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October 1985

INHALABLE PARTICULATE SOURCE CATEGORY REPORT FOR THE NONFERROUS INDUSTRY

By

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Contract 68-02-3156
Technical Directive No. 9

Project Officer: Dale Harmon
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

for

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
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SECTION 1

INTRODUCTION

There is increasing interest in the presence of fine particulate in the atmosphere and how existing technology is controlling fine particulate emissions. Fine particulate emissions (i.e., particles smaller than 20 microns (μm) in size) are of interest since being demonstrated to be of respirable size. The physiological response to inhalation of fine particulate differs widely, however, depending on chemical composition.

This document is a source category report on inhalable particulate emitted by the nonferrous industry, specifically:

- Primary aluminum production
- Primary copper smelting
- Primary lead smelting
- Secondary lead processing
- Primary zinc smelting

This report summarizes available inhalable particulate emissions data from typical sources of each industry. The primary objective is to report reliable total and size-specific emission factors for controlled and uncontrolled emissions for each emission source in each of the nonferrous industries.

The second objective of this report is to summarize existing data on chemical characterization of inhalable particulate emissions from each emission source in each of the five nonferrous industries studied.

The final objective of this report is to present an update for the appropriate section in the document "Compilation of Air Pollutant Emission Factors" (AP-42) which is revised periodically. Section 7.1 "Primary Aluminum Production" was last revised in April 1981; Section 7.3 "Primary Copper Smelting" in January 1984. Section 7.6 "Primary Lead Smelting" was last revised in February 1980, whereas Section 7.7 "Primary Zinc Smelting" has not been revised since February 1972. Section 7.11 "Secondary Lead Processing" was last revised in October 1980. None of the sections, however, currently contain data on fine particulate emissions.

The above objectives were met by an intensive literature search and contacts with individuals and organizations known to be familiar with the nonferrous metal industries. Sources of information included:

- DIALOG computerized literature searches
- Control agencies
  - U.S. Environmental Protection Agency
  - State and local air pollution control agencies
- Trade organizations
  - Aluminum Association
  - Copper Development Association
  - International Lead Zinc Research Organization
- Industry contacts
- AP-42 nonferrous industries files at the Office of Air Quality Planning and Standards (OAQPS)
- Fine Particle Emission Information System (FPEIS)

Particle sizes are usually expressed in terms of the equivalent aerodynamic diameter; i.e., the diameter of a sphere of unit density that reaches the same terminal settling velocity (at low particle Reynolds number in still air) as the actual particle. This method of size expression is useful because it is readily determined through straightforward measurement; where the other properties of actual particle size and density may not be obtainable.

There are two general classifications of particle size measurement systems, 1) inertial separation and 2) optical or electrical mobility measurement. The majority of all particle sizing currently performed in source testing uses equipment based on inertial separation. Inertial impactors are designed so that each plate in the impactor collects particles of one size range expressed as d_{50}, the particle size in microns for which 50 percent of the particles are theoretically collected on the particular sampling plate or stage. When data are analyzed, it is convenient to express the results as a cumulative percentage by weight at selected equivalent aerodynamic diameters or cut points to facilitate analysis.

The data were reviewed, analyzed, and ranked according to the criteria provided in the report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections" April 1980 (Ref. 1). If there were no reason to exclude particular data from consideration, each data set was assigned a ranking. The data were ranked as follows:

A -- Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods are certainly to be used as a guide.

B -- Tests performed by a generally sound methodology but lacking enough detail for adequate validation.

C -- Tests based on an untested or new methodology or lacking a significant amount of background data.

D -- Tests based on a generally unacceptable method but that may provide an order-of-magnitude value for the source.

Upon ranking the data, size-specific emission factors were calculated rather than a range of values for each cut point.

The calculation of the size-specific emission factors was performed in two ways. In the first method, sufficient process and mass emission data were available to calculate cumulative factors directly. These factors are calculated by applying the cumulative percentage for each cut point to the mass emission factor calculated from production data for that test. The size-specific emission factors are subsequently graphed versus particle size and, from the resulting curve, the cumulative emissions factors are determined for equivalent aerodynamic particle diameters of 15, 10, 5, 2.5, 1.25, and 0.625 µm.

Example of Method 1:

- Industry: Primary aluminum
- Source: Horizontal stud Soderberg reduction cell
- Emissions: Fugitive roof monitor
- Particle size distribution (measured)

Run		Particle size mass distribution					
1	d_{50} (µm)	15.78	6.80	3.02	1.65	1.20	0.53
	Cum. % <d_{50}	39.8	23.1	17.1	14.3	11.6	7.3
2	d_{50} (µm)	15.7	6.72	2.94	1.57	1.12	0.46
	Cum. % <d_{50}	39.8	23.1	17.1	14.3	11.6	7.3

When graphed, the following average cut points can be read:

- Mean particle size distribution

Cut point (μm)	15	10	5	2.5	1.25	0.625
Mean cumulative percentage less than cut point	35.5	31.0	25	17.5	12.5	8.5

- Mass emission rate: 7.2 lb/ton of aluminum (calculated using EPA Method 5 total, particulate loading plus process data)
- Size-specific emission factors (EF)*

$$EF_{15\ \mu m} = \text{Mass emission factor} \times \frac{\text{Mean cumulative percentage less than } 15\ \mu m}{100}$$

$$= 7.20 \text{ lb/ton} \times 35.5/100$$

$$= 2.56 \text{ lb/ton}$$

Similarly:

$EF_{10\ \mu m}$ = 2.23 lb/ton

$EF_{6\ \mu m}$ = 1.80 lb/ton

$EF_{2.5\ \mu m}$ = 1.26 lb/ton

$EF_{1.25\ \mu m}$ = 0.86 lb/ton

$EF_{0.625\ \mu m}$ = 0.61 lb/ton

The second method involved the use of the mass emission factors found in AP-42. Emission factors can be calculated by applying the mean cumulative percentages for each cut point to the mass emission factor presented in AP-42. This is the preferred method since AP-42 mass emission factors are generally based on several samples taken at multiple points in ducting rather than single points typical of particle distribution sampling.

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*To convert to kilograms per metric ton (kg/Mg), multiply by 0.5.

Example of Method 2:

- Industry: Primary aluminum
- Source: Prebake cell
- Emissions: Fugitive roof monitor
- Particle size distribution (measured)

Run		Particle size distribution					
1	d_{50} (μm)	16.74	6.86	2.46	1.30	0.71	0.36
	Cum. % $<d_{50}$	53.4	34.8	19.11	15.5	11.1	8.3
2	d_{50} (μm)	16.70	6.83	2.45	1.30	0.71	0.35
	Cum. % $<d_{50}$	58.9	38.9	21.4	16.7	13.5	9.9
3	d_{50} (μm)	16.8	6.90	2.47	1.31	0.72	0.36
	Cum. % $<d_{50}$	97.4	67.3	33.5	28.6	22.5	16.2

When graphed, the following average cut points can be read:

- Mean particle size distribution

Cut point (μm)	15	10	5	2.5	1.25	1.00	0.625
Mean cumulative percentage less than cut point	68.0	58.5	45	26.5	20	18.3	15.5

- Mass emission factor from AP-42: 5 lb/ton of aluminum
- Assumption: During the tests, the fugitive emissions from the prebake cells were approximately equal to the mass emission factor from AP-42
- Size-specific emission factors (EF)*

---

*To convert to kilograms per metric ton (kg/Mg), multiply by 0.5.

$$EF_{15\ \mu m} = \text{mass emission factor} \times \frac{\text{Mean cumulative percentage less than 15 } \mu m}{100}$$

$$= 5\ \text{lb/ton} \times 68/100$$

$$= 3.4\ \text{lb/ton}$$

Similarly:

$$EF_{10\ \mu m} = 2.9\ \text{lb/ton}$$

$$EF_{5\ \mu m} = 2.2\ \text{lb/ton}$$

$$EF_{2.5\ \mu m} = 1.3\ \text{lb/ton}$$

$$EF_{1.25\ \mu m} = 1.0\ \text{lb/ton}$$

$$EF_{1.00\ \mu m} = 0.9\ \text{lb/ton}$$

$$EF_{0.625\ \mu m} = 0.8\ \text{lb/ton}$$

The reliability of the calculated emission factors is indicated by an Emission Factor Rating. The ratings are subjective quality evaluations rather than statistical confidence intervals and range from A (excellent) to E (poor) as follows:

A -- Excellent. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category* is specific enough to minimize variability within the source category population.

B -- Above average. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

C -- Average. Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

D -- Below average. The emission factor was developed only from A-and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the

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*Source category: A category in the emission factor table for which an emission factor has been calculated; generally a single process.

source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E -- Poor. The emission factor was developed from C-and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

Process and control system operating data were obtained and summarized. Cyclic or other peculiarities which may affect emissions were identified and presented in both the specific industry description sections and in the proposed AP-42 sections. Because of the nature of AP-42, some duplication of information occurs in the proposed AP-42 sections and in the industry descriptions.

SECTION 2

PRIMARY ALUMINUM INDUSTRY

This section presents the source category report on inhalable particulate matter emissions from processes within the primary aluminum industry. The industry includes the production of alumina from bauxite and the reduction of alumina to aluminum. Size-specific emission factors are developed from data obtained from particulate sampling tests performed on industrial emission sources. A proposed revision of the AP-42 section for this industry is also presented.

Included in this section are brief descriptions of the aluminum industry including a process flow diagram, the individual processes involved in aluminum production, sources of particulate emissions, and types of control equipment used.

2.1 OVERVIEW

Primary aluminum production is a two-step process involving the production of alumina (Al_2O_3) from bauxite, known as the Bayer Process, and the electrolytic reduction of the alumina to produce aluminum, the Hall-Heroult Process. These two steps are normally carried out at different locations.

Ten domestic firms in the United States currently produce primary aluminum. These are summarized in Table 1. In 1982, 12 domestic firms, owned by 11 companies, were involved in the production of primary aluminum in the United States. Of the domestic firms, only Alcoa and Reynolds were integrated from domestic mines through the primary metal stage (Ref. 2). Figure 1 shows the breakdown of U.S. primary aluminum raw material supply and production as of 1981.

For many years, demand for aluminum had grown at a faster rate than for other metals. Total U.S. industrial demand increased from 4,792 thousand tons (4,347 thousand Mg) in 1972 to an estimated 5,749 thousand tons (5,215 thousand Mg) in 1981, although demand in 1973, 1974, 1977, 1978, and 1979 exceeded 6,200 thousand tons (5,625 thousand Mg). Measured either in quantity or value, the use of aluminum now exceeds all other metals except iron. U.S. demand for aluminum in metal and nonmetal forms is expected to be 8 to 17 million tons (7.3 to 15.4 million Mg) by the year 2000. Principal factors contributing to the high demand forecast include increased use of aluminum in the transportation sector and in a wide variety of both consumer

TABLE 1. PRIMARY ALUMINUM PRODUCERS IN THE UNITED STATES 1984[a]

ALUMAX, Inc.
Owned by AMAX, Inc., MITUSI & Co., Ltd., and NIPPON Steel Corp.
400 S. El Camino Real
San Mateo, CA 94402

Aluminum Company of America (ALCOA)
1501 Alcoa Building
425 Sixth Avenue
Pittsburgh, PA 15219

Anco Metals Co. (previously known as The Anaconda Company)
Subsidiary of Atlantic Richfield Co.
Aluminum Division
2 Continental Tower
1701 Golf Road
Rolling Meadows, IL 60008

Consolidated Aluminum Corp. (CONALCO)
Owned by Swiss Aluminum Corp. and Phelps Dodge Corp.
11960 Westline Industrial Dr.
St. Louis, MO 63178

Kaiser Aluminum & Chemical Corp.
300 Lakeside Drive
Oakland, CA 94612

Martin Marietta Aluminum, Inc.
Subsidiary of Martin Marietta Corp.
6801 Rockledge Drive
Bethesda, MD 20034

National Southwire
Owned by National Intergroup Corp.
2800 Grant Building
310 Grant Street
Pittsburgh, PA 15219
and
Southwire Co.
Fertilla Street
Carrollton, GA 30117

Noranda Aluminum, Inc.
Subsidiary of Noranda Mines, Ltd.
P.O. Box 70
St. Jude Industrial Park
New Madrid, MO 63869

Ormet Corp.
Consolidated Aluminum Corp.
11960 Westline Industrial Drive
St. Louis, MO 63178

Reynolds Metals Co.
P.O. Box 27003
Reynolds Metals Building
6601 W. Broad Street
Richmond, VA 23261

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[a] Source: The Aluminum Association.

