

12.8 Secondary Aluminum Operations

12.8.1 General¹

Secondary aluminum producers recycle aluminum from aluminum-containing scrap, while primary aluminum producers convert bauxite ore into aluminum. The secondary aluminum industry was responsible for 27.5 percent of domestic aluminum produced in 1989. There are approximately 116 plants with a recovery capacity of approximately 2.4 million megagrams (2.6 million tons) of aluminum per year. Actual total secondary aluminum production was relatively constant during the 1980s. However, increased demand for aluminum by the automobile industry has doubled in the last 10 years to an average of 78.5 kilograms (173 pounds) per car. Recycling of used aluminum beverage cans (UBC) increased more than 26 percent from 1986 to 1989. In 1989, 1.3 million megagrams (1.4 million tons) of UBCs were recycled, representing over 60 percent of cans shipped. Recycling a ton of aluminum requires only 5 percent of the energy required to refine a ton of primary aluminum from bauxite ore, making the secondary aluminum economically viable.

12.8.2 Process Description

Secondary aluminum production involves 2 general categories of operations, scrap pretreatment and smelting/refining. Pretreatment operations include sorting, processing, and cleaning scrap. Smelting/refining operations include cleaning, melting, refining, alloying, and pouring of aluminum recovered from scrap. The processes used to convert scrap aluminum to products such as lightweight aluminum alloys for industrial castings are presented in Figure 12.8-1A and Figure 12.8-1B. Some or all the steps in these figures may be involved at any one facility. Some steps may be combined or reordered, depending on scrap quality, source of scrap, auxiliary equipment available, furnace design, and product specifications. Plant configuration, scrap type usage, and product output varies throughout the secondary aluminum industry.

12.8.2.1 Scrap Pretreatment -

Aluminum scrap comes from a variety of sources. "New" scrap is generated by pre-consumer sources, such as drilling and machining of aluminum castings, scrap from aluminum fabrication and manufacturing operations, and aluminum bearing residual material (dross) skimmed off molten aluminum during smelting operations. "Old" aluminum scrap is material that has been used by the consumer and discarded. Examples of old scrap include used appliances, aluminum foil, automobile and airplane parts, aluminum siding, and beverage cans.

Scrap pretreatment involves sorting and processing scrap to remove contaminants and to prepare the material for smelting. Sorting and processing separates the aluminum from other metals, dirt, oil, plastics, and paint. Pretreatment cleaning processes are based on mechanical, pyrometallurgical, and hydrometallurgical techniques.

12.8.2.1.1 Mechanical Cleaning -

Mechanical cleaning includes the physical separation of aluminum from other scrap, with hammer mills, ring rushers, and other machines to break scrap containing aluminum into smaller pieces. This improves the efficiency of downstream recovery by magnetic removal of iron. Other recovery processes include vibratory screens and air classifiers.

