water (4) flow rate was measured with the in-line float meter. The doppler flow meter could not be used at this location because the pipe diameter was less than 2 inches.

The scrubber overflow (5) flow rate was measured with the dopper flow meter. The pipe was not full at the point of measurement hence it was necessary to calculate the actual flow rate. This calculation is given in Appendix B. The scrubber effluent (6) flow rate was measured in two ways; with the doppler flow meter and by a bucket and stopwatch. The number given by the doppler was used rather than a bucket measurement technique, because of the consistent numbers given.

Stack velocity was measured using an S-type pitot tube and type K thermocouple that was attached to the sampling probe. The flow rate for all streams for each run are given in Table 6.

TABLE 6. STREAM FLOW RATES (wet Kg/hr)

Date		5/16/80	5/14/80	5/19/80
Run		3	2	4
Bed	Temperature °F	1,300	1,500	1,700
1A	Sludge before centrifuge	5,613	5,757	5,734
1B	Sludge after centrifuge	843	947	1,041
1C	Centrate	4,770	4,811	4,692
1E	Sand	11	11	11
2	Fuel oil	7	10	12
3	Treated water	37,496	38,405	38,178
4	City water	1,705	1,727	1,727
5	Scrubber overflow	52,949	57,267	53,176
6	Scrubber effluent	10,681	9,544	9,544

PARTICULATE EMISSIONS

The concentrations of particulate matter emitted from the Port Washington sludge incinerator scrubber outlet stack as obtained by the modified Method 5 train were:

- 0.17 g particulate/Kg dry sludge incinerated at 1300°F
- 0.26 g particulate/Kg dry sludge incinerated at 1500°F
- 0.32 g particulate/Kg dry sludge incinerated at 1700°F.

These emission rates are below the allowable limit of 0.65 g/Kg established by the U.S. EPA New Source Performance Standards. A summary of the modified Method 5 results are given in Table 7.

The Source Assessment Sampling System (SASS) cyclone train was used to collect a size fractionated particulate sample for specific metal content determination. The SASS train collects particulate in the following size ranges; greater than 10 micron, 10 to 3 micron, 3 to 1 micron and less than 1 micron. For all of the SASS runs, particulate was only visible on the less than 1 micron range filter. Any particulate that was collected in the other size ranges was so small that there was not enough for gravimetric or metals analyses. Hence, the cyclones were rinsed with acetone and combined with the probe rinse to determine the total particulate loading. A summary of the SASS sampling results are given in Table 8.

TABLE 7. PARTICULATE RESULTS FROM MODIFIED METHOD 5 TESTS

Date	5/16/80	5/14/80	5/19/~~58~~ 80
Run	3	2	4
Bed Temperature °F	1300	1500	1700
Dry Sludge Incinerated Kg/hr	182.9	212.0	236.3
Stack Temperature °F	83	88	90
Stack Flow Rate			
dscfm	1808	1804	1764
Volume Sampled			
dscf	85.229	49.471	84.216
Percent Isokinetic	95	55	96
Grain loading gr/dscf	0.0044	0.010	0.012
Emission Rate			
g/hr	30.44	54.53	75.72
g/Kg dry sludge	0.17	0.26	0.32

TABLE 8. PARTICULATE RESULTS FROM SASS TRAIN TESTS

Date	5/16/80	5/14/80	5/19/80
Run	3	2	4
Bed Temperature °F	1300	1500	1700
Dry Sludge Incinerated Kg/hr	182.9	212.0	236.3
Stack Temperature °F	92	87	101
Stack Flow Rate			
dscfm	1841	1864	1835
Volume Sampled			
dscf	865.872	960.872	783.430
Percent Isokinetic	95	92	90
Grain Loading			
gr/dscf	0.00127	0.00096	0.00659
Emission Rate			
g/hr	8.86	6.69	44.80
g/Kg dry sludge	0.05	0.03	0.19

By comparing the two methods of particulate sampling, it is noted that the SASS train's reported emission rates are less than the Method 5 reported rate. A possible explanation for this may be the fact that the stack was not traversed during the sampling run. The SASS train is designed for single point sampling at a point of average velocity within the stack. It is possible that the point of average flow velocity is not necessarily the point of average particulate concentration.

Particle size distribution was measured using Andersen cascade impactors. For the low temperature run, 74 percent of the particles were less than 1 micron with a mean mass diameter of 80 microns (Figure 5). For the medium temperature run, 66 percent of the particles were less than 1 micron, while the mean mass diameter was 69 microns (Figure 6). For the high temperature run, 62 percent of the particles were less than 1 micron, while the mean mass diameter was 83 microns (Figure 7). Figure 8 shows an average size distribution for the three runs. The aerodynamic diameters plotted are calculated according to the task group on lung dynamics, alternate methods of presenting particle size data are in Appendix G.

TOTAL SOLIDS BALANCE

A material balance for the total solids was performed around the centrifuge and across the incinerator scrubber system. Closure around the centrifuge for all three runs was within 5 percent. The percent closure across the incinerator/scrubber system was low for all three runs (Table 9 and Figure 9). This can be attributed to the high amount of volatile, or combustible, solids in the sludge. Table 10 lists the percent total solids found in each stream. Table 11 lists the percent volatile, or combustible solids found in each stream. Since stream flow rates were reported in Kg/hr, the stack emission rates (mg/hr) were negligible when compared to the process streams, so they were not included in the solids balance.

Metal Emissions

Metal emissions at the stack were measured using both a modified Method 5 train and a SASS train. A summary of the metal emissions as collected from both trains are given in Table 12. Both sample trains are described in Section 3. Table 13 displays the mg metal emitted per 1000 Kg dry solids incinerated. The SASS emission numbers are used on this table since zinc and chromium were under the detection limit for the Method 5 runs. Table 14 is a listing of the percent metal emitted out the stack. This was calculated based on the total mg of the metal in the incinerator input. Percent metal emission is given for both sample trains.

In many cases the Method 5 reported metal emission rate is greater than the SASS reported rate. This can be attributed to the higher particulate grain loading reported in the Method 5 sampling. Concentrations reported in the impinger solutions of the modified Method 5 train were so small that they had little bearing on total concentration.

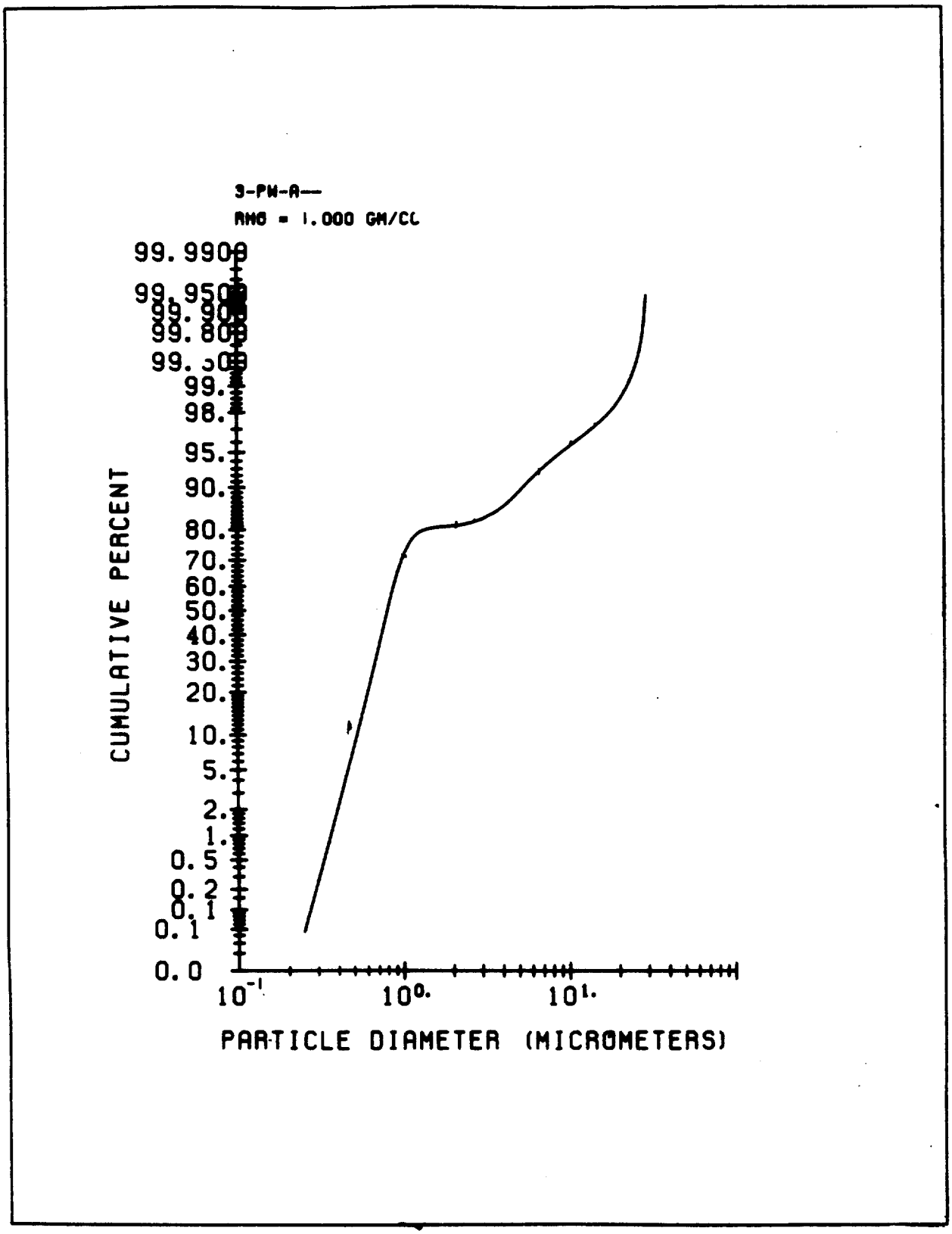


Figure 5. Particle size distribution Run 3 - 1300°F.