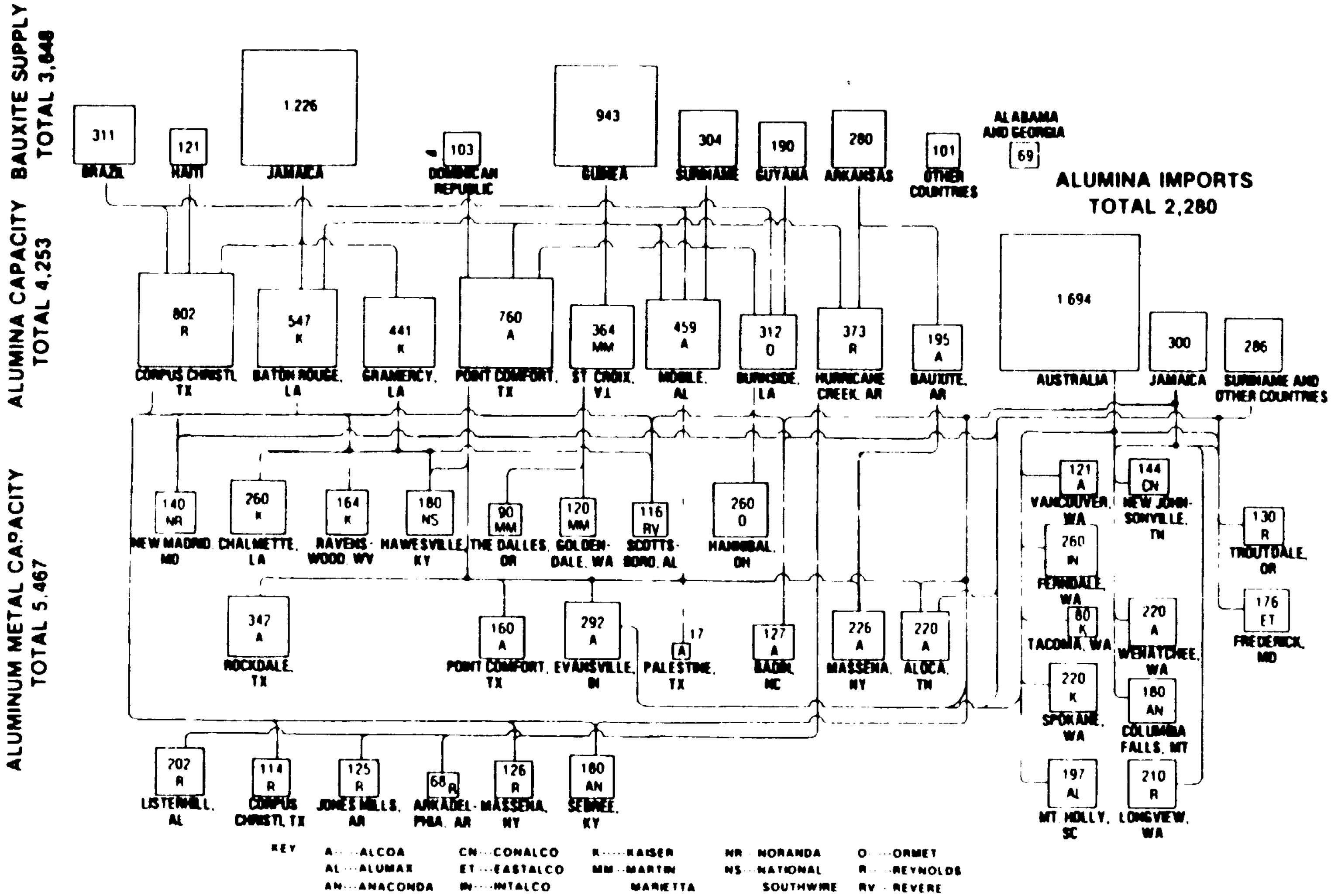

Figure 1. Distribution of U.S. bauxite and alumina supply and aluminum plant capacities, 1981 (thousand short tons aluminum equivalent) (Ref. 3).

and capital goods. In the long term, the availability and anticipated low cost of aluminum, relative to competing materials such as copper and plastics, could also contribute to attainment of the high demand forecast. Factors that could result in a lower use forecast are possible low growth, the high cost of electric energy, and the substitution of other materials for aluminum in transportation, machinery, construction, containers, and electrical distribution lines.

The aluminum industry itself has contributed greatly to the growth in aluminum demand by maintaining a large research effort to develop new products and improve production efficiency. Current research covers the entire field of metal production through the development of new and improved production processes, alloys and casting techniques, protective and decorative finishes, end-use applications, and recycling processes. Research is also being conducted to improve the energy efficiency of the aluminum production process. These efforts include reducing heat losses, regenerative heating, and increasing the product yield in the Bayer process; and reducing the electrical resistance of the anode, cathode, and electrolyte, which wastes much of the power input as heat, in the Hall-Heroult process (Ref. 2 and 3).

2.1.1 Aluminum Production Process

The following section describes the production of primary aluminum, which involves a two-step process as indicated in the aluminum production process flow diagram (Figure 2).

The first step in the aluminum production process consists of alumina extraction from the base ore, normally bauxite, although the use of kaolin, anorthosite, and alumite clays is anticipated in the future. Although research on alumina extraction from all ores is continuing, virtually all of the commercially produced alumina is extracted from bauxite by the Bayer process.

In the Bayer process, the ore is dried, ground in ball mills, then leached with a caustic solution at an elevated temperature and pressure, producing a sodium aluminate solution which is separated and cooled. As the solution cools aluminum precipitates as hydrated aluminum oxide ($Al_2O_3 \cdot 3H_2O$). The resulting Al_2O_3 is then transported to primary aluminum reduction facilities. With the exception of the Alcoa facility at Point Comfort, Texas, alumina production and reduction are accomplished at separate locations (Ref. 2).

Primary aluminum is produced by the electrolysis of alumina in a molten bath of natural or synthetic cryolite (Na_3AlF_6) which serves as both an electrolyte and a solvent for the Al_2O_3. The reduction is carried out in shallow rectangular cells called pots, that are made of carbon-lined steel and include carbon blocks that are suspended above and extend down into the pots (see Figure 3). The pots and carbon blocks serve as cathodes and anodes, respectively, for the electrolytical process. Resistance between the electrodes heats the alumina-cryolite bath to between 1,700° and 1,800°F

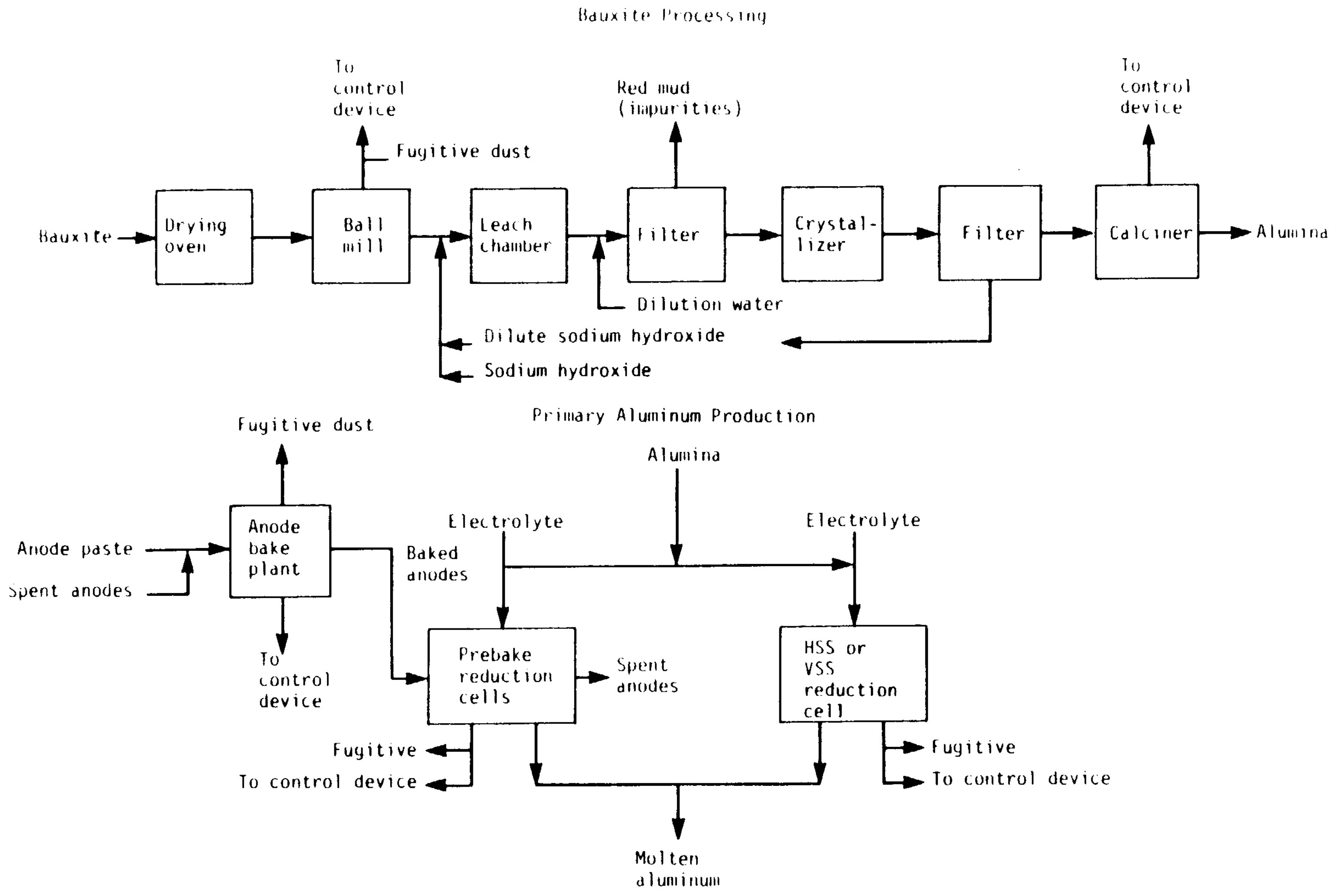

Figure 2. Aluminum production process flow diagram.

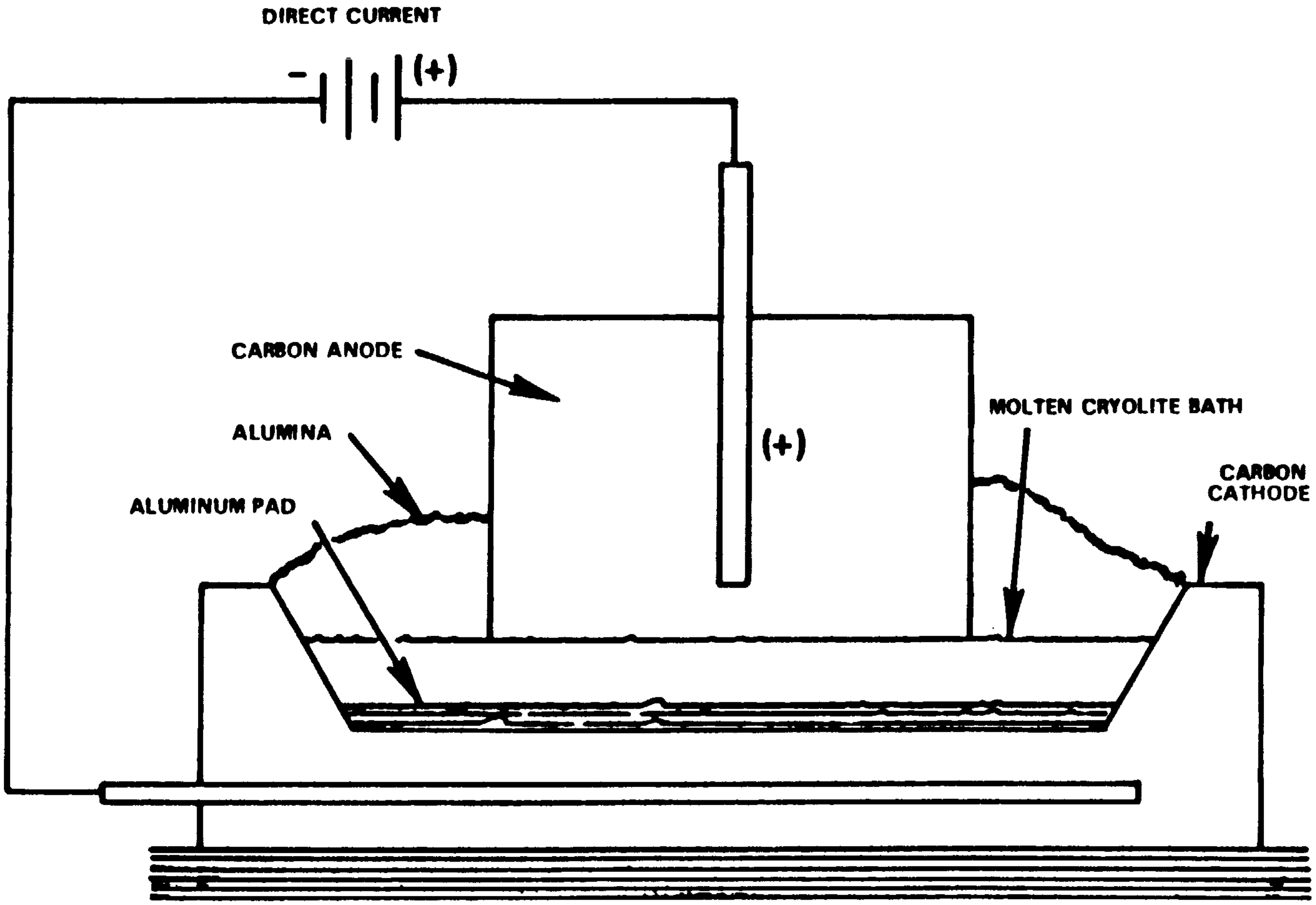

Figure 3. Aluminum reduction cell diagram (Ref. 4).