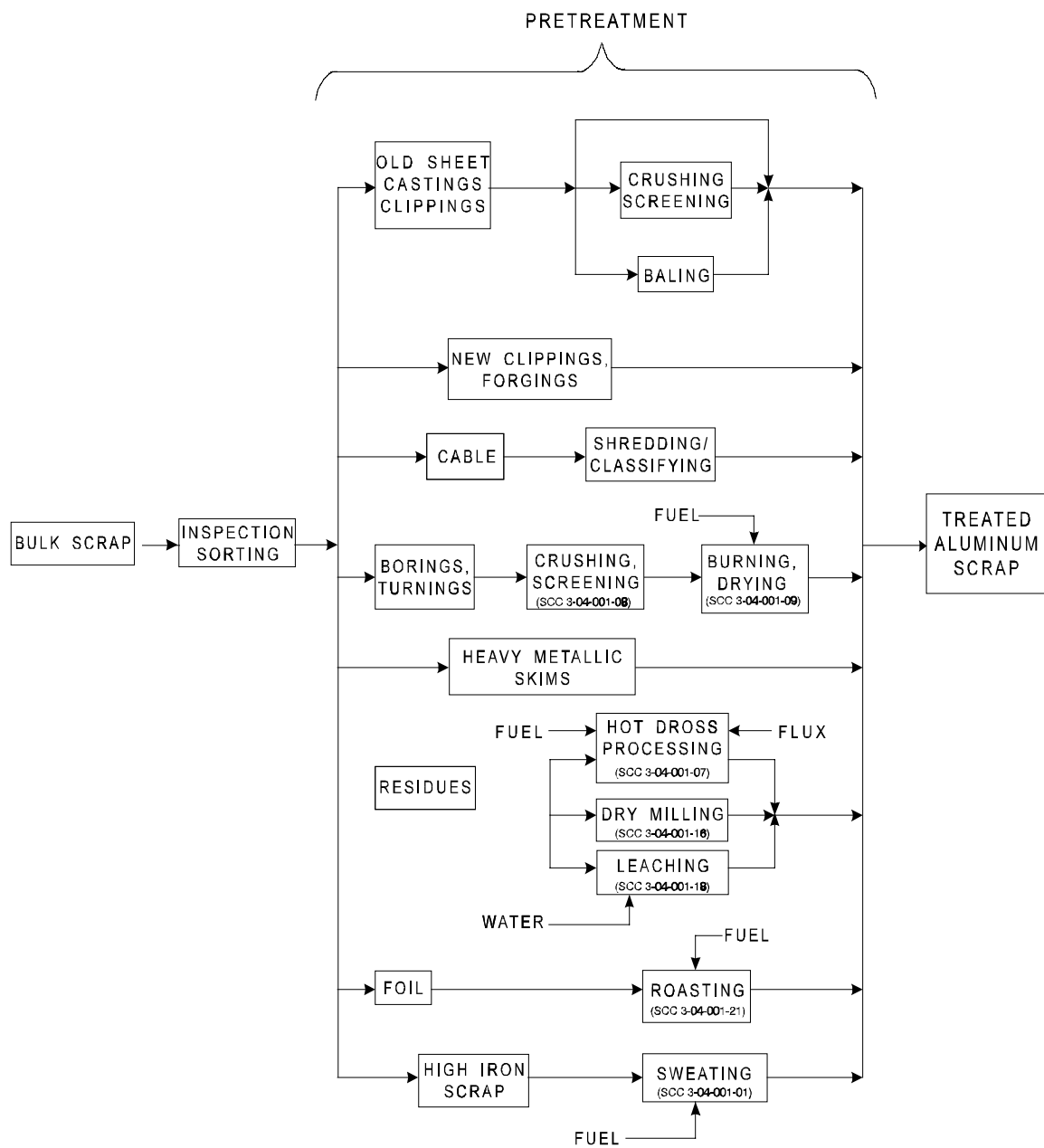


Figure 12.8-1A. Typical process diagram for secondary aluminum processing industry.
(Source Classification Codes in parentheses.)