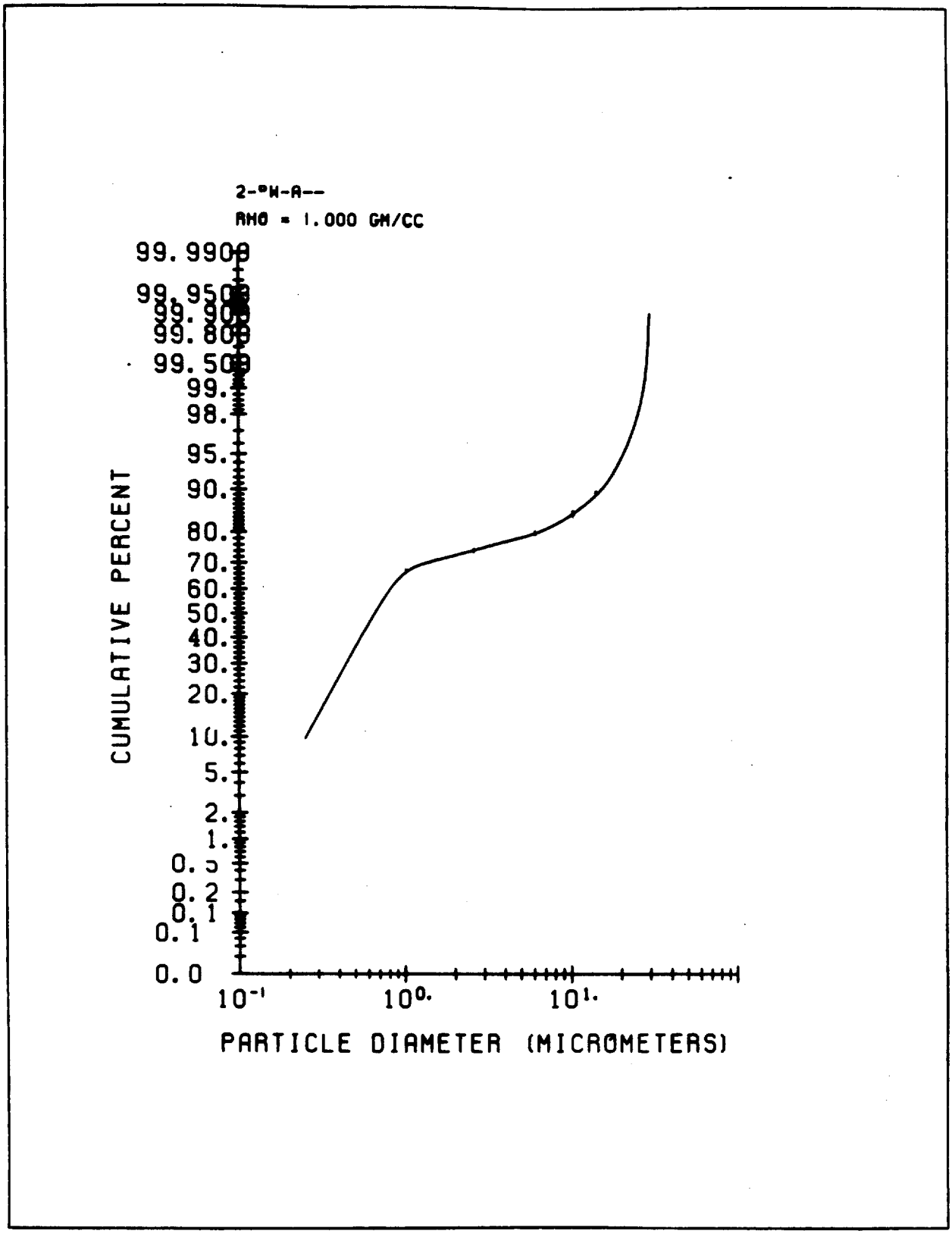


Figure 6. Particle size distribution Run 2 - 1500°F.

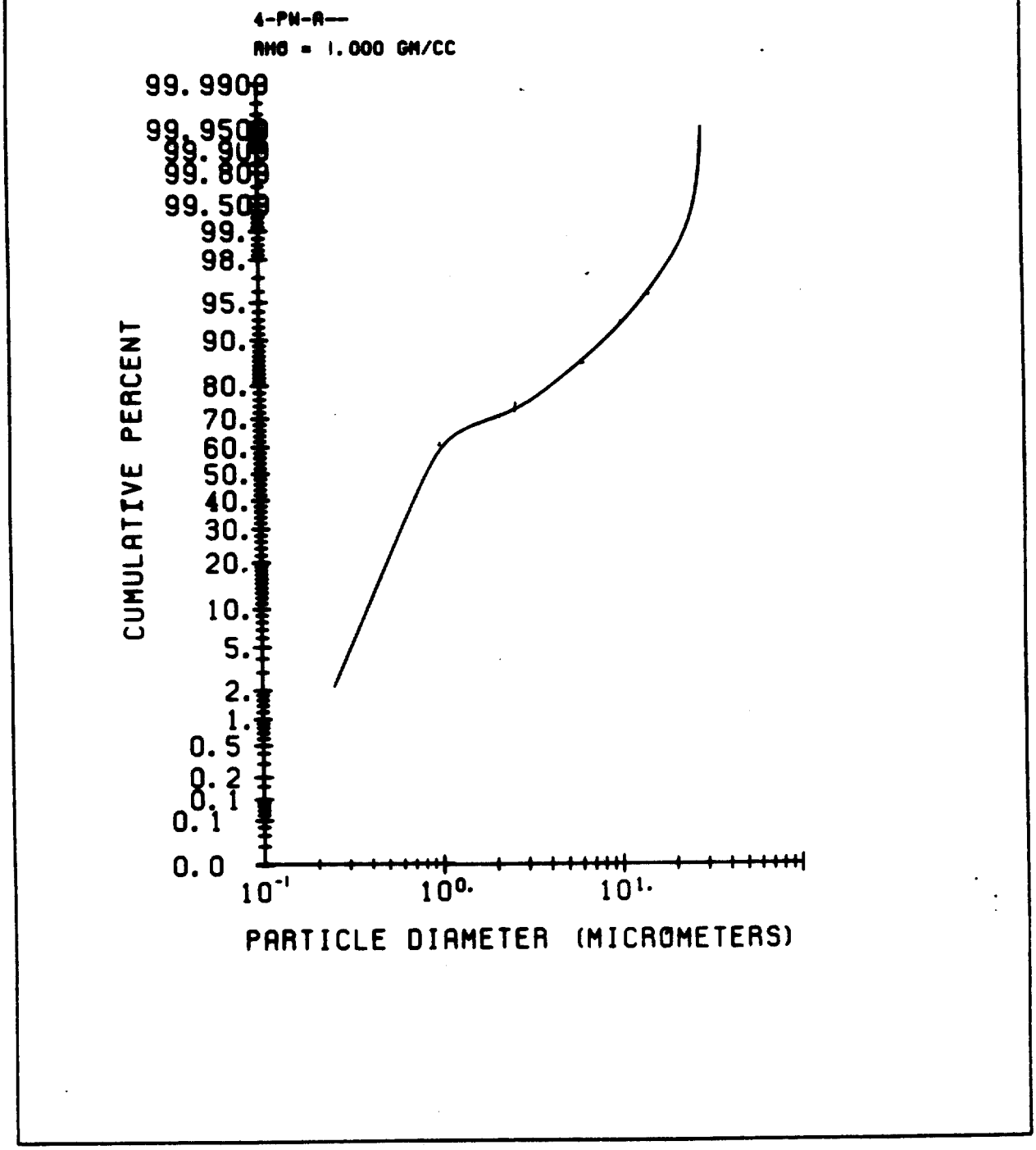


Figure 7. Particle size distribution Run 4 - 1700°F.