(950° and 1,000°C), causing the alumina to dissociate. The aluminum has a higher density than the bath and settles at the cathode.

Al_2O_3 and Na_3AlF_6 are periodically added to the bath to replenish material that is removed or consumed during normal operation. The weight ratio of sodium fluoride (NaF) to aluminum fluoride (AlF_3) in Na_3AlF_6 is 1:50. However it has been found that adding excess AlF_3 to reduce the bath ratio from 1:30 to 1:45 will increase cell current efficiency and lower the bath melting point permitting lower operating temperatures and lower energy consumption per pound of aluminum produced. Calcium fluoride (CaF_2) may also be added to lower the bath temperature (Ref. 2 and 4).

Every 1 or 2 days, the molten aluminum is removed from the bottom of the pot by a vacuum siphon technique. Thermally insulated cast iron pots with airtight lids and downward-sloping spouts are used to withdraw the molten metal. As the cast iron pot is evacuated, the molten aluminum is drawn into the pot. The molten metal is then blended in a holding furnace with other batches of metal and may be fluxed, alloyed, and cast into various solid forms, or transported in the molten state to fabricating plants (Ref. 2).

Pots are connected in electrical series ranging from 100 to 240 cells to form a potline, the basic production unit of the reduction plant. The cells utilize direct current ranging from 65,000 to 150,000 amps, with the majority of plants having 80,000 to 100,000 amps cells. Anode current densities range from 600 to 800 amp/ft^2 (6.5 to 8.6 kA/m^2). The voltage drop across a single cell is 4.5 to 5 volts, and across an entire potline may run as high as 1,000 volts.

Larger cells require less manpower per pound of aluminum produced; however, special problems are encountered in cells designed to use 100,000 or more amperes as powerful magnetic fields are created in the metal and bath, resulting in violent agitation. The agitation disperses the aluminum in the bath, increasing the possibility of reversing the reduction reaction. Also, the molten metal piles up toward the anode leads, causing a variation in the anode-cathode spacing. The magnetic fields may also produce localized thermal effects which can distort the carbon lining in the pots.

Current efficiency ranges from 85 to 90 percent with losses caused by metal spillage, vaporization from the bath, and reoxidation of aluminum. Because of electrical resistance, the voltage efficiency is only 40 percent, with heat being lost by radiation, exhaust gases, tapped metal, and electrodes removed from the cell. As a result, the overall energy efficiency is about 35 percent (Ref. 2).

The dissociation of Al_2O_3 liberates oxygen (O_2) from the bath, which consumes the anode, producing carbon monoxide (CO) and carbon dioxide (CO_2) continually. The method of anode replacement is the only significant variation among primary production facilities within the United States, with two standard methods in use, the prebake process and the Soderberg continuous process.

Prebake Process

As the name implies, the prebake aluminum reduction process uses prebaked carbon blocks as anodes. The carbon blocks are produced as an ancillary operation at the reduction plant site using a process similar to the schematic shown in Figure 4. In the anode production plant, coke is crushed, sized, cleaned, and mixed with the crushed remains of spent anodes. This mixture is then blended with pitch and molded to form self-supporting green anode blocks. The pitch may or may not be coal tar as depicted in the figure and it may be received in a molten state and handled as a liquid. The green anode blocks are then baked in a ring furnace or tunnel kiln.

A ring furnace consists of compartmentalized, sunken brick baking pits with surrounding interconnecting flues. Green anodes are packed within the pits, with all empty space around the blocks filled with a blanket of coke or anthracite. A blanket of calcined petroleum coke covers the top of each pit. The packing and cover help to prevent oxidation of the carbon anodes.

The pits are then fired with manifold burners for a period of 40 to 48 hr using either natural gas or oil. The flue system is designed so hot gas being fired into the pits is drawn through the next batch of anodes to preheat them gradually. Also, by incorporating flues on the outside walls, which operate under draft, and pit walls of dry-type construction, the flue system draws most volatile materials (principally hydrocarbons from the pitch binder) along with the burner combustion products into the flue gases, where they are burned at about 2,370°F (1,300°C). Combustion air is drawn through the previously fired sections, thereby cooling them. The anodes are fired to approximately 2,190°F (1,200°C), and the cycle of placing the green anodes, preheating, firing, cooling, and removal takes approximately 28 days (Ref. 4).

Firing of sections proceeds down one side of the rectangular furnace building and back up the other in a ring pattern. The pattern of cooling, firing, heating, and emptying sections is repeated continually, moving from section to section. The baked anodes are stripped from the furnace pits by an overhead crane on which pneumatic systems for loading and removing the coke pit packing may also be mounted. The packing may subsequently become part of other green anodes in the carbon plant (Ref. 4).

A second type of furnace, the tunnel kiln, has been developed for application in the baking of anodes. The kiln is an indirect-fired chamber in which a controlled atmosphere is maintained to prevent oxidation of the carbon anodes. Green anode blocks are loaded on transporter units that enter the kiln through an air lock, pass successively through a preheating zone, firing zone, and cooling zone, and leave the kiln through a second air lock. The refractory beds of the cars are mechanically sealed to the kiln walls to form the muffle chamber, and still permit movement of the units through the kiln. The muffle chamber is externally heated by combustion gases, and the products of combustion are discharged through an independent stack system.

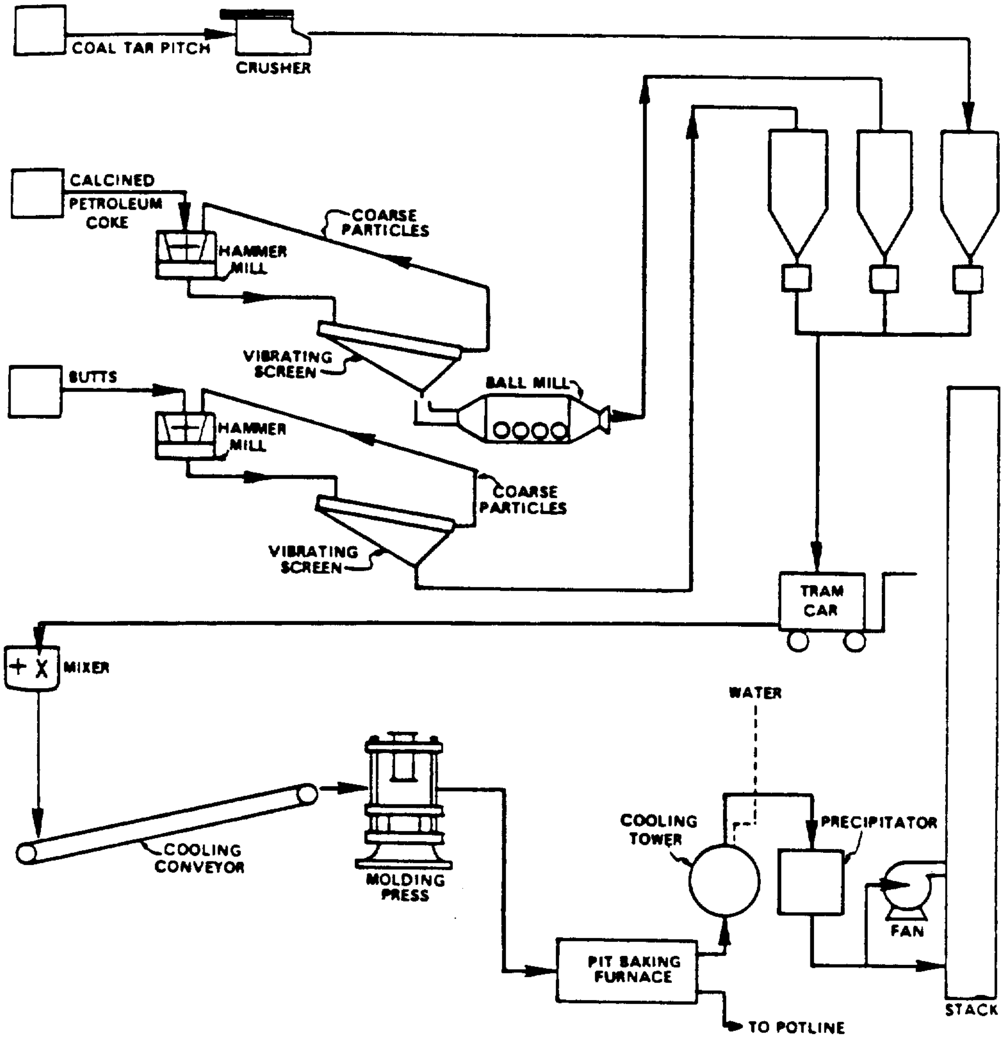

Figure 4. Flow diagram for preparation of prebake anodes (Ref. 5).

Effluent gases from the baking anodes may be introduced into the fire box to recover the fuel value of hydrocarbons and reduce the quantity of unburned hydrocarbon to approximately 1 percent of that coming from a ring furnace.

Although the tunnel kiln presents mechanical problems in design and operation, it is reported to have several appreciable advantages over the ring-type furnace:

- Baking cycle from green to finished anode is much shorter
- Anode baking is more uniform
- Space requirements for equal capacity furnaces is less
- Smaller gas volumes are handled through the furnace emission control system

The successful development of the tunnel kiln in this application is recent, and at this time only one installation is in normal operation.

Baked anodes, from either type of bake plant, are delivered to air blast cleaning machines utilizing fine coke as blasting grit. Fins, scrafs, and adherent packing is removed by this treatment, and the baked anodes are then transferred to the rodding room where the electrodes are attached (Ref. 4).

Prebake Cell

Figure 5 shows a sectional view of a typical prebake reduction cell with a hood for collecting cell emissions.

Prebake cells use up to 26 anode assemblies per cell, which are attached to the anode bus on the cell superstructure by clamps. The anode bus is attached to the steel superstructure by anode jacks that may be driven by an air motor or other means, giving a travel distance ranging from 10 to 14 in. (25 to 36 cm) and permitting the raising or lowering of all 26 assemblies in the cell simultaneously. Each of the 26 assemblies may also be raised or lowered individually by means of an overhead crane after the anode clamp is loosened.

The anodes are lowered as they are consumed, typically at a rate of about 1 in. (2.5 cm) per day (Ref. 6). When the anodes are completely spent, they are removed and replaced on a rotating basis, usually a pair at a time. The total operating time before replacement is dependent on the size of the anode blocks and the amperage of the potline.