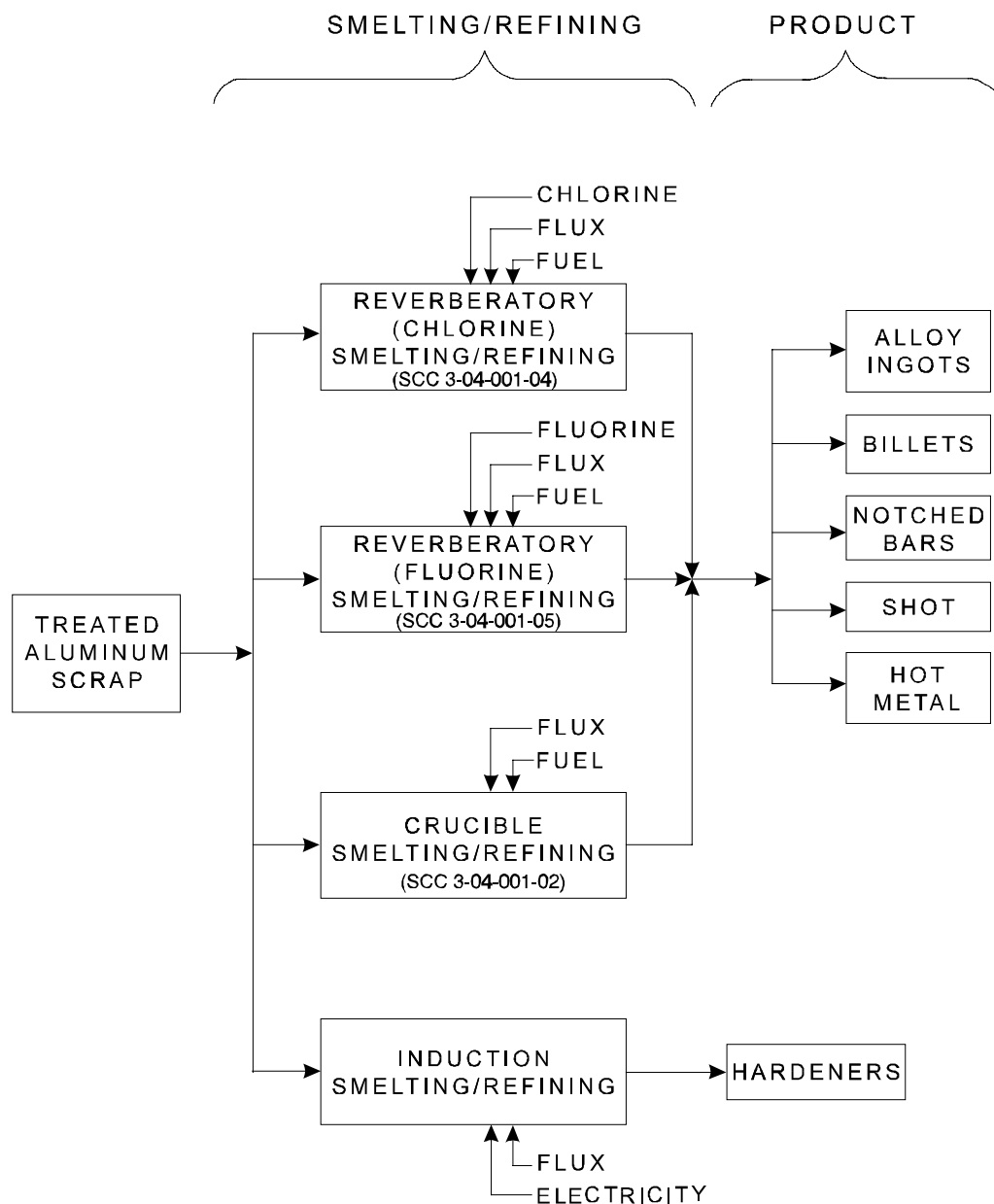


Figure 12.8-1B. Typical process diagram for secondary aluminum processing industry.
(Source Classification Codes in parentheses.)

An example of mechanical cleaning is the dry milling process. Cold aluminum-laden dross and other residues are processed by milling and screening to obtain a product containing at least 60 to 70 percent aluminum. Ball, rod, or hammer mills can be used to reduce oxides and nonmetallic particles to fine powders for ease of removal during screening.

12.8.2.1.2 Pyrometallurgical Cleaning -

Pyrometallurgical techniques (called drying in the industry) use heat to separate aluminum from contaminants and other metals. Pyrometallurgical techniques include roasting and sweating. The roasting process involves heating aluminum scrap that contains organic contaminants in rotary dryers to temperatures high enough to vaporize or carbonize organic contaminants, but not high enough to melt aluminum (660°C [1220°F]). An example of roasting is the APROS delacquering and preheating process used during the processing of used beverage cans (shown in Figure 12.8-2). The sweating process involves heating aluminum scrap containing other metals in a sweat furnace to temperatures above the melting temperature of aluminum, but below that of the other metal. For example, sweating recovers aluminum from high-iron-content scrap by heating the scrap in an open flame reverberatory furnace. The temperature is raised and maintained above the melting temperature of aluminum, but below the melting temperature of iron. This condition causes aluminum and other low melting constituents to melt and trickle down the sloped hearth, through a grate and into air-cooled molds or collecting pots. This product is called "sweated pig". The higher-melting materials, including iron, brass, and the oxidation products formed during the sweating process, are periodically removed from the furnace.

In addition to roasting and sweating, a catalytic technique may also be used to clean aluminum dross. Dross is a layer of impurities and semisolid flux that has been skimmed from the surface of molten aluminum. Aluminum may be recovered from dross by batch fluxing with a salt/cryolite mixture in a mechanically rotated, refractory-lined barrel furnace. Cryolite acts as a catalyst that decreases aluminum surface tension and therefore increases recovery rates. Aluminum is tapped periodically through a hole in the base of the furnace.