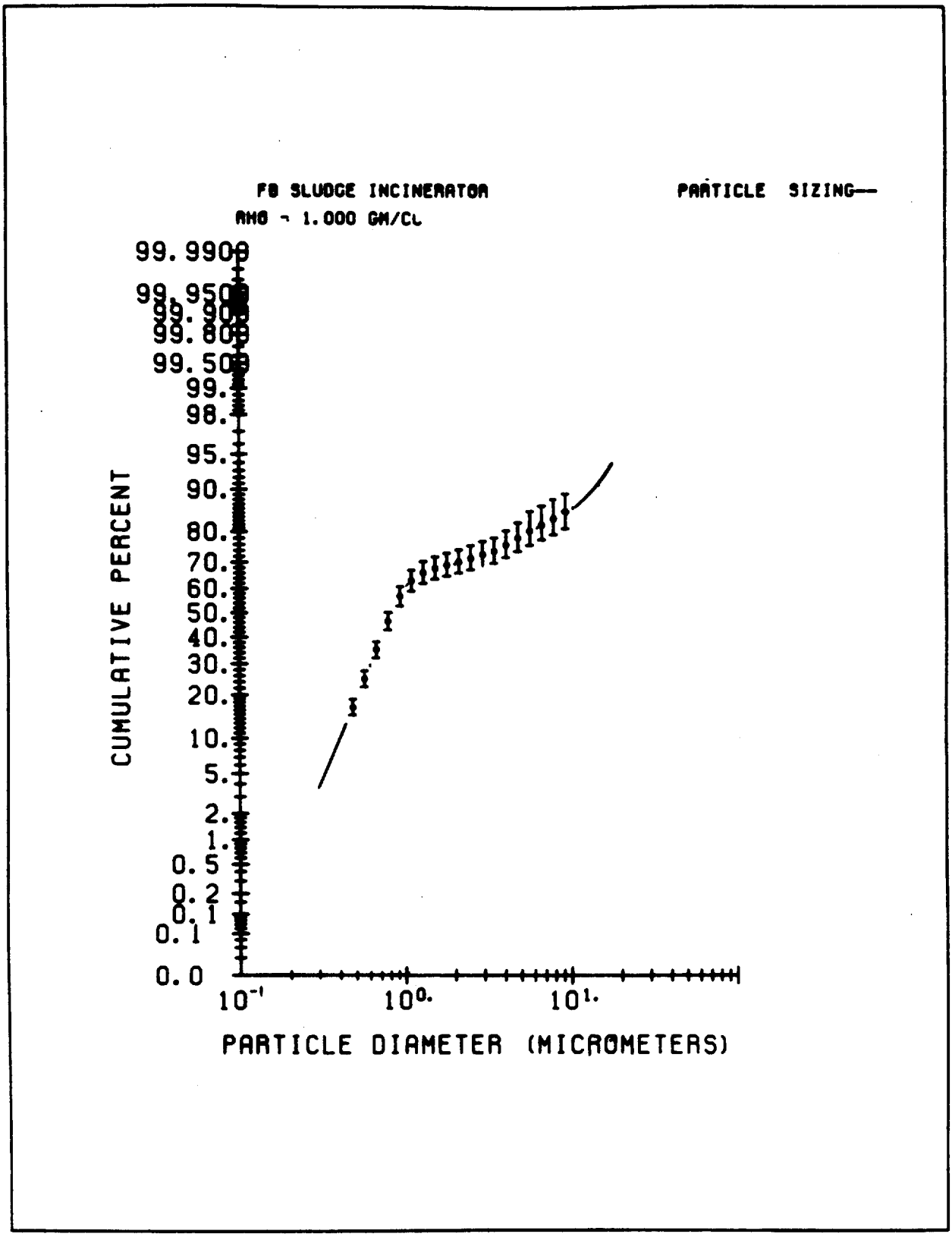


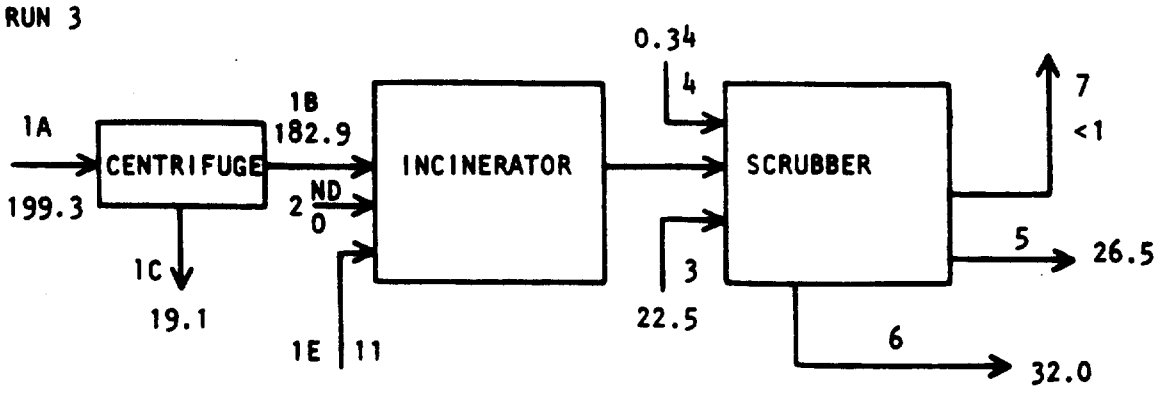
Figure 8. Average size distribution for Runs 3, 2 and 4.

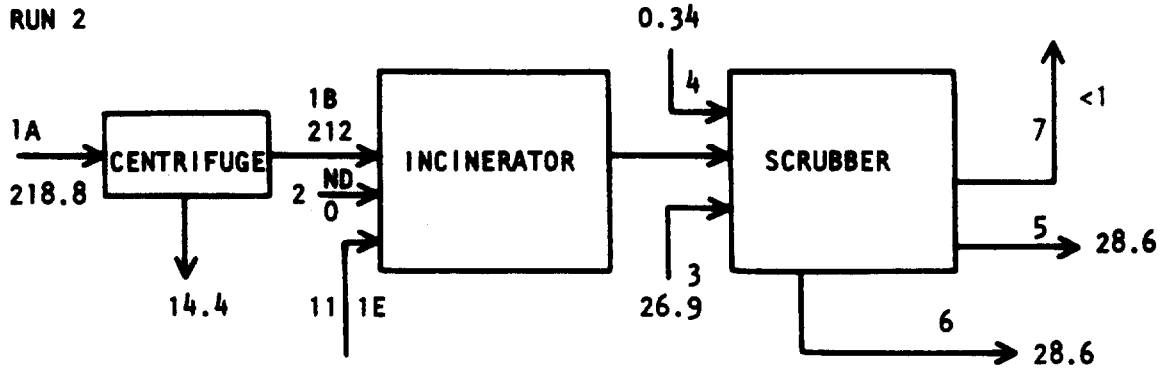
TABLE 9. TOTAL SOLIDS MATERIAL BALANCE

Run	3	2	4
Bed Temperature °F	1300	1500	1700
Stream	Kg/hr	Kg/hr	Kg/hr
1A Sludge Before Centrifuge	199.3	218.8	255.1
1B Sludge After Centrifuge	182.9	212.0	236.3
1C Centrate	19.1	9.7	18.8
1E Sand	11	11	11
2 Fuel Oil	0	0	0
3 Treated Water	22.5	26.9	22.9
4 City Water	0.3	0.3	0.3
5 Scrubber Overflow	26.5	28.6	21.3
6 Scrubber Effluent	32.0	28.6	28.6
% Closure Around Centrifuge	101	103	100
% Closure Incinerator/Scrubber	19	13	11

TABLE 10. PERCENT TOTAL SOLIDS

Run	3	2	4
Bed Temperature °F	1300	1500	1700
Stream			
1A Sludge Before Centrifuge	3.55	3.8	4.5
1B Sludge After Centrifuge	21.7	22.4	22.7
1C Centrate	0.4	0.3	0.4
3 Treated Water	0.06	0.07	0.06
4 City Water	0.02	0.02	0.02
5 Scrubber Overflow	0.05	0.05	0.04
6 Scrubber Effluent	0.3	0.3	0.3





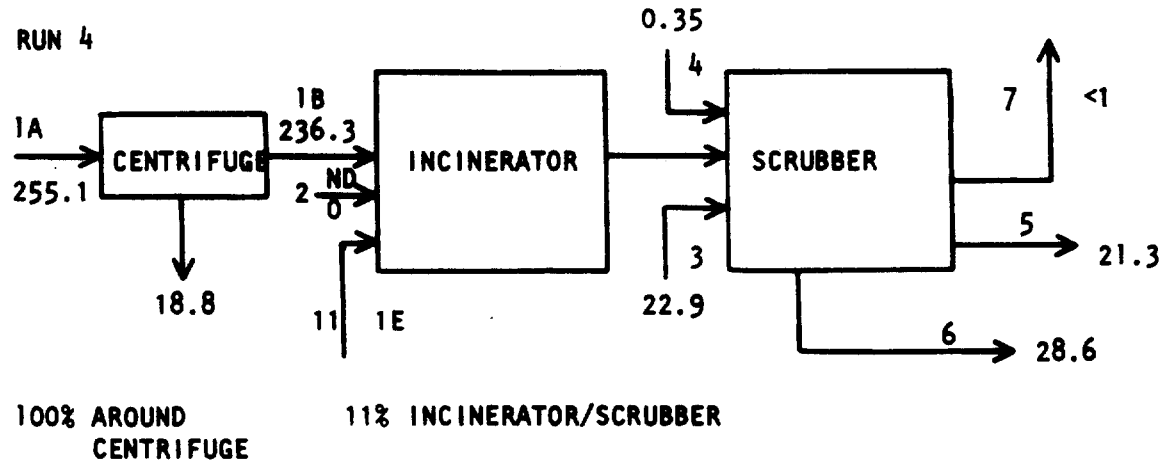


Figure 9. Percent closure total solids.

TABLE 11. PERCENT VOLATILE SOLIDS

Run		3	2	4
Bed Temperature °F		1300	1500	1700
Stream				
1A	Sludge Before Centrifuge	83.7	81.8	83.6
1B	Sludge After Centrifuge	82.1	84.2	82.5
1C	Centrate	85	78.9	85
3	Treated Water	41.2	32.0	36.5
4	City Water	26.0	26.5	31.3
5	Scrubber Overflow	52.4	50.8	43.3
6	Scrubber Effluent	25.0	22.5	22.5

TABLE 12. SUMMARY OF METAL EMISSIONS (mg/hr)

Run	3		2		4	
Bed Temperature °F	1300		1500		1700	
Train	M5	SASS	M5	SASS	M5	SASS
Nickel	ND	ND	ND	ND	ND	ND
Copper	94	64	372	139	847	2450
Chromium	ND	7.3	ND	7.0	ND	47
Lead	0.13	28	249	112	3704	3633
Arsenic	0.43	0.36	2.2	0.33	7.4	1.1
Cadmium	0.07	1.0	32.5	7.0	169	382
Zinc	ND	58	ND	25	180	495

ND = Not detected.

TABLE 13. METAL EMISSIONS (mg METAL EMITTED/1000 Kg DRY SOLIDS)[a]

Run	3	2	4
Bed Temperature °F	1,300	1,500	1,700
Metal	mg/1000 Kg	mg/1000 Kg	mg/1000 Kg
Arsenic	2.2	1.6	4.6
Cadmium	5.5	33.0	1616.6
Lead	153	528.0	15,370
Zinc	317	117.8	2,095
Nickel	ND	ND	ND
Copper	350	655	10,367
Chromium	40	32.9	198.9

[a]Calculated from SASS sampling results.

TABLE 14. PERCENT METAL EMITTED OUT STACK[a]

Run	3		2		4	
Bed Temperature °F	1300		1500		1700	
Train	M5	SASS	M5	SASS	M5	SASS
Metal						
Nickel	ND	ND	ND	ND	ND	ND
Copper	0.055	0.038	0.21	0.08	0.37	1.07
Chromium	ND	0.15	ND	0.11	ND	0.66
Lead	0.0003	0.07	0.56	0.25	7.8	7.7
Arsenic	0.41	0.34	2.7	0.4	10.1	1.5
Cadmium	0.01	0.13	3.7	0.8	17.7	40.4
Zinc	ND	0.048	ND	0.02	0.12	0.34

[a] $\frac{\text{mg metal emitted/hr}}{\text{mg metal incinerator input/hr}} \times 100$

The SASS train values were used for the metals balance across the incinerator scrubber system. The SASS data was chosen over the Method 5 data because results were available for two more metals from the SASS data. In any case, the metals emitted from the stack had little bearing on the percent closure across the incinerator/scrubber system.

Metals Balance - Around Centrifuge

A metals material balance was performed around the centrifuge and across the incinerator/scrubber system. Figure 10 presents the data for the metals material balances around the centrifuge.

Many of the closures around the centrifuge are within 10 percent. Run 3 for nickel was 147 percent. The concentration in the sludge before the centrifuge was 20 µg/g dry sludge while after the centrifuge it was 30 µg/g dry sludge. Runs 2 and 4 both reported 20 µg/g before and after the centrifuge. Run 2 for copper was reported with 79 percent closure. For this run the reported value in the centrate was somewhat lower than the other two runs. Mercury and arsenic both had a high closure, a low closure and a closure within 10 percent. It is possible the sampling and or analysis technique was at fault for these runs. There was not enough sample left for the analysis of the centrate for Run 2. Arsenic had a high material balance for the incinerator/scrubber also.

Table 15 lists the metal concentration per Kilogram of dry sludge input.