The anode assemblies are usually installed in two rows extending the length of the cell. In some arrangements the two rows are closely spaced in the center of the cell, providing a working area on each side of the cell between the cell side lining and the anodes (side-worked). In other cases, the rows are separated and placed closer to the cell side lining, providing

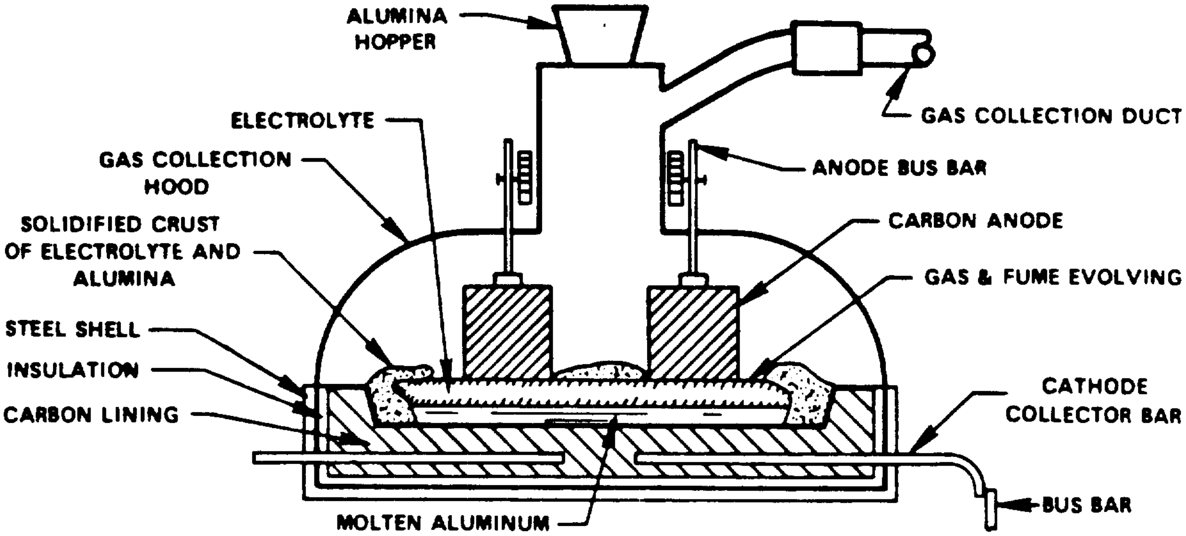

Figure 5. Details of prebake cell (Ref. 6).

the working area in the center of the cell between the rows of anodes (center-worked).

The general trend in prebake anode design has been toward larger anode blocks, obtaining greater effective anode/cathode surface ratios and lower current densities at the anodes for equivalent power inputs.

Soderberg Cells

There are two types of Soderberg cells -- vertical stud Soderberg (VSS) and horizontal stud Soderberg (HSS). Each is a single large carbon anode, but they differ in the method of anode bus connection to the anode mass. In both the VSS and HSS a green anode paste is fed periodically into the open top of a rectangular steel compartment and baked by the heat of the cell to a solid coherent mass as the material moves down the casing.

In both types of Soderberg cells, the in-place baking of the anode paste results in the release of hydrocarbon fumes and volatiles derived from the pitch binder of the paste mixture. These products are a component of the Soderberg cell emissions and are essentially absent from those of the prebake cells. If not removed from the gas stream, the pitch components will condense and plug subsequent ductwork and emission control devices.

Although the Soderberg cells require more electrical energy to produce a given weight of metallic aluminum and create problems in emission control, they were acclaimed initially because they eliminated the need for a separate anode manufacturing facility.

Partially because the volatile pitch components can condense in the ductwork and control device, and partially because of the problems of simultaneously controlling fluorides and organic emissions, any economic advantage the Soderberg systems once had is diminishing and the trend appears to be toward the use of the prebake cell.

Furthermore, although prebake cells may be center-worked or side-worked, the use of a single large carbon anode requires that both types of Soderberg cells be side-worked. Center-worked cells lend themselves to more efficient hooding and hence more efficient emission control.

Vertical Stud Cells

Figure 6 shows a sectional view of a typical VSS reduction cell. The anode casing is stationary, the electrical connection from the studs to the busbar is rigid, and the steel current-carrying studs project vertically through the unbaked paste portion into the baked portion of the anode. As the anode is consumed and moves down the casing, the bottom-most studs are periodically extracted before they become exposed to the bath at the bottom of the anode.

The stationary anode casing and the projection of the studs through the top of the anode allow the installation of a gas collection skirt between the

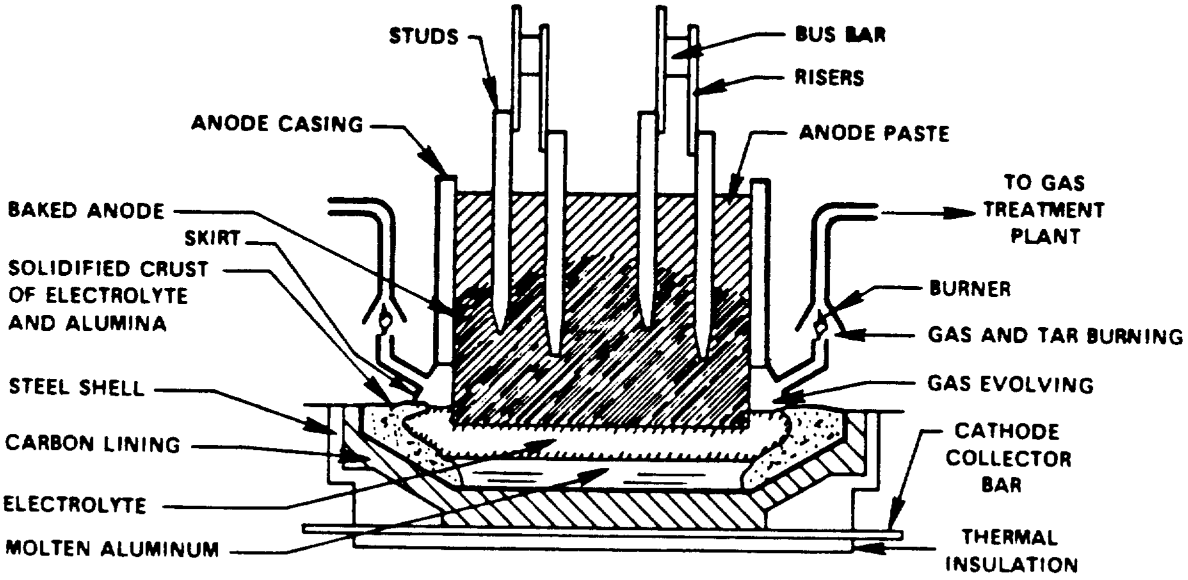

Figure 6. Details of a VSS reduction cell (Ref. 6).

anode casing and the bath surface. The gases are ducted to integral gas burners where the hydrocarbon tars are burned to gaseous fractions that do not interfere with the operation of subsequent pollutant removal equipment. Maintenance of the skirt system is a problem, however. Irregularities in cell operation can extinguish the burner flame, and the skirts may melt or be deformed by the heat. Pilot lights can help ensure that the burners stay lit.

Horizontal Stud Cells

Figure 7 shows a sectional view of a typical HSS reduction cell. The anode, suspended over the pot, is contained in a rectangular compartment made of aluminum sheeting and perforated steel channels that is raised or lowered by powered jacks. The entire anode assembly is moved downward as the working surface is oxidized. Studs are inserted into the anode through 3-in. (7.6-cm) perforations in the steel channels at a point approximately 3 ft (0.9m) above the molten bath where the paste is still fairly soft. Electrical contact is made through flexible connectors between the studs and the busbar. As the anode is moved downward, the paste becomes solid as it bakes and grips the stud. When the bottom channel reaches the bath, the flexible connectors are moved to a higher row of studs, the studs in the bottom row are pulled out, and the bottom channels are removed.

The construction of the HSS cell prevents the installation of an integral gas collection device such as a skirt, since the anode casing is formed by removable channels supporting the horizontal stud electrodes, and these channels are periodically changed as the anode moves downward and is consumed. Hooding is restricted to canopy suspension, resulting in so much air dilution that self-supporting combustion in burners is not possible. Therefore, the hydrocarbon tars condense in the ductwork and tend to plug pollutant removal equipment.

2.1.2 Particulate Emission Sources

Sources of particulate emissions within the primary aluminum industry are shown schematically in Figure 8. At the alumina production plant, bauxite is ground and digested to produce sodium aluminate. The major source of emissions during this operation is the ore grinder. After precipitation, the $Al_2O_3 \cdot 3H_2O$ is calcined in a rotary kiln to produce Al_2O_3. The kiln is usually equipped with a particulate collection device to recover the alumina dust for economic reasons.

At the aluminum reduction plant, Al_2O_3 is reduced to aluminum in an electrolytic cell. This operation produces particulate, sulfur, carbon monoxide, and hydrocarbon emissions as well as fluoride emissions. The amount of emissions depends upon the type of cell used.

Prebake Cells

The electrolytic reduction of aluminum produces a CO exhaust at the anode of the cell. As the exhaust leaves the cell, it entrains particulates

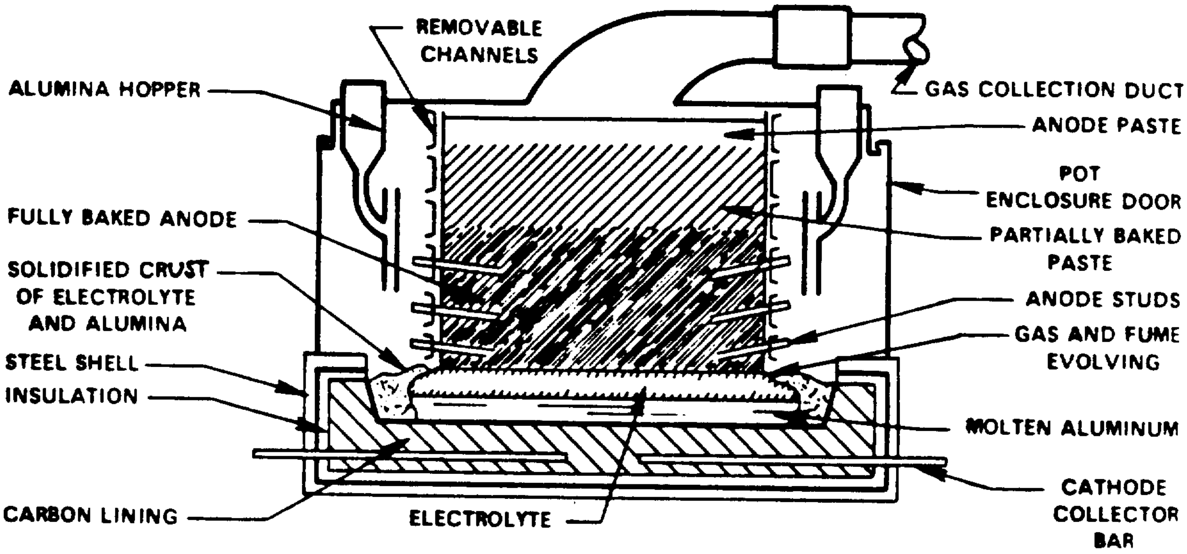

Figure 7. Details of an HSS reduction cell (Ref. 6).

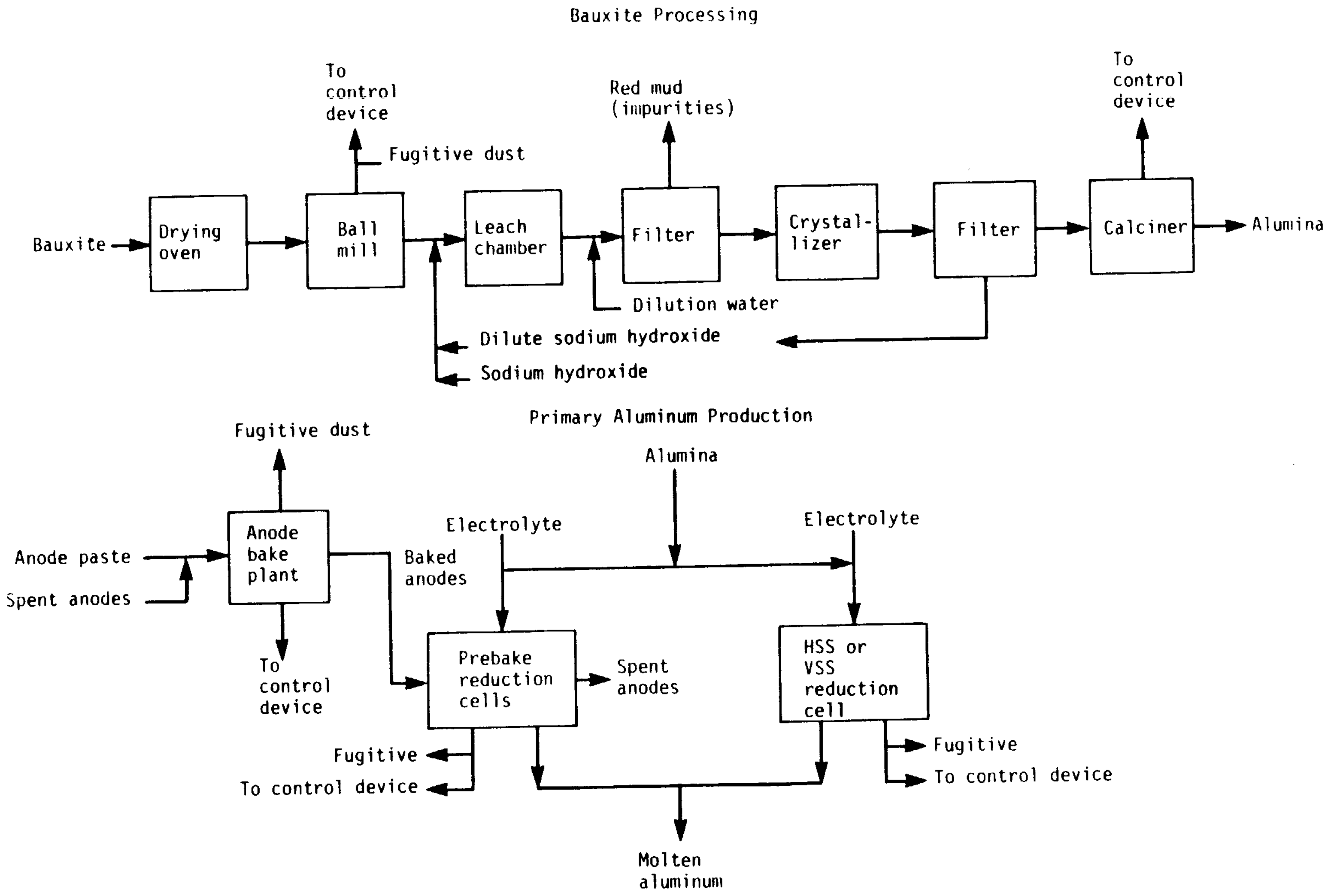

Figure 8. Emission sources within the primary aluminum industry.

including fluoride salts. This exhaust also contains noxious gases such as hydrogen fluoride (HF), sulfur dioxide (SO_2), and traces of hydrogen sulfide (H_2S).