12.8.2.1.3 Hydrometallurgical Cleaning -

Hydrometallurgical techniques use water to clean and process aluminum scrap. Hydrometallurgical techniques include leaching and heavy media separation. Leaching is used to recover aluminum from dross, furnace skimmings, and slag. It requires wet milling, screening, drying, and finally magnetic separation to remove fluxing salts and other waste products from the aluminum. First, raw material is fed into a long rotating drum or a wet-ball mill where water soluble contaminants are rinsed into waste water and removed (leached). The remaining washed material is then screened to remove fines and undissolved salts. The screened material is then dried and passed through a magnetic separator to remove ferrous materials.

The heavy media separation hydrometallurgical process separates high density metal from low density metal using a viscous medium, such as copper and iron, from aluminum. Heavy media separation has been used to concentrate aluminum recovered from shredded cars. The cars are shredded after large aluminum components have been removed (shredded material contains approximately 30 percent aluminum) and processed in heavy media to further concentrate aluminum to 80 percent or more.

12.8.2.2 Smelting/Refining -

After scrap pretreatment, smelting and refining is performed. Smelting and refining in secondary aluminum recovery takes place primarily in reverberatory furnaces. These furnaces are brick-lined and constructed with a curved roof. The term reverberatory is used because heat rising

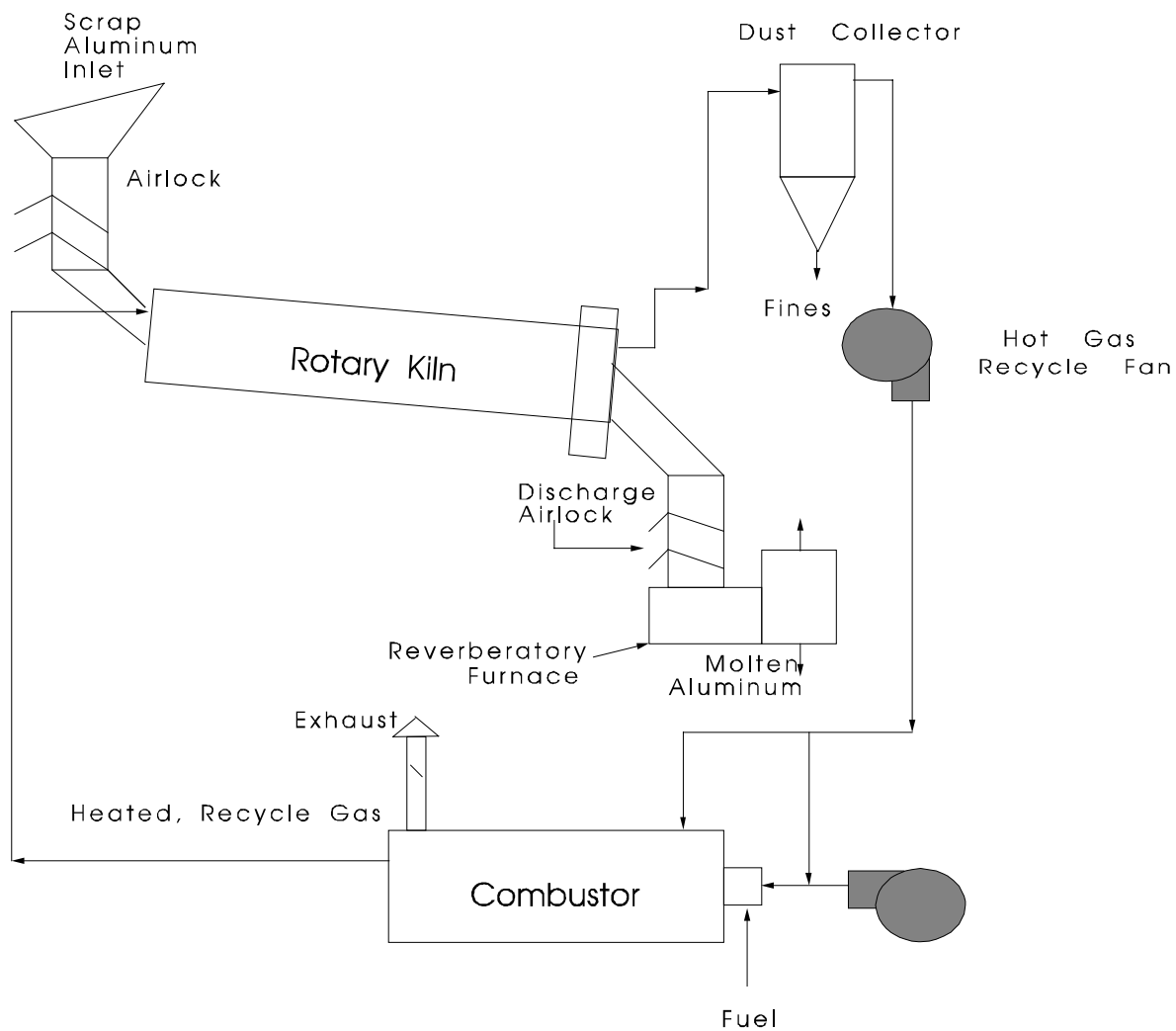


Figure 12.8-2. APROS delacquering and preheating process.

from ignited fuel is reflected (reverberated) back down from the curved furnace roof and into the melted charge. A typical reverberatory furnace has an enclosed melt area where the flame heat source operates directly above the molten aluminum. The furnace charging well is connected to the melt area by channels through which molten aluminum is pumped from the melt area into the charging well. Aluminum flows back into the melt section of the furnace under gravity.

Most secondary aluminum recovery facilities use batch processing in smelting and refining operations. It is common for 1 large melting reverberatory furnace to support the flow requirements for 2 or more smaller holding furnaces. The melting furnace is used to melt the scrap, and remove impurities and entrained gases. The molten aluminum is then pumped into a holding furnace. Holding furnaces are better suited for final alloying, and for making any additional adjustments necessary to ensure that the aluminum meets product specifications. Pouring takes place from holding furnaces, either into molds or as feedstock for continuous casters.