TABLE 15. METAL INPUT mg METAL/Kg DRY SLUDGE

Metal	mg input/Kg of dry sludge			Average
Run	3	2	4	
Chromium	30	30	30	30
Copper	840	920	960	907
Nickel	20	30	20	23
Zinc	650	660	620	643
Lead	210	230	200	213
Cadmium	4.0	4.0	4.0	4.0
Arsenic	0.23	0.39	0.27	0.29
Mercury	0.23	0.39	0.27	0.29

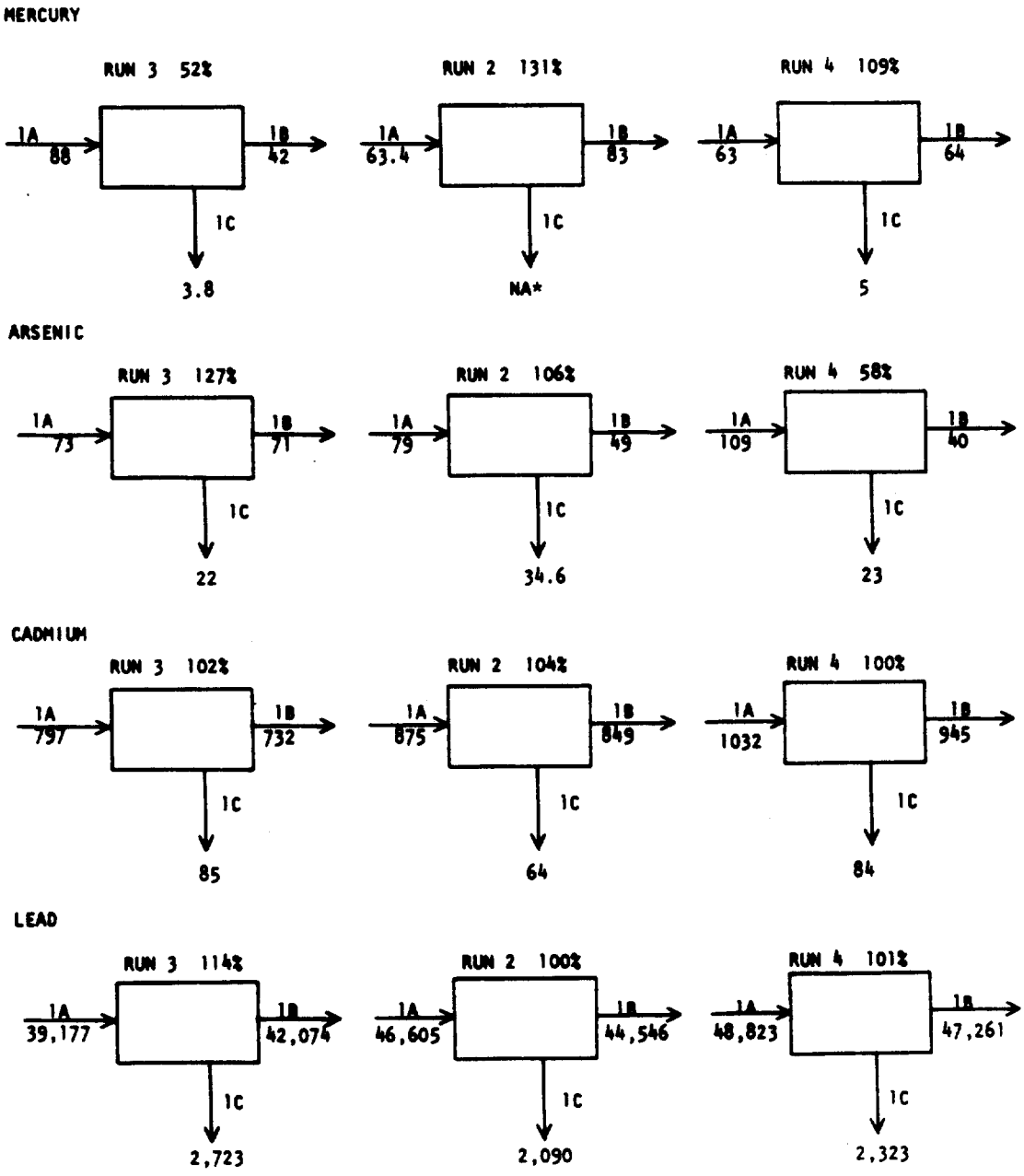
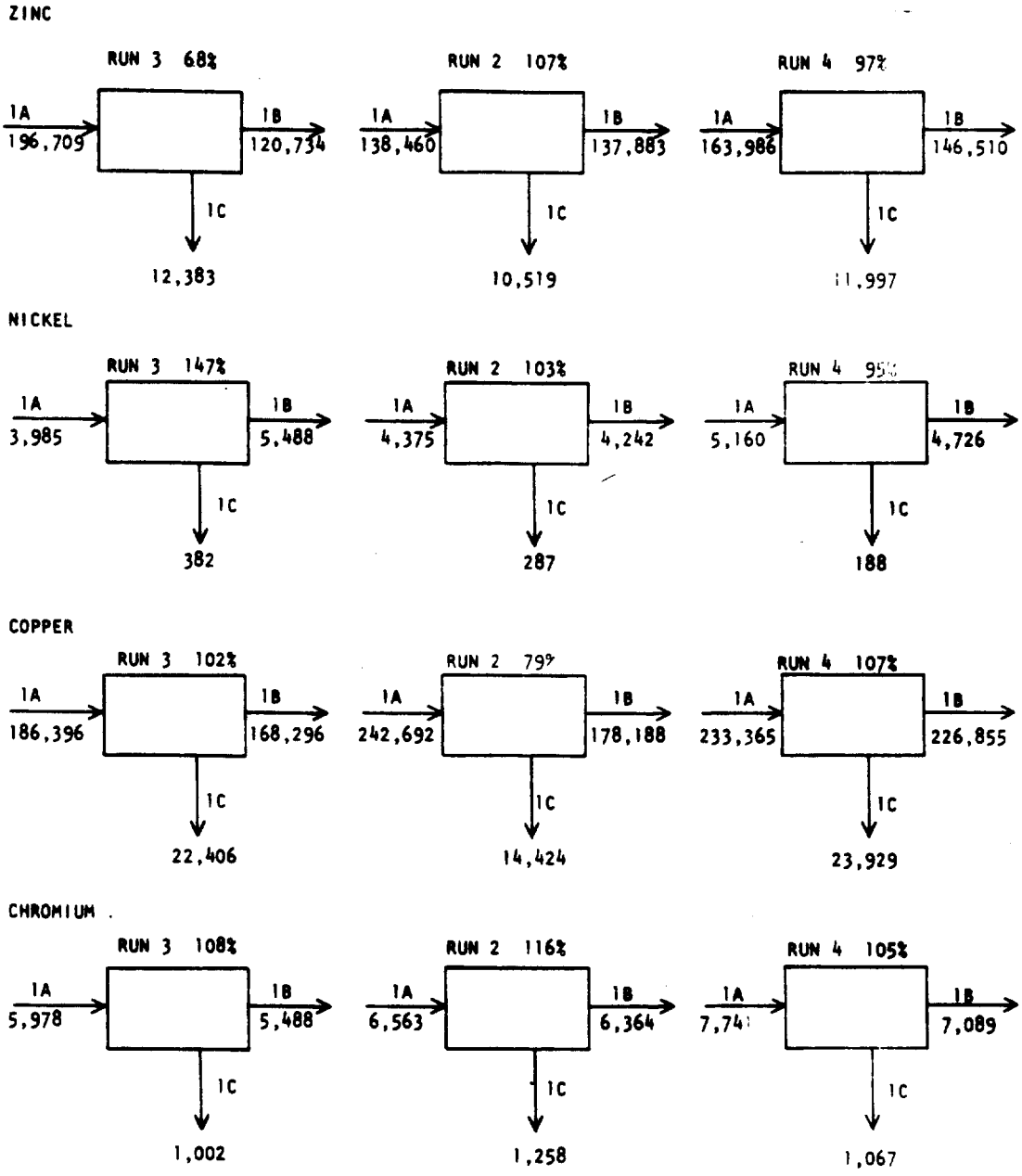


Figure 10. Percent closure around the centrifuge values reported are mg metal/hr.



*NA = Not analyzed

Figue 10 (continued)

Metals Balance - Incinerator/Scrubber System

The following tables and figures display the numbers used for the material balance of each metal. Sample calculations for the balances can be found in Appendix B.

Chromium--

As shown in Table 16 and Figure 11, the material balance for the low and medium temperature runs were within 10 percent of closure with more than 99 percent emissions from the scrubber. The emission rate at the stack increased six times between the medium and high temperature run.

Copper--

As shown in Table 17 and Figure 12, the percent closure for the medium temperature run was 147 percent. This is attributed to the high concentration of the aqueous portion of the scrubber effluent (18,000 µg/l). This number is much higher when compared to the low (4,000 µg/l) and high (8,000 µg/l) temperature runs. The copper emission rate increased for the high temperature run 15 times what it was for the medium temperature run.

Zinc--

As shown in Table 18 and Figure 13, less zinc could be accounted for, as the incinerator operation temperature increased. A possible explanation is that more zinc volatilized at the higher temperature and instead of adhering to the fine particulate it maintained a gaseous state and was emitted out the stack.

Nickel--

As shown in Table 19 and Figure 14, there was little change in any of the nickel emission rates despite changing bed temperature. Nickel was not detected in the stack for any of the runs. Approximately 30 percent of the nickel was unaccounted for in all three of the material balances.

Arsenic--

As shown in Table 20 and Figure 15, there was a higher emission rate of arsenic found in the scrubber effluent than in the incinerator input for all three runs. Therefore, the percent closure for all three runs was greater than 100. A possible explanation for this could be the sand. Arsenic was found in the sand (1.2 µg/g). The flow rate of the sand was an estimate, since there was no accurate method of measuring it. It could be possible that more than 11.4 Kg of sand of was passing out the incinerator per hour.

Mercury--

As shown in Table 21 and Figure 16, more than 40 percent of the mercury was not accounted for in any of the runs. Stack samples were not analyzed for mercury content. The amount of mercury in the scrubber effluent decreased for the medium and high temperature runs. It can be assumed that some portion of the unaccounted mercury was emitted out the stack. Mercury was found in the city water (0.5 µg/l).