In a prebake plant the carbon anode, which is consumed as part of the reaction, is formed in a baking furnace. The manufacturing process is similar to coke-making in that a paste made of pitch and coal is devolatilized forming a solid carbon anode. The process emits large amounts of hydrocarbons, sulfur compounds, and particulates.

Soderberg Cells

Plants which use Soderberg cells do not require anode furnaces because the anode is formed from a coke-based paste within the electrolytic cell itself. In this case, the particulate, sulfur dioxide, hydrogen sulfide, and hydrocarbon emissions common to the anode furnace of a prebake cell will be emitted in the electrolytic cell of the Soderberg process instead.

As has been discussed, there are two types of Soderberg cells: HSS and VSS. With respect to air pollution control, the primary difference between these two is the ease with which a hood can be placed over a cell to capture emissions. In HSS cells, the hood does not fit close to the pot and large volumes of air are entrained with the hot exhaust from the cell. This has the effect of quenching the combustion of hydrocarbons, resulting in a large tar fouling problem as the heavy hydrocarbons condense on ducts and control equipment (Ref. 7).

2.1.3 Particulate Emission Controls

The Bayer plant has only two sources of particulate emissions to control as follows:

- Particulates from the ore grinder are normally collected in a hood and removed using a high efficiency electrostatic precipitator (ESP), venturi scrubber, or bag filter. Low efficiency wet collection devices such as spray towers, floating bed scrubbers, quench towers, and spray screens have been used in the past, but are generally not effective enough to comply with current standards and have probably been replaced.

- Particulates from the rotary kiln calcining operation are removed using a combination of multicyclone followed by ESP or bag filter. Because of the economic value of the collected alumina dust, low efficiency devices that have been used have probably all been replaced.

The electrolytic reduction process requires controls for particulates, fluorides, sulfur dioxide (SO_2), and hydrocarbons. The control technology applied depends upon the type of electrolytic cell being used. Table 2 contains a summary of the pertinent emission characteristics of the three cell types. Most control systems rely primarily upon a dry alumina scrubber

TABLE 2. SUMMARY OF AIR POLLUTION CHARACTERISTICS AND CONTROL

Process	Particulates	Gaseous fluorides	Hydrocarbons	Sulfur oxides	Control devices
Bauxite grinding	Yes	Neg[a]	Neg	Neg	ESP Venturi scrubber Bag filter
Calcining	Yes	Neg	Neg	Neg	Cyclones followed by ESP or bag filter
Anode baking	Yes	No	Volatiles	Yes[b]	Spray tower ESP Self-induced spray Dry alumina adsorption
Prebake reduction	Yes	Yes	Carbon dust	Trace	Multiple cyclone Fluid-bed dry scrubber Coated filter dry scrubber ESP Spray tower Floating bed scrubber Chamber scrubber Vertical flow packed bed Dry alumina adsorption
Horizontal stud Soderberg reduction	Yes	Yes	Tars	Yes[b]	Spray tower Floating bed dry scrubber Wet ESP
Vertical stud Soderberg reduction	Yes	Yes	Carbon dust	Yes[b]	Spray tower Self-induced spray Venturi scrubber Wet ESP Multiple cyclones Dry alumina adsorption
Materials handling	Yes	Neg	No	No	Spray tower Floating bed dry scrubber Quench tower and spray screen ESP

[a] Neg -- Negligible.
[b] In the form of SO_2 or H_2S.

to remove particulates and gaseous HF acid. However, many of the plants with the older control systems (i.e., other than dry alumina scrubbers) have closed down due to economic reasons and probably will not be restarted. Note, however, the following specific emission control requirements:

- Prebake cells -- Almost all reduction cells use dry alumina scrubbers for control of emissions. Controls are required for the anode baking furnace as well as for the reduction cell. Hydrocarbon and SO_2 emissions are emitted primarily from this furnace and most are controlled by dry alumina scrubbers with the remainder using a wet conditioner followed by an ESP.

- Soderberg cells -- Hydrocarbons and SO_2 are emitted in the cell along with particulate matter and gaseous fluorides

  -- Vertical studs: hooding fits close enough so that hydrocarbons are burned, leaving only carbon dust, SO_2 and gaeous fluorides. Controls include dry alumina scubbers, caustic scrubbers, and wet ESP's.

  -- Horizontal studs: the cell exhaust is diluted with too much excess air so hydrocarbons do not completely burn. Subsequent condensation of tars on ducts and control equipment creates a serious tar fouling problem. Venturi scrubbers plus ESP or dry alumina scrubbers are used to avoid fouling the control device with tar.

These cell types are difficult to hood. Estimates have been made of the coverage, as listed in Table 3.

Because of the incomplete hooding, a large fraction of the emissions escape collection and are emitted through roof vents or monitors in the building. In some cases, roof scrubbers have been installed to remove the gaseous fluorides and particulate matter. It is also possible to collect these emissions in a duct along the roof line and remove the pollutants using

TABLE 3. PARTICULATE EMISSION CAPTURE BY CELL HOODS

Pot type	Percent of particulates captured by best available hooding
New prebake	95
Older prebake	79
Vertical stud Soderberg	50
Horizontal stud Soderberg	80

high-efficiency scrubbers, bag filters, or wet precipitators. This type of fugitive emission control is costly but may be required to meet current standards (Ref. 5 and 7).

2.2 ALUMINUM INDUSTRY EMISSION FACTORS

The following subsection outlines the methodology involved in the development of size-specific emission factors for various processes within the primary aluminum industry. The data from which the emission factors are developed is reviewed, analyzed, and rated according to the guidelines established in the document "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections" (Ref. 8).

2.2.1 Data Review

Data on size-specific emissions from processes within the primary aluminum industry are sparse. The data search yielded no data that could be given an "A" rating according to the criteria outlined in Section 1. Data collected is summarized in the following sections.

Kaiser Mead (Ref. 9)

The first data set was obtained from a report produced to document testing at the Kaiser Aluminum & Chemical Corporation's Mead works, a prebake primary aluminum reduction facility located approximately 15 miles north of Spokane, Washington. The test was conducted to measure fugitive particulate, fluoride, and SO_2 emissions being emitted through a roof monitor for determination of compliance with the State of Washington's Department of Ecology (WDOE) regulations. Testing was carried out in March 1982.

The plant has eight potlines, seven of which were in operation at the time of the test, producing 500 tons (450 Mg) of aluminum per day. Each potline has two potrooms, with an average of 71 operating pots per room. All pots within a line are hooded and served by two manifold systems which discharge into a common manifold. Eight four-sectioned baghouses draw exhaust from the common manifold via forced draft blowers. Aluminum ore is injected into the exhaust streams downstream of the fans, forming a fluoride-absorbing bed of alumina in each baghouse. The ore and entrained particulate matter are then collected in the bags. Gases that escape from the hooding system during the addition of Al_2O_3, tapping molten aluminum, or breaking the crust, are carried upward by natural convection and emitted through the roof monitor.

Coke for the anodes is received by the mill and fed through a rotary kiln. A cyclone is used to control emissions. The coke is then mixed to form an anode paste in the green carbon plant. Emissions from the mixing and handling operations are vented through a baghouse.

The formed anodes are then baked in the anode bake plant, which is normally fired by natural gas. Emissions are controlled by a baghouse, which has the same configuration as those used on the potlines.

Three 24-hr WDOE Method 13 particulate plus gaseous fluoride samples were collected from each of three roof monitor sampling points since the roof monitor area of 446.86 m^2 was divided into three zones. Three 24-hr particulate size samples were also collected using University of Washington Mark III cascade impactors at one of the sampling points, concurrent with total particulate testing.

Since percent isokinetic sampling flowrate values for WDOE Method 13 were not all within 100 ±10 percent and percent isokinetic sampling flowrate values for impactor sampling were not reported, this data is ranked B-quality since it was all taken for an extended period of time (24 hours) in an opening subjected only to natural convection (average velocity of 1.4 mps (4.5 fps)). On runs 1 and 3 the stainless steel substrates of the University of Washington Mark III Impactor were coated with Apizon H grease to minimize particle bounce and re-entrainment. No grease was used on Run 2 because of the large size of the particulate and the type of impactor used. The size percentage presented for 10 and 15 μm particulate is not as accurate for the lower end of the scale. The particle size distribution is presented in Table 4 and Figure 9.

Reynolds Longview (Ref. 10)

The second B-rated data set was obtained from a WDOE report produced to document compliance testing at the Reynolds Metals Company, Longview, Washington primary aluminum reduction plant. This facility incorporates HSS reduction cells. The purpose of the testing was to measure fugitive particulate emissions and gas velocity distribution across the roof monitor, and to compare two different methods for measuring fluorides. Testing was performed in February 1982.

The north plant has three potlines, with a combined capacity of 140,000 ton/yr (127,000 Mg/yr). The total output of the north and south plants is 210,00 ton/yr (191,000 Mg/yr). Each potline has four rows of 168 cells in two potrooms, or two 42-cell rows per potroom for a plant total of 504 cells. The potrooms have sidewall and basement ventilation. This facility was constructed in 1968.

The HSS cells are elevated slightly above the floor and have total-enclosure hooding with mechanically operated aluminum doors extending the full length of both sides of each cell. Pollutants continuously escape from the top of the cell enclosure and also from the hood doors when they are open. The doors have to be opened frequently to add Al_2O_3 to the Na_3AlF_6 bath by working the cell, to tap the molten layer from beneath the bath, and to insert and remove studs from the anode block while raising the flexible current connectors.