Smelting and refining operations can involve the following steps: charging, melting, fluxing, demagging, degassing, alloying, skimming, and pouring. Charging consists of placing pretreated aluminum scrap into a melted aluminum pool (heel) that is maintained in melting furnaces. The scrap, mixed with flux material, is normally placed into the furnace charging well, where heat from the molten aluminum surrounding the scrap causes it to melt by conduction. Flux materials combine with contaminants and float to the surface of the aluminum, trapping impurities and providing a barrier (up to 6 inches thick) that reduces oxidation of the melted aluminum. To minimize aluminum oxidation (melt loss), mechanical methods are used to submerge scrap into the heel as quickly as possible. Scrap may be charged as high density bales, loosely packed bales, or as dry shredded scrap that is continuously fed from a conveyor and into the vortex section of the charging well. The continuous feed system is advantageous when processing uniform scrap directly from a drier (such as a delacquering operation for UBCs).

Demagging reduces the magnesium content of the molten charge from approximately 0.5 percent to about 0.1 percent (a typical product specification). In the past, when demagging with liquid chlorine, chlorine was injected under pressure to react with magnesium as the chlorine bubbled to the surface. The pressurized chlorine was released through carbon lances directed under the heel surface, resulting in high chlorine emissions.

A more recent chlorine aluminum demagging process has replaced the carbon lance procedure. Molten aluminum in the furnace charging well gives up thermal energy to the scrap as scrap is melted. In order to maintain high melt rates in the charging well, a circulation pump moves high temperature molten aluminum from the melt section of the reverberatory furnace to the charging well. Chlorine gas is metered into the circulation pump's discharge pipe. By inserting chlorine gas into the turbulent flow of the molten aluminum at an angle to the aluminum pump discharge, small chlorine-filled gas bubbles are sheared off and mixed rapidly in the turbulent flow found in the pump's discharge pipe. In actual practice, the flow rate of chlorine gas is increased until a slight vapor (aluminum chloride) can be seen above the surface of the molten aluminum. Then the flow rate is decreased until no more vapor is seen. It is reported that chlorine usage approaches the stoichiometric relationship using this process. Chlorine emissions resulting from this procedure have not been made available, but it is anticipated that reductions of chlorine emissions (in the form of chloride compounds) will be reported in the future.

Other chlorinating agents or fluxes, such as anhydrous aluminum chloride or chlorinated organics, are used in demagging operations. Demagging with fluorine is similar to demagging with chlorine, except that aluminum fluoride (AlF_3) is employed instead of chlorine. The AlF_3 reacts with

magnesium to produce molten metallic aluminum and solid magnesium fluoride salt that floats to the surface of the molten aluminum and is trapped in the flux layer.