TABLE 16. CHROMIUM BALANCE

Run		3			2			4	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	<200	30	5978	<200	30	6563	<200	30	7741
1B Sludge After Centrifuge	NA	30	5488	NA	30	6364	NA	30	7089
1C Centrate	131	20	1002	172	30	1258	148	20	1067
1D Coagulant	<1.0	NA	ND	<1.0	NA	ND	<1.0	NA	ND
1E Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
1F Spent Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
2 Fuel Oil No. 2	NA	<20	ND	NA	<20	ND	NA	<20	ND
3 Treated Water	<200	NA	ND	<200	NA	ND	<200	NA	ND
4 City Water	<200	NA	ND	<200	NA	ND	<200	NA	ND
5 Scrubber Overflow	<200	NA	ND	<200	NA	ND	<200	NA	ND
6 Scrubber effluent	<200	190	6088	<200	200	5726	<200	200	5726
7 Stack M5/ SASS	<1/NA	<1000/ 800	ND/ 7.3	<1/NA	<900/ 1000	ND/ 7.0	<1/NA	<500/ 1000	ND/ 47.1
% Closure		110.9				89.97			81.43

NA = Not Analyzed ND = Not Detected

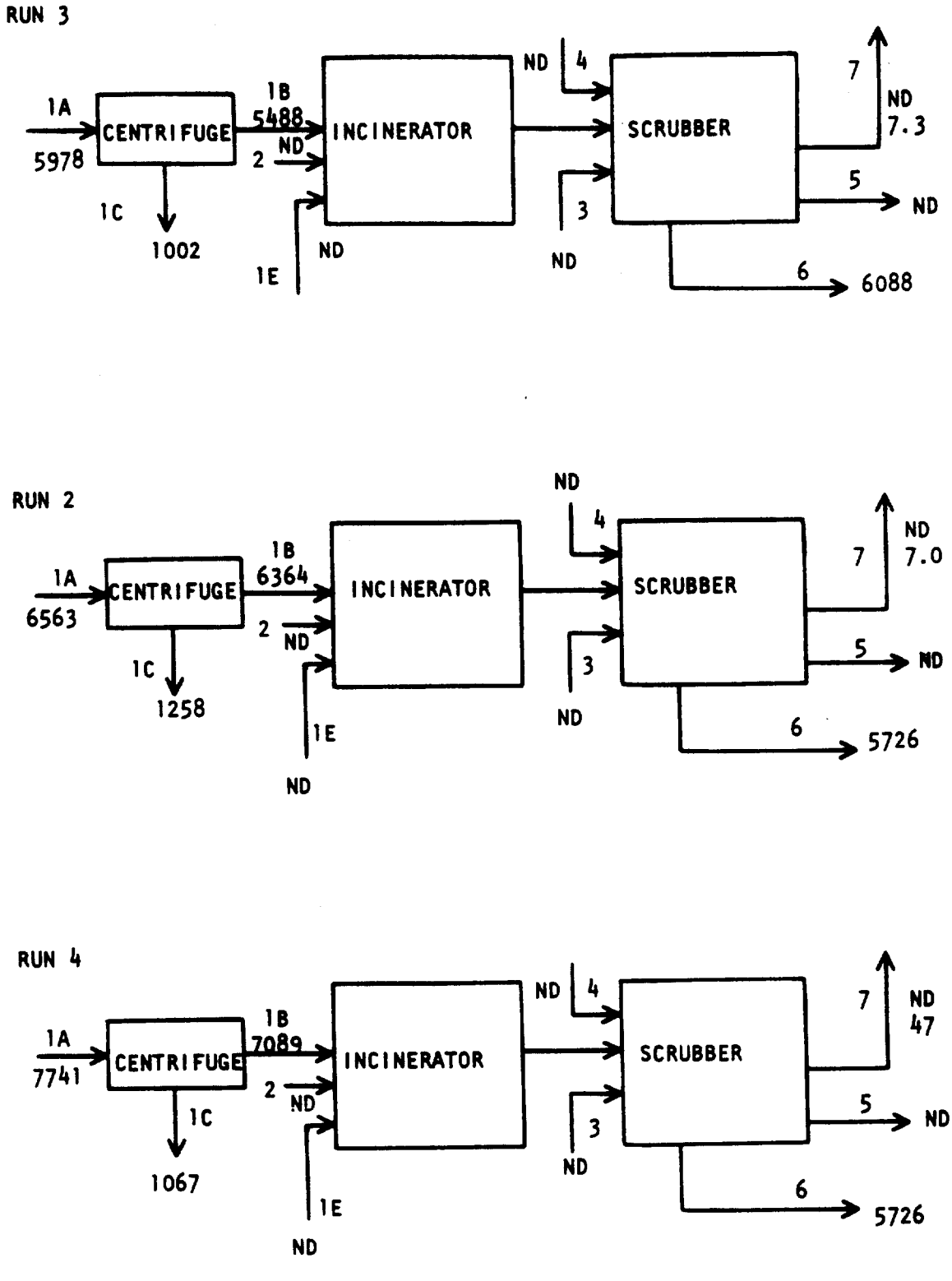


Figure 11. Chromium balance.

TABLE 17. COPPER BALANCE

Run		3			2			3	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	200	930	186,396	370	1100	242,692	<200	900	233,365
1B Sludge After Centrifuge	NA	920	168,296	NA	840	178,188	NA	960	226,855
1C Centrate	700	1,000	22,406	600	800	14,424	700	1,100	23,929
1D Coagulant	<200	NA	ND	<200	NA	ND	<200	NA	ND
1E Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
1F Spent Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
2 Fuel Oil No. 2	NA	<20	ND	NA	<20	ND	NA	<20	ND
3 Treated Water	<200	NA	ND	<200	NA	ND	<200	NA	ND
4 City Water	<200	NA	ND	<200	NA	ND	<200	NA	ND
5 Scrubber Overflow	300	NA	15,877	300	NA	17,180	200	NA	10,635
6 Scrubber Effluent	4,000	2,700	129,112	18,000	2,300	237,130	8,000	2,400	144,840
7 Stack M5/SASS	<200/ NA	3,000/ 7,000	94/ 64	<200/ NA	5,300/ 20,000	372/ 139	<200/ NA	11,000/ 52,000	847/ 2,450
% Closure			86			143			68.9

NA = Not Analyzed ND = Not Detected

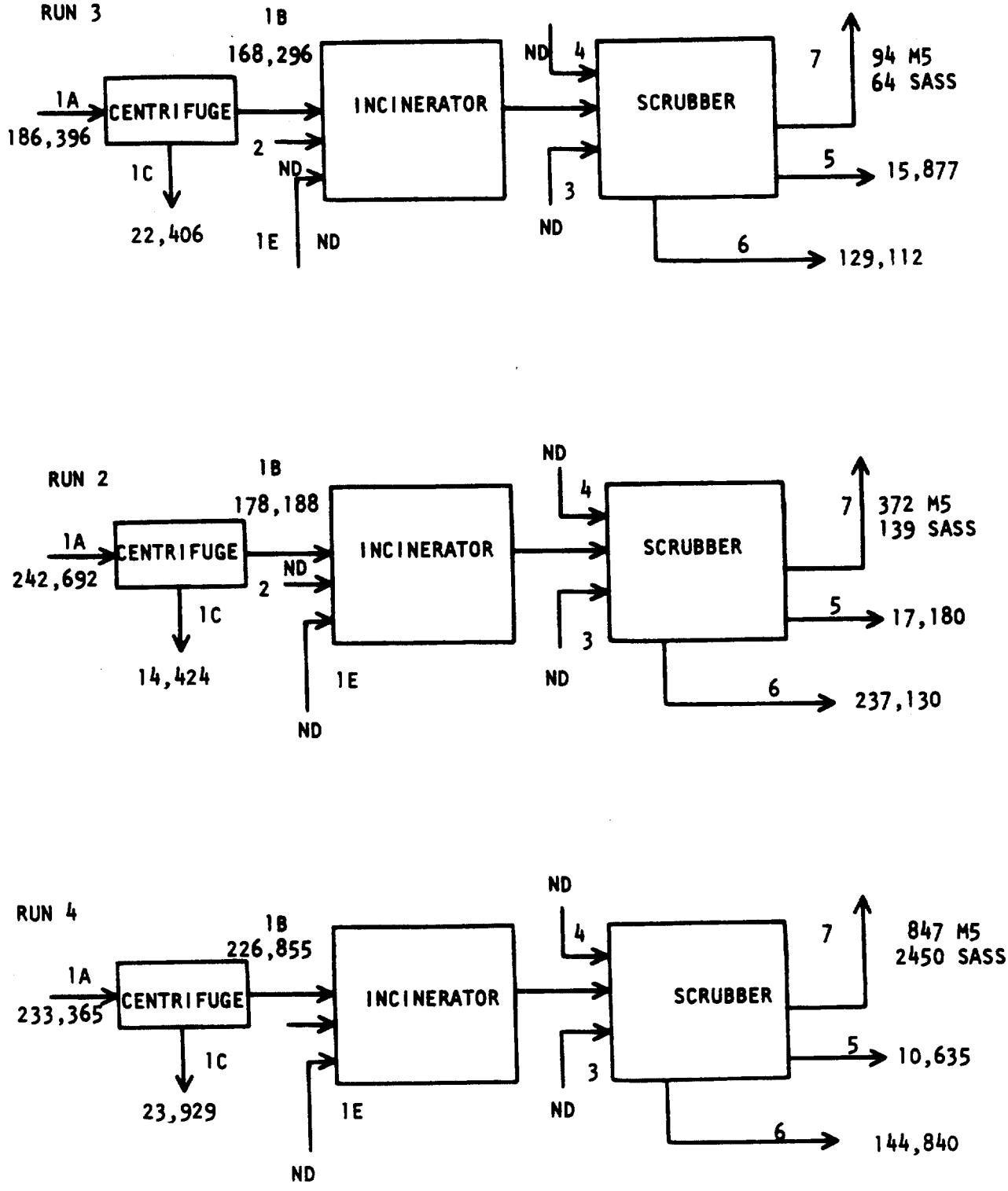


Figure 12. Copper balance.