Four ducts, two on each end of each cell, pick up the primary exhaust from the top of the cell hooding enclosure and carry it to a manifold duct. One manifold handles primary exhaust from 14 cells, at a flowrate of 3,500 ft^3/min (100 m^3/min). Spray towers were used for primary pollution control until 1975. Wet ESP's are presently used to control primary

TABLE 4. SUMMARY OF ACCEPTABLE DATA

			Cumulative mass percent less than stated size (in microns)							
Plant/type	Emission source	Run	0.625	1.25	2.5	5	10	15	Data Rank	Reference
Kaiser Mead/ prebake	Fugitive (roof monitor)	1	12	17	22	27	36	42	B	9
		2	8	10	14	21	29	35	B	
		3	14	19	25	32	45	53	B	
		Average	11	15	20	27	37	43		
Reynolds Longview/ HSS	Fugitive (roof monitor)	1	8	13	17	23	31	39	B	10
ALCOA Vancouver/ prebake	Fugitive (roof monitor)	1	11	13	19	30	43	52	B	11
		2	13	16	22	34	48	57	B	
		Average	12	15	21	32	46	55		
ALCOA Badin/ prebake	Fugitive (roof monitor)	Average of 20 short runs	17	25	43	70	91	96	B	12
Kaiser Tacoma/ HSS	Reduction cell (uncontrolled)	Average of 140 short runs	26	32	40	50	58	63	B	13

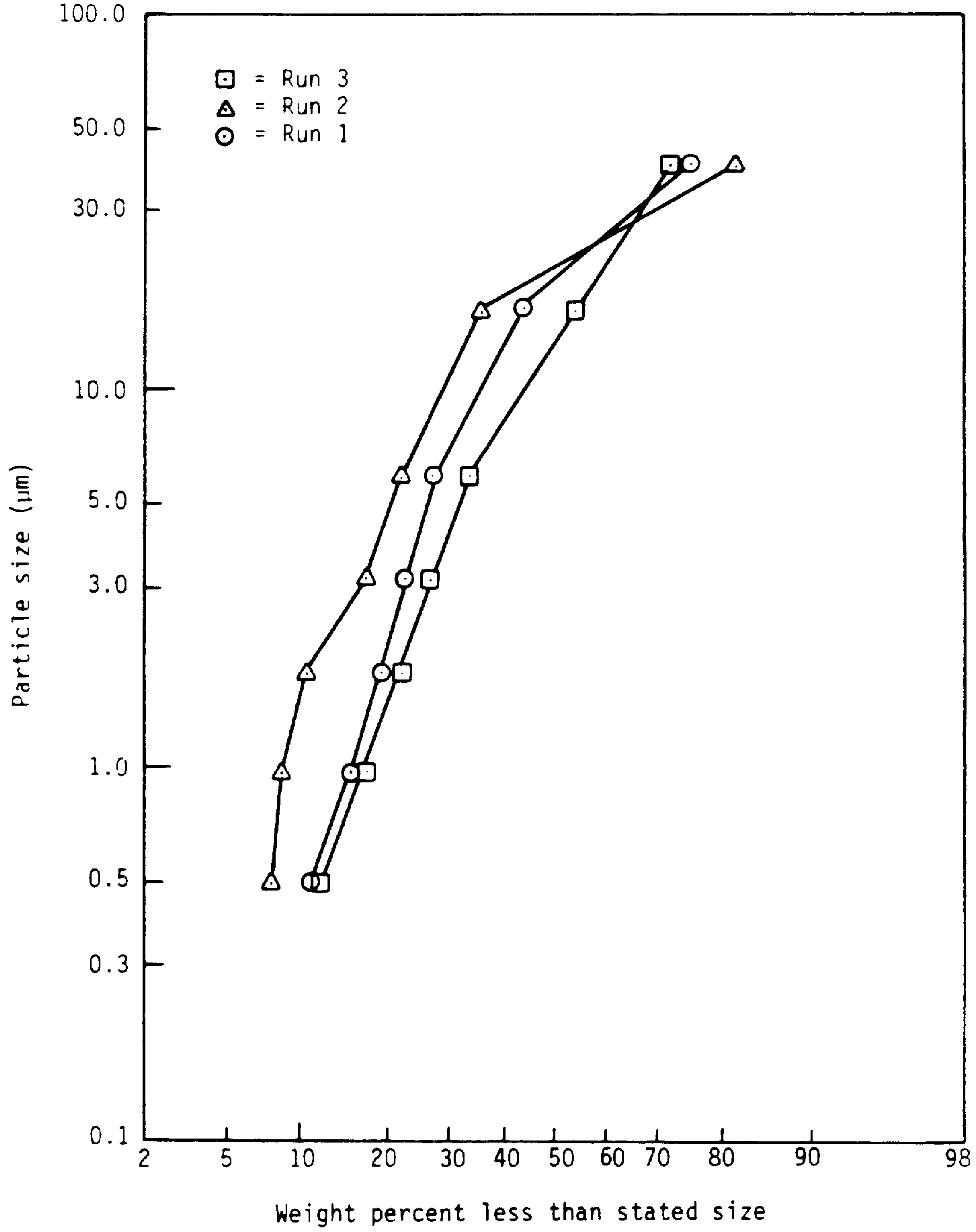

Figure 9. Particle size distribution for fugitive roof monitor emissions from the Kaiser Mead prebake aluminum plant.

emissions from the cells. Estimated control efficiency for the north plant primary control system is 90 percent. There is one sampling site on each ESP stack. There are three sampling sites evenly separated on each roof monitor.

All emissions not captured by the total enclosure hood are vented by convection through the secondary system, or roof monitors, which have no control. Each potroom has a roof monitor which is a hood opening 8 ft (2.4m) wide by 1,360 ft (415m) long running down the center of the roof. Three particulate/fluoride tests, which lasted approximately 1 day, were run at the potroom 52 center location, and on the final day a particle size test was run at the potroom 52 north location using the University of Washington Mark III Impactor. However, the particle size percent isokinetic sampling flowrate was not reported since the average velocity through the roof monitor was only 1.2 mps (4 fps) sampling was essentially for ambient particulate. As a result, the data can only be considered B quality, without a percent isokinetic sampling flowrate.

Each 1-day (24-hr) particulate/fluoride test set consisted of four samples, collected by four sampling trains separated by 2-ft (0.6m) intervals across the width of the roof monitor. Four samplers were used to determine differences in particulates. Two different types of particulate/fluoride sampling trains were used. The front half or nozzle and filter portions of the trains were identical in configuration, and consisted of a standard 0.500-in. (1.3-cm) ID nozzle followed by a filter-holder containing a preweighed 1.8-in. (47-mm) acetate filter. Particulate concentrations were determined by the particulate weight gains of the filter and a 50 percent aliquot of the nozzle rinse. The other 50 percent of the nozzle rinse, as well as the particulate filters, were sent to the DOE laboratory for fluoride analysis.

Table 4 summarizes the B-rated data collected during this testing. The size distribution of the particulate matter emitted from the HSS plant is presented in Figure 10.

Alcoa Vancouver (Ref. 11)

Testing was performed at Alcoa's Vancouver aluminum plant by WDOE to determine particle sizes of fugitive emissions. The Vancouver facility is a prebake-type primary aluminum reduction facility located near the Columbia River, west of the city of Vancouver, Washington.

The plant has five potlines with 65 pots per room and two rooms per line. At the time of the test only two potlines were operating, producing approximately 133 tons (121 Mg) of aluminum per day. Emissions from the pots are collected by hoods and ducted to a reactor baghouse. There are five baghouses per potline and two stacks per baghouse. Prior to the baghouse, effluents from the pots are ducted to the reactors where they are passed through a fluid bed of Al_2O_3 for fluoride removal.

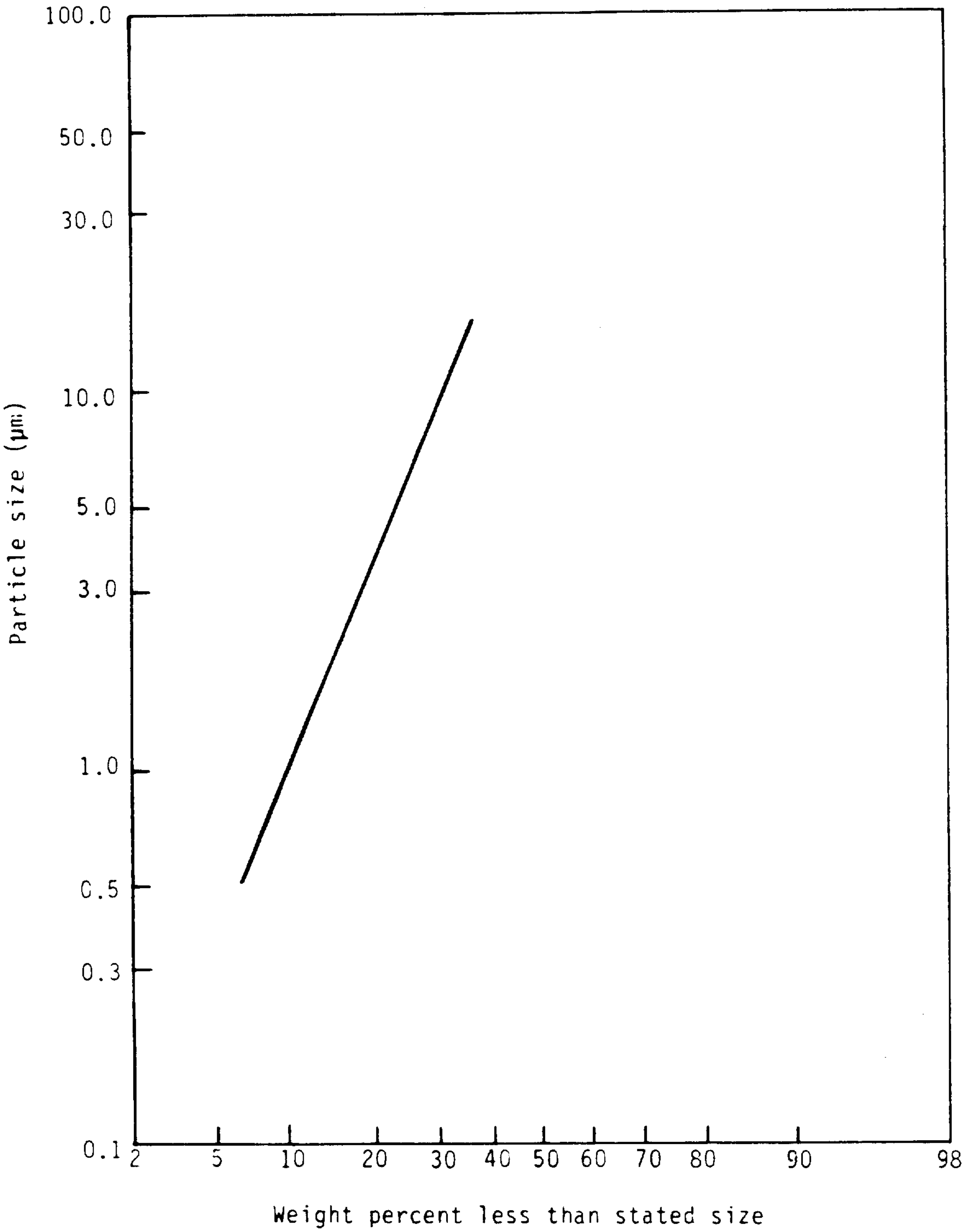

Figure 10. Particle size distribution for fugitive emissions from the Reynolds Longview HSS aluminum plant.

Most secondary emissions are released when the pots are drossed, tapped, or more Al_2O_3 is added. Emissions are carried to the ceiling by convection and released to the atmosphere through roof monitors. No control system is used with the roof monitors which are rectangular vents running the length of the roof of the potroom. On potroom no. 8, nine small diameter inlet ducts are connected and routed to a single 15-in. (38-cm) diameter stack located in the courtyard between potrooms no. 8 and 10 where samples were drawn for measurement of particulate and fluoride concentrations using EPA Method 14.

Three particle size samples were taken following WDOE Method 22. A University of Washington Mark III Impactor was used to collect all samples over a 50-hr period. Run 1 went from 12:10 to 21:30 on May 18, run 2 from 21:42 on May 18 to 12:06 on May 19, and run 3 from 12:12 on May 19 to 13:08 on May 20. For runs no. 1 and 2, the stainless steel substrates were coated with Apizon H grease to minimize particle bounce and reentrainment. No grease was used on run no. 3. Since it was noted that a large amount of loose material was in the first stage on run 3 and thought that some of the material may have migrated down from the other stages, Run 3 data was not included in the particle size determination. All three samples were taken at a point of near average velocity. Because of low stack temperature (about 90°F (32°C)) and the low moisture, the use of a heated probe and impingers for water collection was not required.

As with the other WDOE reports, percent isokinetic sampling rate values were not reported for this extremely low velocity stream. The overall procedure and equipment used, however, allow the particle sizing data for runs 1 and 2 to be ranked as B-quality.

Alcoa Badin (Ref. 12)

An extensive test program was carried out at Alcoa's Badin North Carolina prebake aluminum reduction facility to determine the size distribution of fugitive particulate exhausted through the potroom roof ventilator. The testing was carried out to develop a better understanding of the nature of the fugitive particulate and fluoride particulate matter, and to evaluate the accuracy of particulate determination from the monitor sampling manifold, EPA Method 14, which was developed primarily for determining fluoride emissions.

The aluminum reduction process at the Badin plant is similar to the process outlined for prebake reduction facilities in Section 2.1.2, but detailed process and emission control information was unavailable.

Testing was performed at the Badin facility using an Andersen In-Stack Cascade Impactor and a Bausch and Lomb analyzer. The Andersen sampler is an aerodynamic particle sizer with nine jet plates that divide the sample into eight fractions of particle sizes by weight and requires a lengthy sampling period of several hours. It does not lend itself to the sampling of the various short duration tasks conducted in a potroom but is well suited for long duration sampling. Since short duration task data was considered important, the Bausch and Lomb analyzer was also used. That analyzer consisted of a Bausch and Lomb Model 1300 ERC aerosol diluter and Model 40-1 particle counter, modified by the attachment of a multichannel electronic counter system, enabling the counting of particles in eight size fractions simultaneously.