Degassing is a process used to remove gases entrained in molten aluminum. High-pressure inert gases are released below the molten surface to violently agitate the melt. This agitation causes the entrained gasses to rise to the surface to be absorbed in the floating flux. In some operations, degassing is combined with the demagging operation. A combination demagging and degassing process has been developed that uses a 10 percent concentration of chlorine gas mixed with a nonreactive gas (either nitrogen or argon). The combined high-pressure gases are forced through a hand held nozzle that has a designed distribution pattern of hole sizes across the face of the nozzle. The resulting high turbulent flow and the diluted chlorine content primarily degasses the melt. Chlorine emissions resulting from this process are not available.

Alloying combines aluminum with an alloying agent in order to change its strength and ductility. Alloying agents include zinc, copper, manganese, magnesium, and silicon. The alloying steps include an analysis of the furnace charge, addition of the required alloying agents, and then a reanalysis of the charge. This iterative process continues until the correct alloy is reached.

The skimming operation physically removes contaminated semisolid fluxes (dross, slag, or skimmings) by ladling them from the surface of the melt. Skimming is normally conducted several times during the melt cycle, particularly if the pretreated scrap contains high levels of contamination. Following the last skimming, the melt is allowed to cool before pouring into molds or casting machines.

The crucible smelting/refining process is used to melt small batches of aluminum scrap, generally limited to 500 kg (1,100 lb) or less. The metal-treating process steps are essentially the same as those of reverberatory furnaces.

The induction smelting and refining process is designed to produce aluminum alloys with increased strength and hardness by blending aluminum and hardening agents in an electric induction furnace. The process steps include charging scrap, melting, adding and blending the hardening agent, skimming, pouring, and casting into notched bars. Hardening agents include manganese and silicon.

12.8.3 Emissions And Controls²⁻⁸

The major sources of emissions from scrap pretreatment processes are scrap crushing and screening operations, scrap driers, sweat furnaces, and UBC delacquering systems. Although each step in scrap treatment and smelting/refining is a potential source of emissions, emission factors for scrap treatment processes have not been sufficiently characterized and documented and are therefore not presented below.

Smelting and refining emission sources originate from charging, fluxing, and demagging processes. Tables 12.8-1 and 12.8-2 present emission factors for sweating furnaces, crucible furnaces, reverberatory furnaces, and chlorine demagging process.

Table 12.8-1 (Metric Units). PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS^a

Operation	Uncontrolled	EMISSION FACTOR RATING	Baghouse	EMISSION FACTOR RATING	Electrostatic Precipitator	EMISSION FACTOR RATING
Sweating furnace ^b (SCC 3-04-001-01)	7.25	E	1.65	E	ND	NA
Smelting						
Crucible furnace ^b (SCC 3-04-001-02)	0.95	E	ND	NA	ND	NA
Reverberatory ^c (SCC 3-04-001-03)	2.15	E	0.65 ^e	E	0.65	E
Chlorine demagging ^d (SCC 3-04-001-04)	500	E	25	E	ND	E

^a Reference 3. Emission factors for sweating and smelting furnaces expressed as kg/Mg of metal processed. For chlorine demagging, emission factor is kg/Mg of chlorine used. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Based upon averages of 2 source tests.

^c Uncontrolled, based on averages of 10 source tests. Standard deviation of uncontrolled emission factor is 1.75 kg/Mg (3.5 lb/ton), that of controlled emission factor is 0.15 kg/Mg.

^d Based on average of 10 source tests. Standard deviation of uncontrolled emission factor is 215 kg/Mg; that of controlled emission factor is 18 kg/Mg.

^e This factor may be lower if a coated baghouse is used.

Table 12.8-2 (English Units). PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS^a

Operation	Uncontrolled	EMISSION FACTOR RATING	Baghouse	EMISSION FACTOR RATING	Electrostatic Precipitator	EMISSION FACTOR RATING
Sweating furnace ^b (SCC 3-04-001-01)	14.5	E	3.3	E	ND	NA
Smelting						
Crucible furnace ^b (SCC 3-04-001-02)	1.9	E	ND	NA	ND	NA
Reverberatory ^c (SCC 3-04-001-03)	4.3	E	1.3 ^e	E	1.3	E
Chlorine demagging ^d (SCC 3-04-001-04)	1000	E	50	E	ND	NA

^a Reference 3. Emission factors for sweating and smelting furnaces expressed as lb/ton of metal processed. For chlorine demagging, emission factor is lb/ton of chlorine used. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Based upon averages of 2 source tests.