TABLE 18. ZINC BALANCE

Run		3			2			4	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	10,000	580	196,709	1,300	600	138,460	3,100	570	163,986
1B Sludge After Centrifuge	NA	660	120,734	NA	650	137,883	NA	620	146,510
1C Centrate	1,000	400	12,383	1,200	330	10,519	800	440	11,997
1D Coagulant	<20	NA	ND	<20	NA	ND	<20	NA	ND
1E Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
1F Spent Sand	NA	530	NA	NA	530	NA	NA	530	NA
2 Fuel Oil No. 2	NA	<20	ND	NA	<20	ND	NA	<20	ND
3 Treated Water	190	NA	7,120	150	NA	5,761	160	NA	6,108
4 City Water	<20	NA	ND	<20	NA	ND	<20	NA	ND
5 Scrubber Overflow	270	NA	14,296	200	NA	11,453	190	NA	10,103
6 Scrubber Effluent	2,400	2,900	118,482	4,600	2,300	109,624	2,400	2,400	91,554
7 Stack M5/SASS	<20/ NA	<120/ 6,400	ND/ 66	<20/ NA	<90/ 3,600	ND/ 25	<20/ NA	2,300/ 10,500	180/ 495
% Closure			104			83			64

NA = Not Analyzed ND = Not Detected

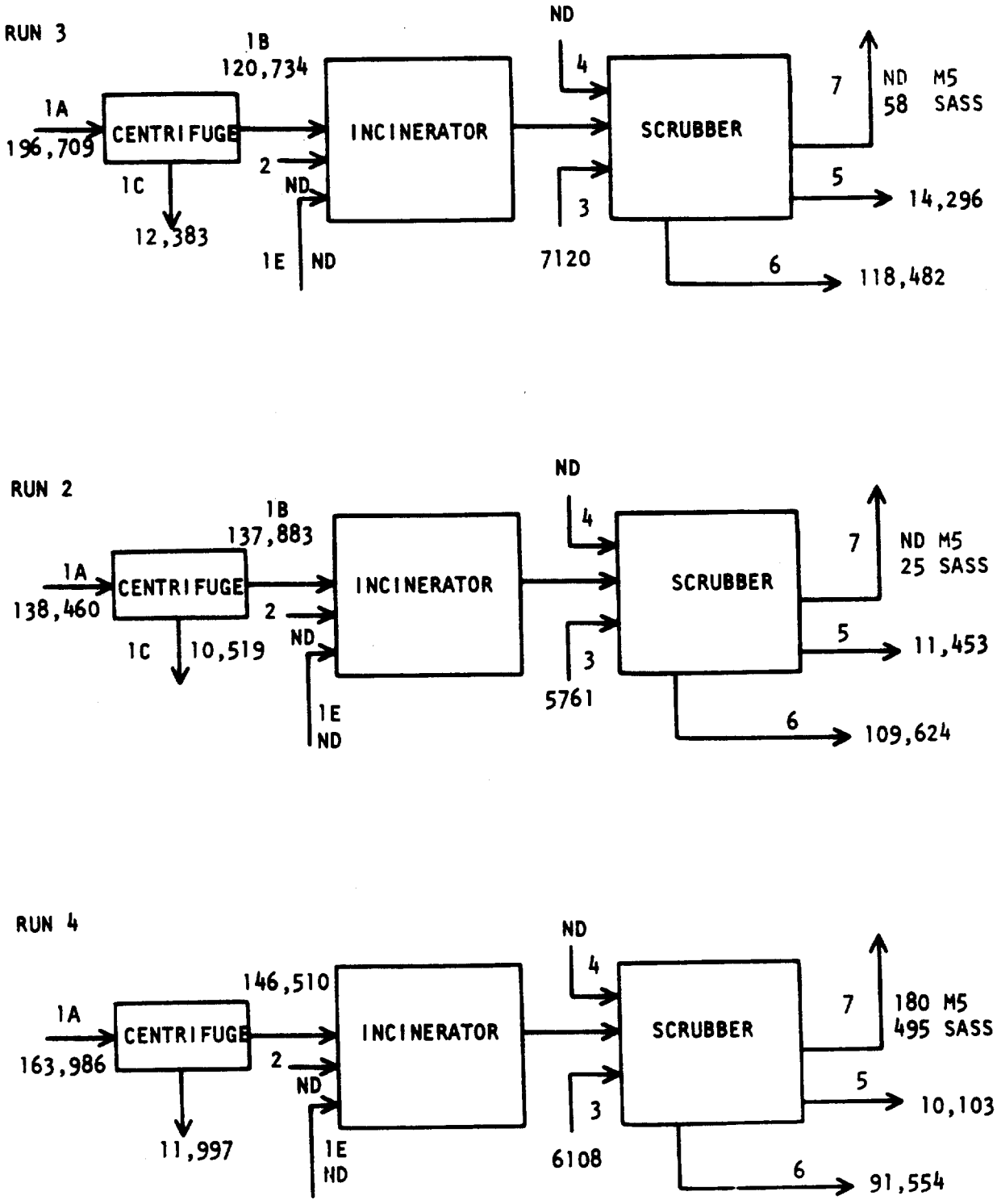


Figure 13. Zinc balance.

TABLE 19. NICKEL BALANCE

Run		3			2			4	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	<200	20	3985	<200	20	4375	<200	20	5160
1B Sludge After Centrifuge	NA	30	5488	NA	20	4242	NA	20	4726
1C Centrate	<200	20	382	<200	20	287	<200	10	188
1D Coagulant	<200	NA	ND	<200	NA	ND	<200	NA	ND
1E Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
1F Spent Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
2 Fuel Oil No. 2	NA	<20	ND	NA	<20	ND	NA	<20	ND
3 Treated Water	<200	NA	ND	<200	NA	ND	<200	NA	ND
4 City Water	<200	NA	ND	<200	NA	ND	<200	NA	ND
5 Scrubber Overflow	<200	NA	ND	<200	NA	ND	<200	NA	ND
6 Scrubber Effluent	<200	120	3845	<200	110	3150	<200	110	3150
7 Stack M5/SASS	<200/ NA	<200/ <200	ND/ ND	<200/ NA	<200/ <200	ND/ ND	<200/ NA	<200/ <200	ND/ ND
% Closure			70			74			67

NA = Not Analyzed ND = Not Detected

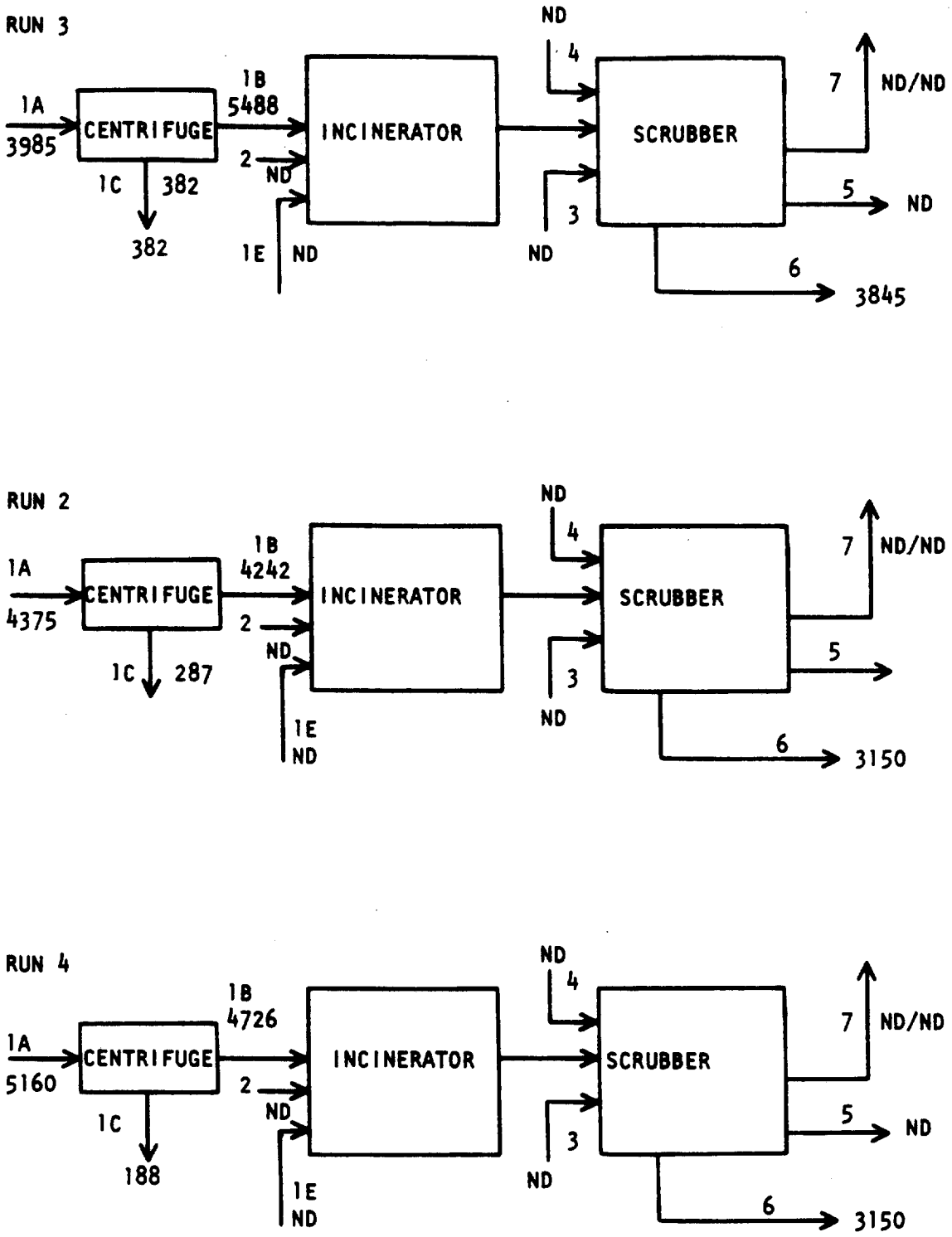


Figure 14. Nickel balance.