The data gathered with the Bausch and Lomb was not considered for inclusion with the rest of the data since that equipment used an optical method for particle sizing. The data from the Andersen Impactor sampling was reduced and presented in limited tabular and graphical form. A search to obtain a more primary source of test data was fruitless. Due to the limited documentation available, these fugitive roof monitor emissions could only be considered as B-quality.

Kaiser Tacoma (Ref. 13)

Testing at the Kaiser Aluminum and Chemical Corporation's Tacoma, Washington aluminum facility was initiated as a research project by the University of Washington to aid in the design of emission control equipment.

The Tacoma facility incorporates HSS reduction cells, however, process and production information at the time of the test were not provided.

Testing was performed with a University of Washington Mark II Cascade Impactor. A total of 140 particle size distribution tests of 4 to 6 minutes in duration were conducted and a composite size distribution curve was produced, taking into account the percentage of time each cell operation takes during a day.

Figure 11 is the B-rated emission factor particle size curve for fugitive emissions in prebake plants and was obtained by taking an arithmetic average of the cut points of interest. Figure 12 illustrates the emission factor particle size curve for primary uncontrolled emissions from an HSS reduction cell.

An additional five data sets were reviewed for inclusion in this document but were rejected. In the Environmental Assessment Data System (EADS) Fine Paraticulate Emissions Inventory System (FPEIS) Series Report 139, three sets of fugitive emission particle size data were reported for the Reynolds Metal Company's Longview, Washington, plant which uses HSS aluminum reduction cells. A Nelson cascade impactor was used for particle sampling, but the sampling flowrate values were reported as being 194 to 197 percent (Ref. 14). These values were too excessive to allow use of the data.

EADS FPEIS Series Report 156 presented two sets of data for the Kaiser's Mead, Washington Prebake plant. The primary uncontrolled emissions from the prebake reduction cells were collected with a Nelson cascade impactor with sampling isokinetic flowrate values of 297 to 299 percent (Ref. 15). These values are also too excessive to allow use of the data.

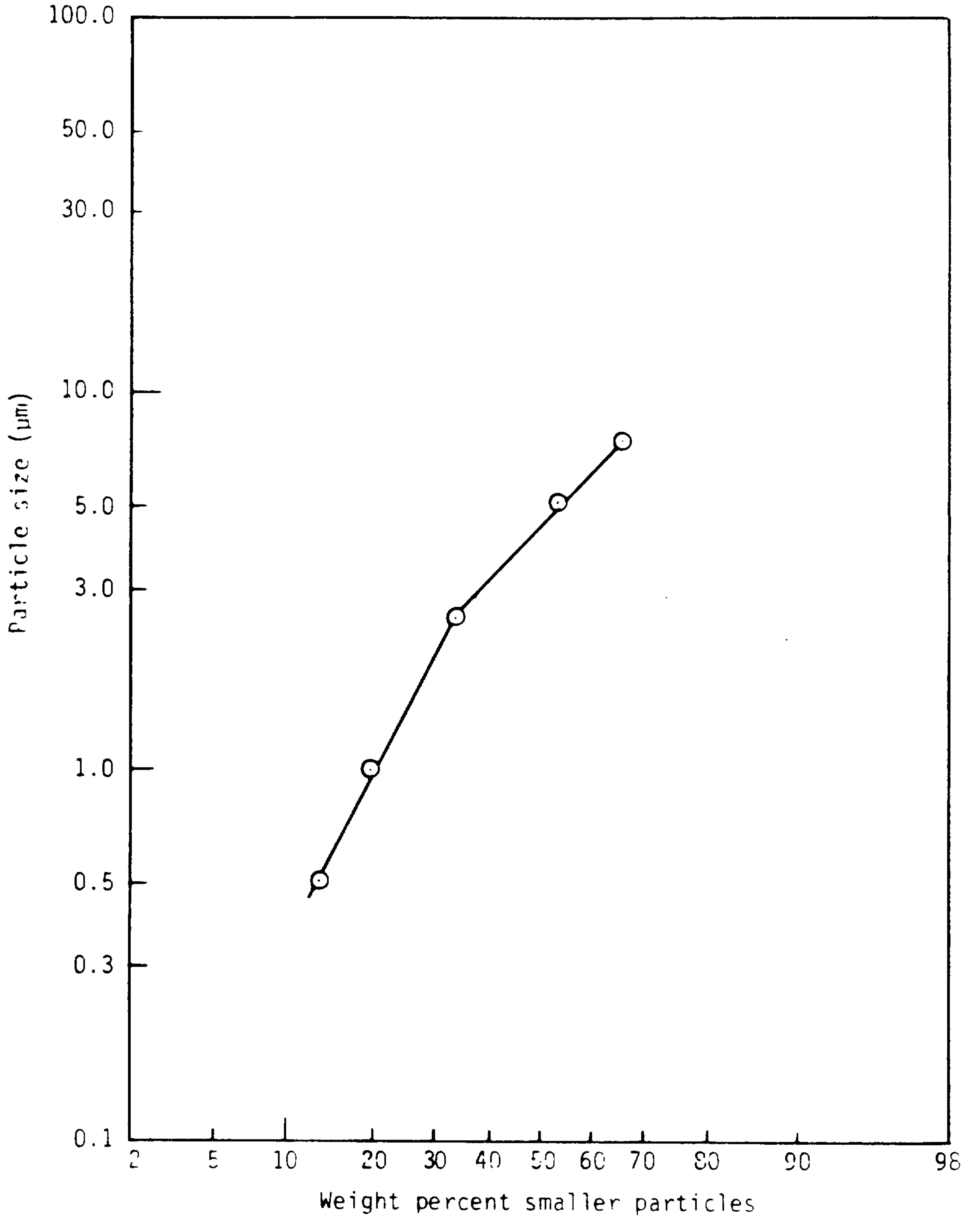

Figure 11. B-rated particle size distribution for fugitive roof monitor emissions from the Kaiser Mead prebake aluminum plants.

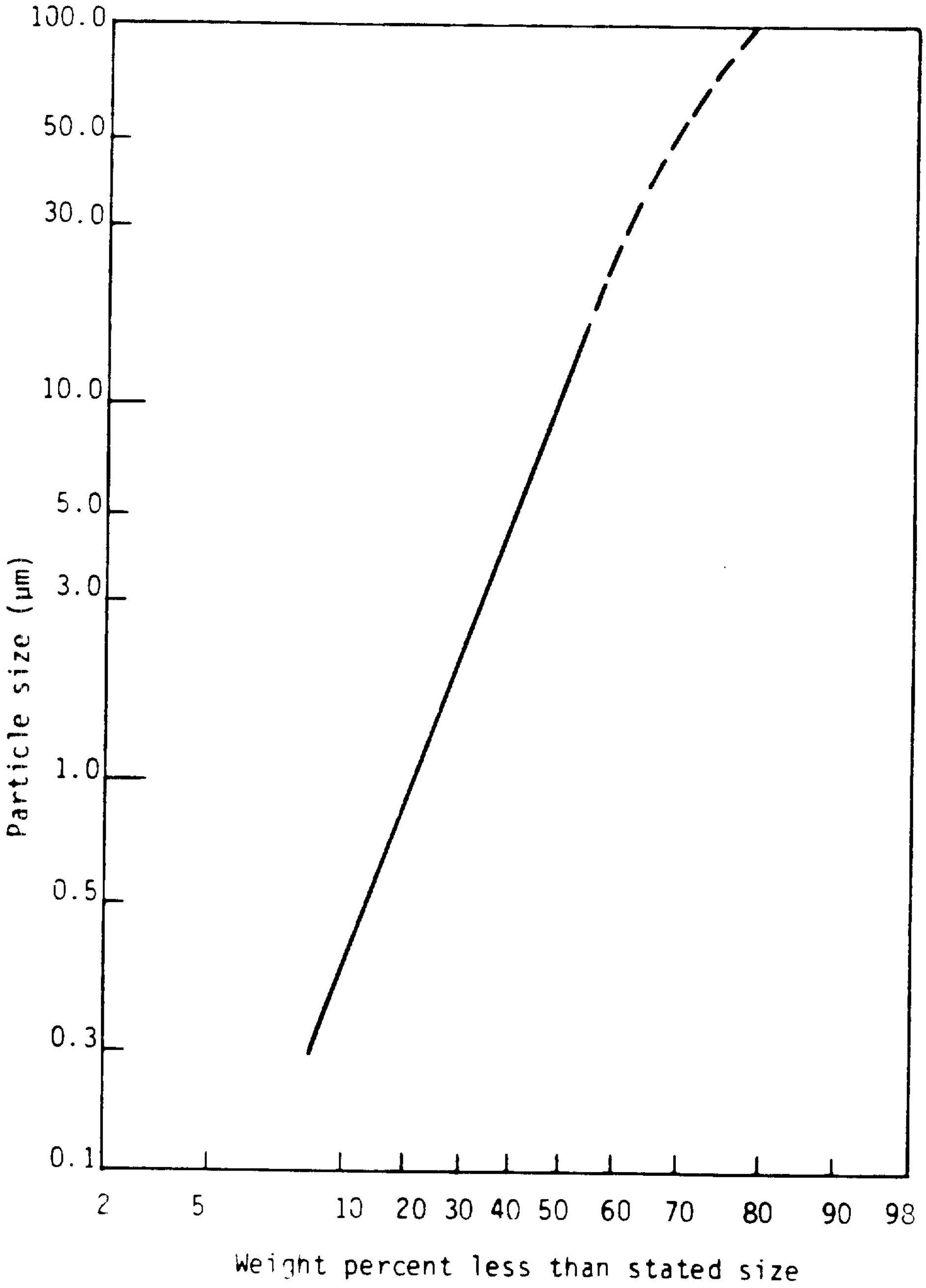

Figure 12. B-rated particle size distribution for primary uncontrolled emissions from an HSS reduction cell (Ref. 10).

2.2.2 Data Analysis

Size-specific emission factors have been developed for each of the aluminum production emission sources where sufficient data were available to produce an emission factor curve in Section 2.2.1 (these data are summarized in Table 5). The procedure used to develop the size-specific emission factors is discussed in this subsection.

Rating of Size-Specific Emission Factors

By combining the B-ranked test data for fugitive (roof monitor) emissions from prebake plants, coverage of prebake plants is sufficient to warrant a "C" rating for the developed cumulative size-specific emission factors by mass percent. The size-specific emission factors have been calculated by arithmetically averaging the B-rated size distribution data, developed in Section 2.2.1, at the cut points of interest (15, 10, 5, 2.5, 1.25, 0.625 µm). The cumulative mass percent less than the size of interest is then multiplied by the A-rated total emission factor presented in AP-42 and summarized in Table 6 to develop a C-rated size specific emission factor. Table 7 and Figure 13 present the C-rated size-specific emission factors.

Although B-ranked test data have been used to develop the cumulative size-specific emission factors by mass percent for fugitive (roof monitor) emissions from HSS aluminum reduction plants, the size-specific emission factors have been given a "D" rating, according to the criteria outlined in Section 1. The D rating was given because only one set of sizing test data was available although the total emission factor presented in AP-42 was A-rated. The specific emission factors may or may not be representative of the industry as a whole. Table 8 and Figure 14 present the D-rated size-specific emission factors for fugitive emissions from HSS aluminum reduction plants. The size-specific emission factors were calculated in the same manner as the prebake fugitive emission factors.

Finally, D-rated size-specific emission factors have been developed for the primary uncontrolled emissions from HSS aluminum reduction cells. The emission factors were given a D rating because the particle size distribution curve was obtained from an old report that had little particle sizing data process information for the tested facility, hence the representation of the industry as a whole by the emission factors could not be ensured.

The size-specific emission factors were once again calculated using the AP-42 total emission factors presented in Table 6. The analogous information for HSS aluminum reduction cells is presented in Table 9 and Figure 15.

A review of the size-specific emission factor development reveals a few interesting points:

- First, there are only a few published reports concerning particulate emissions from the aluminum industry, with even fewer test results available

TABLE 5. SUMMARY OF PARTICULATE EMISSION TEST DATA

Plant/type	Emission source	Control device[a]	Type of data[b]	Test date(s)	Test rating	Reference
Kaiser Mead/ prebake	Fugitive (roof monitor)	None	1,2	Mar 1982	A	9
Reynolds Longview/ HSS[c]	Fugitive (roof monitor)	None	1,2	Apr 1982	A	10
ALCOA Vancouver/ prebake	Fugitive (roof monitor)	None	1	May 1982	B	11
ALCOA Badin/ prebake	Fugitive (roof monitor)	None	1	NA[c]	B	12
Kaiser Tacoma/HSS	Reduction cell	Uncontrolled	1	NA[d]	B	13

[a] None -- Control device not normally used.
Uncontrolled -- Testing performed at sampling point prior to control devices.