^c Uncontrolled, based on averages of 10 source tests. Standard deviation of uncontrolled emission factor is 3.5 lb/ton, that of controlled emission factor is 0.3 lb/ton.

^d Based on average of 10 source tests. Standard deviation of uncontrolled emission factor is 430 lb/ton; that of controlled emission factor is 36 lb/ton.

^e This factor may be lower if a coated baghouse is used.

12.8.3.1 Scrap Pretreatment Emissions -

Mechanical cleaning techniques involve crushing, shredding, and screening and produce metallic and nonmetallic particulates. Burning and drying operations (pyrometallurgic techniques) emit particulates and organic vapors. Afterburners are frequently used to convert unburned VOCs to carbon dioxide and water vapor. Other gases that may be present, depending on the composition of the contaminants, include chlorides, fluorides, and sulfur oxides. Specific emission factors for these gases are not presented due to lack of data. Oxidized aluminum fines blown out of the dryer by the combustion gases contain particulate emissions. Wet scrubbers or fabric filters are sometimes used in conjunction with afterburners.

Mechanically generated dust from rotating barrel dross furnaces constitutes the main air emission of hot dross processing. Some fumes are produced from the fluxing reactions. Fugitive emissions are controlled by enclosing the barrel furnace in a hood system and by ducting the emissions to a fabric filter. Furnace offgas emissions, mainly fluxing salt fume, are often controlled by a venturi scrubber.

Emissions from sweating furnaces vary with the feed scrap composition. Smoke may result from incomplete combustion of organic contaminants (e. g., rubber, oil and grease, plastics, paint, cardboard, paper) that may be present. Fumes can result from the oxidation of magnesium and zinc contaminants and from fluxes in recovered dross and skims.

In dry milling, large amounts of dust are generated from the crushing, milling, screening, air classification, and materials transfer steps. Leaching operations (hydrometallurgic techniques) may produce particulate emissions during drying. Particulate emissions from roasting result from the charring of carbonaceous materials (ash).

12.8.3.2 Smelting/Refining Emissions -

Emissions from reverberatory furnaces represent a significant fraction of the total particulate and gaseous effluent generated in the secondary aluminum industry. Emissions from the charging well consist of organic and inorganic particulate, unburned organic vapors, and carbon dioxide. Emissions from furnace burners contain carbon monoxide, carbon dioxide, sulfuric oxide, and nitrogen oxide. Furnace burner emissions are usually separated from process emissions.

Emissions that result from fluxing operations are dependent upon both the type of fluxing agents and the amount required, which are a function of scrap quality. Emissions may include common fluxing salts such as sodium chloride, potassium chloride, and cryolite. Aluminum and magnesium chloride also may be generated from the fluxing materials being added to the melt. Studies have suggested that fluxing particulate emission are typically less than 1 micrometer in diameter. Specific emission factors for these compounds are not presented due to lack of information.

In the past, demagging represented the most severe source of emissions for the secondary aluminum industry. A more recent process change where chlorine gas is mixed into molten aluminum from the furnace circulation pump discharge may reduce chlorine emissions. However, total chlorine emissions are directly related to the amount of demagging effort and product specifications (the magnesium content in the scrap and the required magnesium reduction). Also, as the magnesium percentage decreases during demagging, a disproportional increase in emissions results due to the decreased efficiency of the scavenging process.

Both the chlorine and aluminum fluoride demagging processes create highly corrosive emissions. Chlorine demagging results in the formation of magnesium chloride that contributes to fumes leaving the dross. Excess chloride combines with aluminum to form aluminum chloride, a

vapor at furnace temperatures, but one that condenses into submicrometer fumes as it cools. Aluminum chloride has an extremely high affinity for water (hygroscopic) and combines with water vapor to form hydrochloric acid. Aluminum chloride and hydrochloric acid are irritants and corrosive. Free chlorine that does not form compounds may also escape from the furnace and become an emission.