TABLE 20. ARSENIC BALANCE

Run		3			2			4	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	3.9	0.26	73	4.8	0.27	79	2.7	0.36	109
1B Sludge After Centrifuge	NA	0.39	71	NA	0.23	49	NA	0.17	40
1C Centrate	2.5	0.51	22	5.2	0.67	34.6	4.0	0.25	23
1D Coagulant	7.9	NA	ND	7.9	NA	ND	7.9	NA	ND
1E Sand	NA	2.9	33.0	NA	2.9	33.1	NA	2.9	33.1
1F Spent Sand	NA	2.7	NA	NA	2.7	NA	NA	2.7	NA
2 Fuel Oil No. 2	NA	<0.2	ND	NA	<0.2	ND	NA	<0.2	ND
3 Treated Water	<2	NA	ND	<2	NA	ND	<2	NA	ND
4 City Water	<2	NA	< ND	<2	NA	ND	<2	NA	ND
5 Scrubber Overflow	<2	NA	ND	<2	NA	ND	<2	NA	ND
6 Scrubber Effluent	12.4	0.60	151	19	0.54	196	23	0.54	234
7 Stack M5/SASS	ND/NA	13.8/ 39.9	0.43/ 0.36	ND/NA	37.7/ 47.4	2.2/ 0.33	2.1/ NA	94.6/ 23.9	7.4/ 1.1
% Closure			145			238			320

NA = Not Analyzed ND = Not Detected

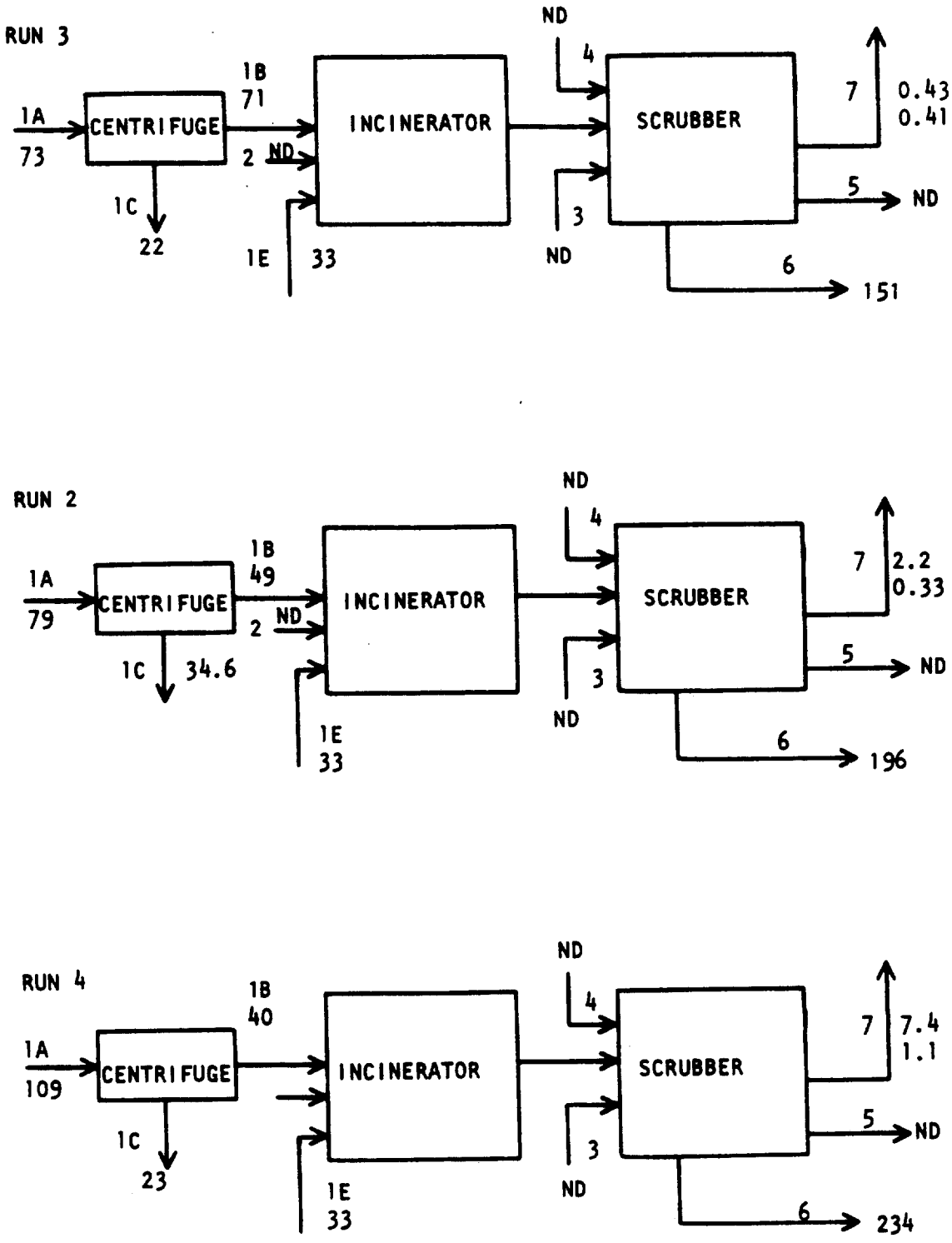


Figure 15. Arsenic balance.

TABLE 21. MERCURY BALANCE

Run		3			2			4	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	<5	0.44	88	NA	0.29	63.4	<5	0.24	63.1
1B Sludge After Centrifuge	NA	0.23	42	NA	0.39	83	NA	0.27	64
1C Centrate	<0.5	0.20	3.8	<0.5	NA	ND	<0.5	0.26	5
1D Coagulant	<5	NA	ND	<5	NA	ND	<5	NA	ND
1E Sand	NA	<2	ND	NA	<2	ND	NA	<2	ND
1F Spent Sand	NA	<2	ND	NA	<2	ND	NA	<2	ND
2 Fuel Oil No. 2	NA	<1	ND	NA	<1	ND	NA	<1	ND
3 Treated Water	0.8	NA	30	0.8	NA	30	0.5	NA	19
4 City Water	0.5	NA	0.85	0.5	NA	0.9	0.5	NA	0.86
5 Scrubber Overflow	0.7	NA	37	0.8	NA	46	0.7	NA	37
6 Scrubber Effluent	<0.5	0.8	26	<0.5	0.25	7	<0.5	0.38	11
7 Stack M5/SASS	NA/NA	NA/NA	NA/NA	NA/NA	NA/NA	NA/NA	NA/NA	NA/NA	NA/NA
% Closure			76			27			44

NA = Not Analyzed ND = Not Detected

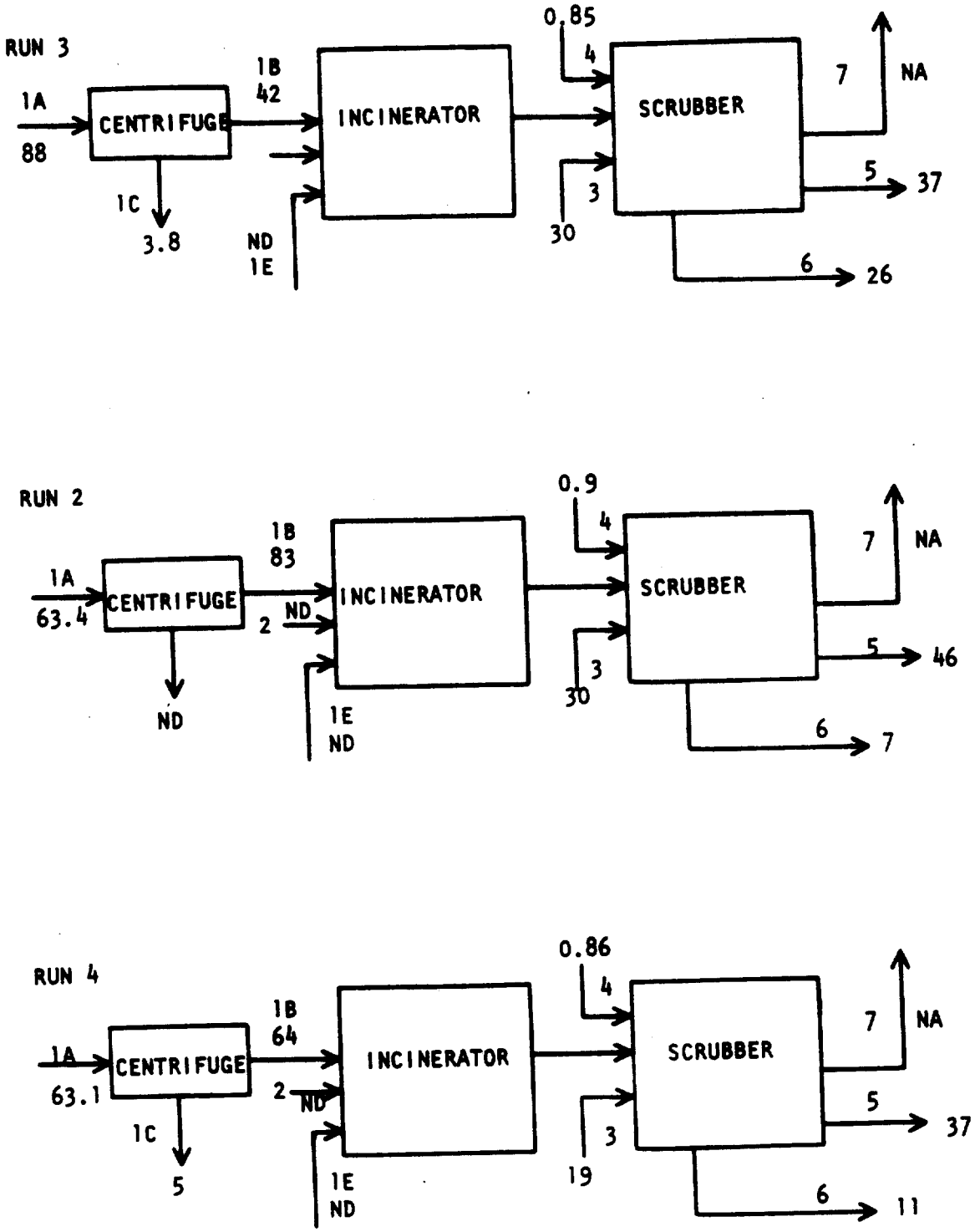


Figure 16. Mercury balance.

Cadmium--

As shown in Table 22 and Figure 17, the percent closure for cadmium, around the centrifuge was within 5 percent for each run. However, the balances across the incinerator/scrubber system varied. Portions of the cadmium were unaccounted for the low (79 percent closure) and medium (91 percent closure) temperature runs. The amount of cadmium collected in the scrubber increased as bed temperature increased. However, the amount emitted out the stack increased sharply for the high temperature run.

Lead--

As shown in Table 23 and Figure 18, the low temperature balance had accounted for 97 percent of the lead in the system for that run. For the medium and high temperature run, approximately 20 percent of the lead could not be accounted for. The amount of lead collected in the scrubber decreased while stack emission rates increased for the medium and high temperature runs. This points out that the scrubber was not collecting the lead at the higher temperatures as efficiently as at the low temperatures.