[b] 1 -- Particle size distribution.
2 -- Total particulate (lb/ton Al).

[c] Reference 12 fails to state test dates but based on publication date, testing was conducted prior to June, 1976.

[d] Reference 13 fails to state test dates but based on publication date and information in the publication, testing commenced no earlier than 1968 and was completed no later than November 1970.

TABLE 6. EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[a]

EMISSION FACTOR RATING: A

	Total particulate[b]		Gaseous fluoride (HF)		Particulate flouride (F)		Sulfur oxides		
Operation	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Reference
Bauxite grinding									
Uncontrolled	3.0	6.0	Neg	Neg	NA	NA	NA	NA	2,3
Spray tower	0.9	1.8	Neg	Neg	NA	NA	NA	NA	2,3
Floating bed scrubber	0.85	1.7	Neg	Neg	NA	NA	NA	NA	2,3
Quench tower and spray scrubber	0.5	1.0	Neg	Neg	NA	NA	NA	NA	2,3
Electrostatic precipitator (ESP)	0.06	0.12	Neg	Neg	NA	NA	NA	NA	2,3
Aluminum hydroxide calcining									
Uncontrolled	100.0	200.0	Neg	Neg	NA	NA	NA	NA	2,3
Spray tower	30.0	60.0	Neg	Neg	NA	NA	NA	NA	2,3
Floating bed scrubber	28.0	56.0	Neg	Neg	NA	NA	NA	NA	2,3
Quench tower	17.0	34.0	Neg	Neg	NA	NA	NA	NA	2,3
ESP	2.0	4.0	Neg	Neg	NA	NA	NA	NA	2,3
Anode baking furnace									
Uncontrolled	1.5	3.0	0.45	0.9	0.05	0.1	[c]	[c]	4,10,11
Fugitive	NA	NA	NA	NA	NA	NA	NA	NA	
Spray tower	0.375	0.75	0.02	0.04	0.015	0.03	NA	NA	10
ESP	0.375	0.75	0.02	0.04	0.015	0.03	NA	NA	2
Dry alumina scrubber	0.03	0.06	0.0045	0.009	0.001	0.002	NA	NA	2,9
Prebake cell									
Uncontrolled	47.0	94.0	12.0	24.0	10.0	20.0	[c]	[c]	2,3,10,11
Fugitive	2.5	5.0	0.6	1.2	0.5	1.0	NA	NA	4,11
Emissions to collector	44.5	89.0	11.4	22.8	2.1	19.0	NA	NA	4
Multiple cyclones	9.8	19.6	11.4	22.8	9.5	4.2	NA	NA	4
Dry alumina scrubber	0.9	1.8	0.1	0.2	0.2	0.4	NA	NA	4,11
Dry ESP + spray tower	2.25	4.5	0.7	1.4	1.7	3.4	NA	NA	4,11
Spray tower	8.9	17.8	0.7	1.4	1.9	3.8	NA	NA	4
Floating bed scrubber	8.9	17.8	0.25	0.5	1.9	3.8	NA	NA	4
Coated bag filter dry scrubber	0.9	1.8	1.7	3.4	0.2	0.4	NA	NA	4
Cross flow packed bed	13.15	26.3	3.25	6.7	2.8	5.6	NA	NA	11
Dry + secondary scrubber	0.35	0.7	0.2	0.4	0.15	0.3	NA	NA	11
VSS cell									
Uncontrolled	39.0	78.0	16.5	33.0	5.5	11.0	NA	NA	4,11
Fugitive	6.0	12.0	2.45	4.9	0.85	1.7	NA	NA	11
Emissions to collector	33.0	66.0	14.05	28.1	4.65	9.3	NA	NA	11
Spray tower	8.25	16.5	0.15	0.3	1.15	2.3	NA	NA	4
Venturi scrubber	1.3	2.6	0.15	0.3	0.2	0.4	NA	NA	4
Multiple cyclones	16.5	33.0	14.05	28.1	2.35	4.7	NA	NA	4
Dry alumina scrubber	0.65	1.3	0.15	0.3	0.1	0.2	NA	NA	4
Scrubber + ESP + spray screen + scrubber	3.85	7.7	0.75	1.5	0.65	1.3	NA	NA	
HSS cell									
Uncontrolled	49.0	98.0	11.0	22.0	6.0	12.0	NA	NA	4,11
Fugitive	5.0	10.0	1.1	2.2	0.6	1.2	NA	NA	4,11
Emissions to collector	44.0	88.0	9.9	19.8	5.4	10.8	NA	NA	4,11
Spray tower	11.0	22.0	3.75	7.5	1.35	2.7	NA	NA	4,11
Floating bed scrubber	9.7	19.4	0.2	0.4	1.2	2.4	NA	NA	4
Scrubber + wet ESP	0.9	1.8	0.1	0.2	0.1	0.2	NA	NA	4,11
Wet ESP	0.9	1.8	0.5	1.0	0.1	0.2	NA	NA	11
Dry alumina scrubber	0.9	1.8	0.2	0.4	0.1	0.2	NA	NA	11

[a] For bauxite grinding, expressed as kg/Mg (lb/ton) of bauxite processed. For calcining of aluminum hydroxide, expressed as kg/Mg (lb/ton) of alumina produced. All other factors per Mg (ton) of molten aluminum product. Emission factors for sulfur oxides have C ratings. NA = not available.

[b] Includes particulate fluorides.

[c] Anode baking furnace, uncontrolled SO_2 emission (excluding furnace fuel combustion emissions):

20(C)(S)(1-0.01 K) kg/Mg [40(C)(S)(1-0.01 K) lb/ton]

Prebake (reduction) cell, uncontrolled SO_2 emissions

0.2(C)(S)(K) kg/Mg [0.4(C)(S)(K) lb/ton]

Where: C = Anode consumption* during electrolysis, lb anode consumed/lb Al produced
S = Percent sulfur in anode before baking
K = Percent of total SO_2 emitted by prebake (reduction) cells

*Anode consumption weight is weight of anode paste (coke + pitch) before baking.

TABLE 7. EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR FUGITIVE (ROOF MONITOR) EMISSIONS FROM PREBAKE ALUMINUM CELLS[a]

EMISSION FACTOR RATING: C

Particle size[b] (µm)	Cumulative mass % <stated size	Cumulative emission factors	
		kg/Mg Al	lb/ton Al
	Uncontrolled	Uncontrolled	Uncontrolled
15	65	1.62	3.23
10	58	1.45	2.90
5	43	1.08	2.15
2.5	28	0.70	1.40
1.25	18	0.46	0.92
0.625	13	0.33	0.67
Total	100	2.5	5.0

[a] References 9, 11, and 12
[b] Expressed as equivalent aerodynamic particle diameter

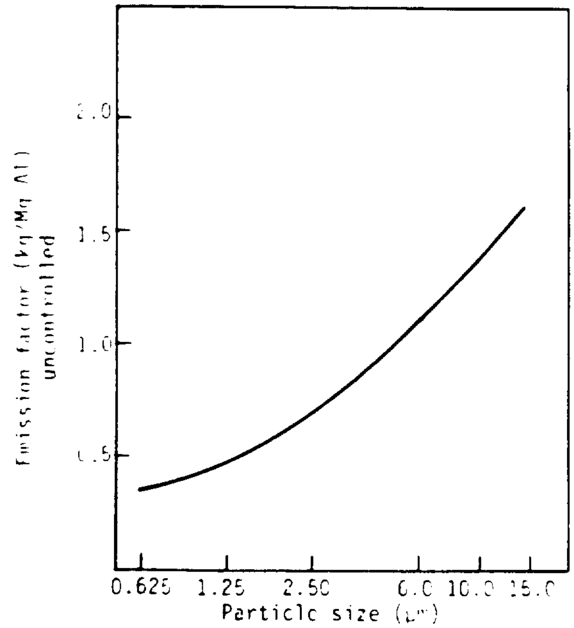

Figure 13. Cumulative emission factors less than stated particle size for fugitive emissions from prebake aluminum cells.

TABLE 8. EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR FUGITIVE (ROOF MONITOR) EMISSIONS FROM HSS ALUMINUM CELLS[a]

EMISSION FACTOR RATING: D

Particle size[b] (µm)	Cumulative mass % <stated size	Cumulative emission factors	
		kg/Mg Al	lb/ton Al
	Uncontrolled	Uncontrolled	Uncontrolled
15	39	1.95	3.9
10	31	1.55	3.1
5	23	1.15	2.3
2.5	17	0.85	1.7
1.25	13	0.65	1.3
0.625	8	0.40	0.8
Total	100	5.0	10.0

[a] Reference 10

[b] Expressed as equivalent aerodynamic particle diameter

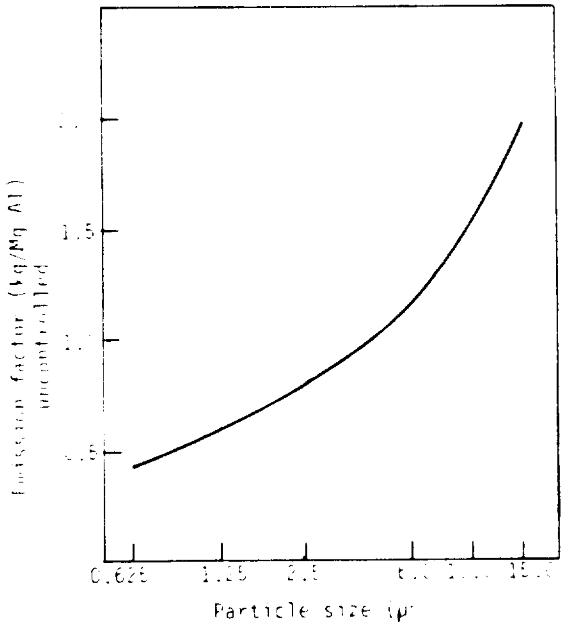

Figure 14. Cumulative emission factors less than stated particle size for fugitive emissions from HSS aluminum cells.

TABLE 9. EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR PRIMARY EMISSIONS FROM HSS REDUCTION CELLS[a]

EMISSION FACTOR RATING: D

Particle size[b] (μm)	Cumulative mass % <stated size	Cumulative emission factors	
		kg/Mg Al	lb/ton Al
	Uncontrolled	Uncontrolled	Uncontrolled
15	63	30.9	61.7
10	58	28.4	56.8
5	50	24.5	49.0
2.5	40	19.6	39.2
1.25	32	15.7	31.4
0.625	26	12.7	25.5
Total	100	49.0	98.0

[a] Reference 13

[b] Expressed as equivalent aerodynamic particle diameter

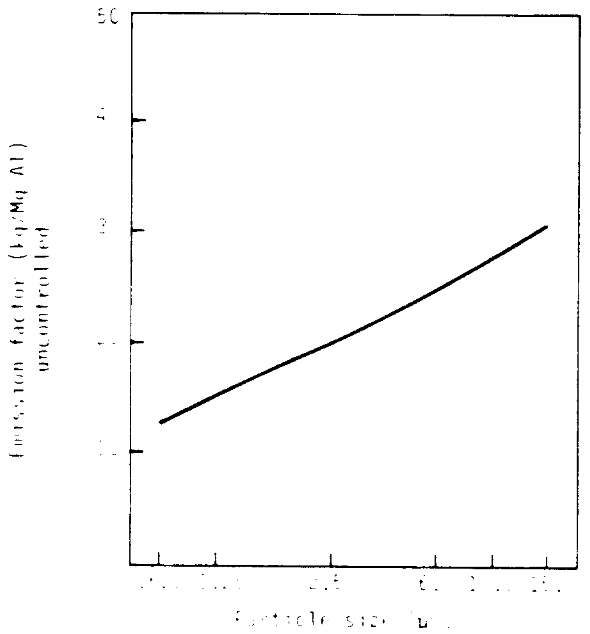

Figure 15. Cumulative emission factors less than stated particle size for primary emissions from HSS reduction cells.

- Second, those tests that have been performed are generally localized in the State of Washington

- Finally, no particle size or total particulate information was available for controlled emissions, except for the total particulate presented in AP-42, and repeated here in Table 6. It should be remembered, however, that roof monitor vents are typically several feet wide and at least a quarter mile long.

2.3 CHEMICAL CHARACTERIZATION

The largest particulate component is alumina. Fluoride components that have been identified include Na_3AlF_6, AlF_3, CaF_2, and chriolite ($Na_5Al_3F_{14}$). Other nonfluoride particulates are carbon, hydrocarbon tars, and iron oxides.

2.4 PROPOSED AP-42 SECTION -- PRIMARY ALUMINUM PRODUCTION