TABLE 22. CADMIUM BALANCE

Run		3			2			4	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	<20	4.0	797	<20	4.0	875	<20	4.0	1032
1B Sludge After Centrifuge	NA	4.0	732	NA	4.0	849	NA	4.0	945
1C Centrate	5.9	3.0	85	4.4	3.0	64	5.8	3.0	84
1D Coagulant	9	NA	NA	9	NA	NA	9	NA	NA
1E Sand	NA	0.64	7.0	NA	0.64	7.0	NA	0.64	7.0
1F Spent Sand	NA	3.3	NA	NA	3.3	NA	NA	3.3	NA
2 Fuel Oil No. 2	NA	<0.1	ND	NA	<0.1	ND	NA	<0.1	ND
3 Treated Water	1.67	NA	63	1.4	NA	54	2.3	NA	88
4 City Water	0.5	NA	0.9	0.6	NA	1.0	1.0	NA	1.7
5 Scrubber Overflow	1.2	NA	64	0.9	NA	53	3.8	NA	202
6 Scrubber Effluent	40	4.0	554	60	6.5	762	80	8.0	990
7 Stack M5/SASS	0.48/ NA	ND/ 100	0.07/ 1.0	1.91/ NA	440/ 1000	32.5/ 7.0	ND/ NA	2200/ 8100	169/ 382
% Closure			72			91			131

NA = Not Analyzed ND = Not Detected

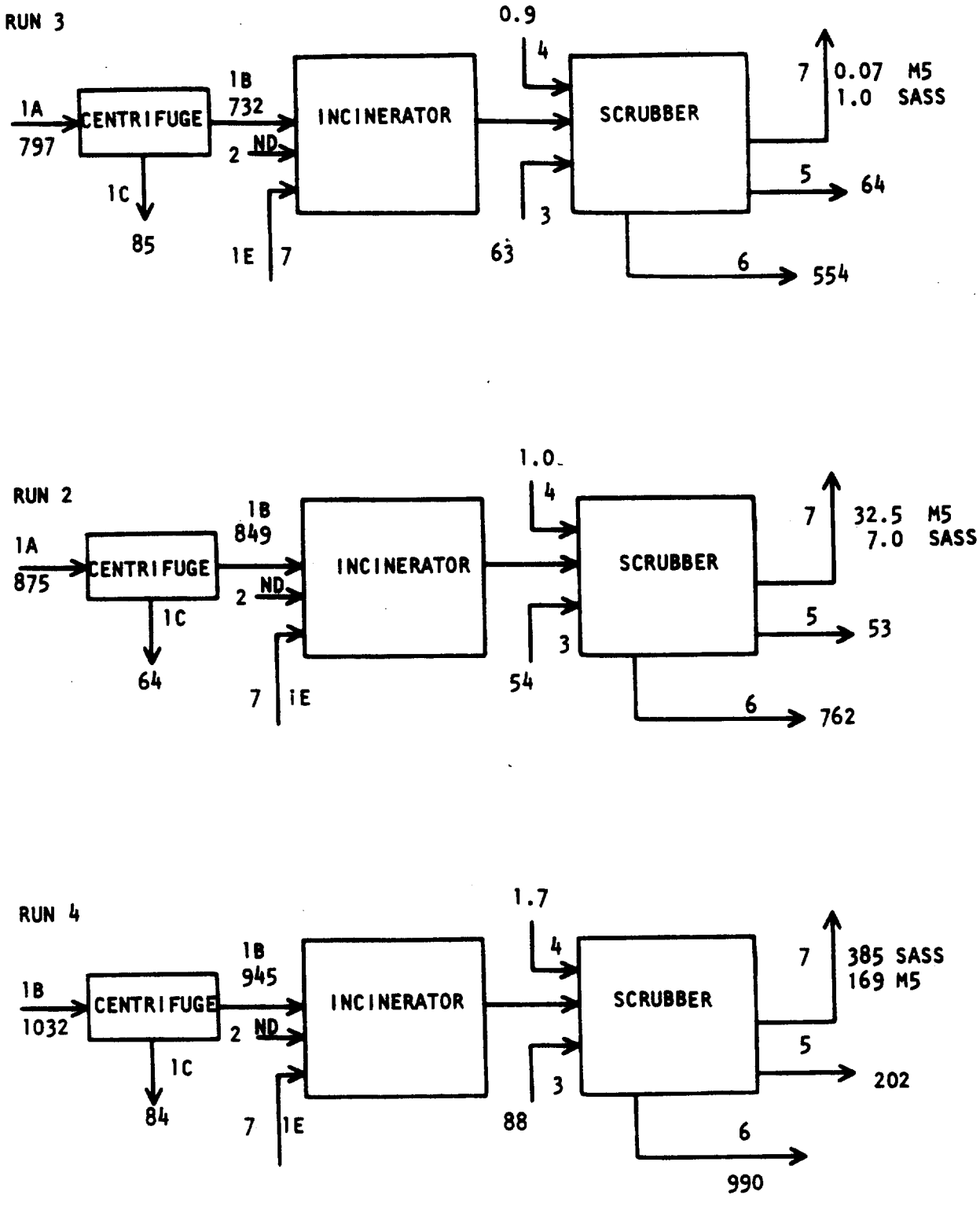


Figure 17. Cadmium balance.

TABLE 23. LEAD BALANCE

Run		3			2			4	
Bed Temperature °F		1300			1500			1700	
Emission	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr	Aqueous µg/l	Solid µg/g	Total mg/hr
Stream									
1A Sludge Before Centrifuge	148	190	39,177	120	210	46,605	15	190	48,823
1B Sludge After Centrifuge	NA	230	42,074	NA	210	44,546	NA	200	47,261
1C Centrate	260	78	2,723	180	85	2,090	216	70	2,323
1D Coagulant	<1.0	NA	ND	<1.0	NA	ND	<1.0	NA	ND
1E Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
1F Spent Sand	NA	<80	ND	NA	<80	ND	NA	<80	ND
2 Fuel Oil No. 2	NA	0.51	3.6	NA	0.51	5.1	NA	0.51	6.1
3 Treated Water	9.8	NA	367	11.4	NA	438	10.7	NA	408
4 City Water	<5	NA	ND	<5	NA	ND	<5	NA	ND
5 Scrubber Overflow	13	NA	688	9.4	NA	538	10.1	NA	537
6 Scrubber Effluent	199	1,200	40,570	308	1,100	34,425	656	1,100	37,737
7 Stack M5/SASS	1.0/ NA	ND/ 3,100	0.13/ 28	8.1/ NA	3,500/ 16,000	249/ 112	1.1/ NA	48,000/ 77,000	3,704/ 3,633
% Closure			97			77			88

NA = Not Analyzed ND = Not Detected

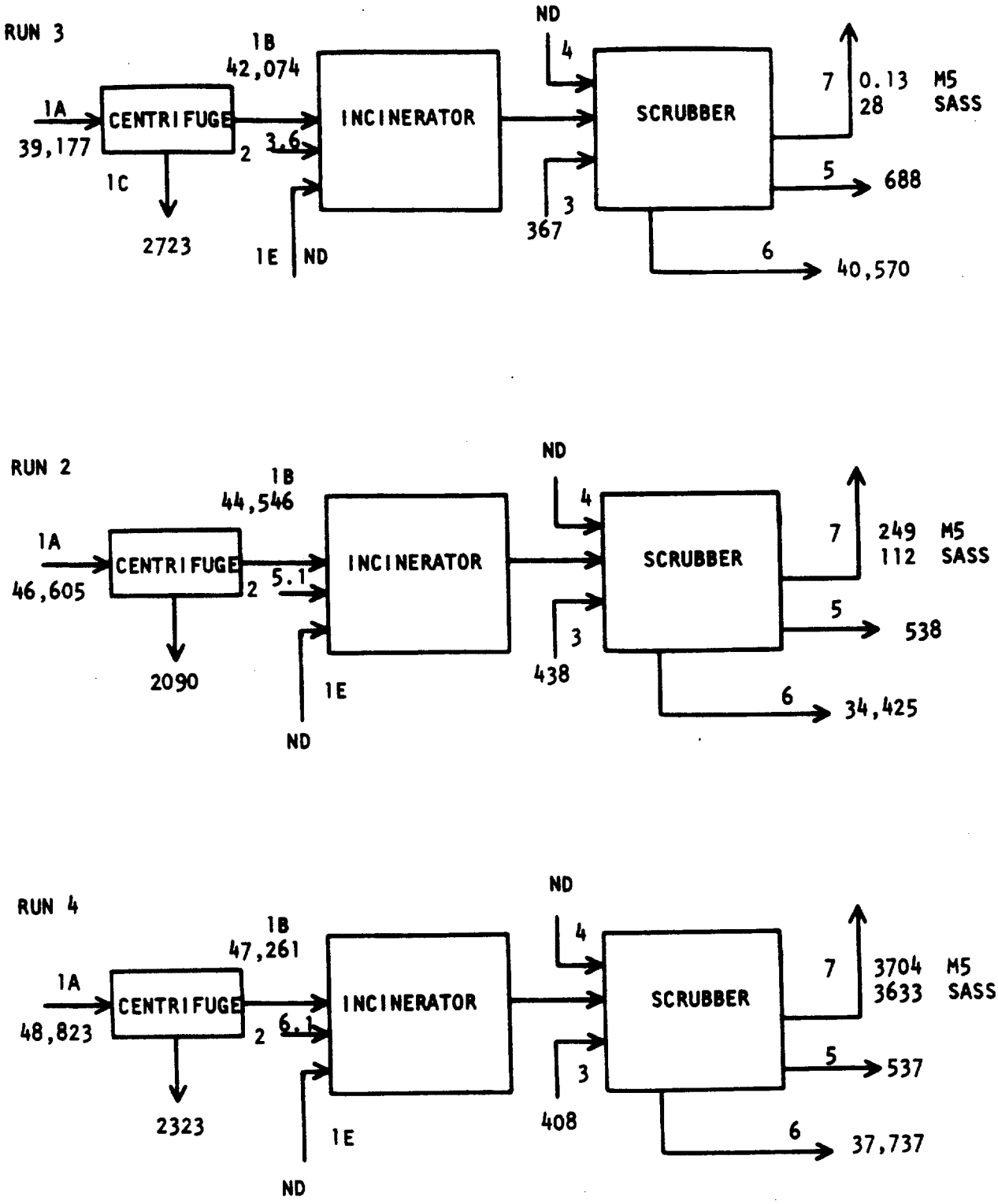


Figure 18. Lead balance.

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REFERENCES

1. Dorr Oliver F/S Incinerator Operators Manual.

2. Acurex Corporation. Aerotheum Source Assessment Sampling System. Operation and Service Manual

3. 40 CFR 60 Appendix A.