Aluminum fluoride (AlF_3) demagging results in the formation of magnesium fluoride as a byproduct. Excess fluorine combines with hydrogen to form hydrogen fluoride. The principal emissions resulting from aluminum fluoride demagging is a highly corrosive fume containing aluminum fluoride, magnesium fluoride, and hydrogen fluoride. The use of AlF_3 rather than chlorine in the demagging step reduces demagging emissions. Fluorides are emitted as gaseous fluorides (hydrogen fluoride, aluminum and magnesium fluoride vapors, and silicon tetrafluoride) or as dusts. Venturi scrubbers are usually used for gaseous fluoride emission control.

Tables 12.8-3 and 12.8-4 present particle size distributions and corresponding emission factors for uncontrolled chlorine demagging and metal refining in secondary aluminum reverberatory furnaces.

According to the VOC/PM Speciate Data Base Management System (SPECIATE) data base, the following hazardous air pollutants (HAPs) have been found in emissions from reverberatory furnaces: chlorine, and compounds of manganese, nickel, lead, and chromium. In addition to the HAPs listed for reverberatory furnaces, general secondary aluminum plant emissions have been found to include HAPs such as antimony, cobalt, selenium, cadmium, and arsenic, but specific emission factors for these HAPs are not presented due to lack of information.

In summary, typical furnace effluent gases contain combustion products, chlorine, hydrogen chloride and metal chlorides of zinc, magnesium and aluminum, aluminum oxide and various metals and metal compounds, depending on the quality of scrap charged.

Table 12.8-3 (Metric Units). PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR UNCONTROLLED REVERBERATORY FURNACES IN SECONDARY ALUMINUM OPERATIONS^a

Aerodynamic Particle Diameter (μm)	Particle Size Distribution ^b		Size-Specific Emission Factor ^c (kg/Mg)			
	Chlorine Demagging	Refining	Chlorine Demagging	EMISSION FACTOR RATING	Refining	EMISSION FACTOR RATING
2.5	19.8	50.0	99.5	E	1.08	E
6.0	36.9	53.4	184.5	E	1.15	E
10.0	53.2	60.0	266.0	E	1.30	E

^a References 4-5.

^b Cumulative weight percent is less than the aerodynamic particle diameter, μm .

^c Size-specific emission factor equals total particulate emission factor multiplied by particle size distribution (percent)/100. From Table 12.8-1, total particulate emission factor for chloride demagging is 500 kg/Mg chlorine used, and for refining, 2.15 kg/Mg aluminum processed.

Table 12.8-4 (English Units). PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR UNCONTROLLED REVERBERATORY FURNACES IN SECONDARY ALUMINUM OPERATIONS^a

Aerodynamic Particle Diameter (µm)	Particle size Distribution ^b		Size-Specific Emission Factor ^c (lb/ton)			
	Chlorine Demagging	Refining	Chlorine Demagging	EMISSION FACTOR RATING	Refining	EMISSION FACTOR RATING
2.5	19.8	50.0	199	E	2.16	E
6.0	36.9	53.4	369	E	2.3	E
10.0	53.2	60.0	532	E	2.6	E

^a References 4-5.

^b Cumulative weight percent is less than the aerodynamic particle diameter, µm.

^c Size-specific emission factor equals total particulate emission factor multiplied by particle size distribution (percent)/100. From Table 12.8-2, total particulate emission factor for chloride demagging is 1000 lb/ton chlorine used, and for refining, 4.3 lb/ton aluminum processed.

References For Section 12.8

1. *Mineral Commodity Summaries 1992*, U. S. Department Of The Interior, Bureau of Mines.
2. W. M. Coltharp, *et al.*, *Multimedia Environmental Assessment Of The Secondary Nonferrous Metal Industry*, Draft Final Report, 2 vols., EPA Contract No. 68-02-1319, Radian Corporation, Austin, TX, June 1976.
3. W. F. Hammond and S. M. Weiss, Unpublished Report On Air Contaminant Emissions From Metallurgical Operations In Los Angeles County, Los Angeles County Air Pollution Control District, July 1964.
4. Emission Test Data From Environmental Assessment Data Systems, Fine Particle Emission Information System (EPEIS), Series Report No. 231, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.
5. Environmental Assessment Data Systems, *op.cit.*, Series Report No. 331.
6. Danielson, John., "Secondary Aluminum-Melting Processes". *Air Pollution Engineering Manual*, 2nd Ed., U. S. Environmental Protection Agency, Washington, DC, Report Number AP-40, May 1973.
7. Secondary Aluminum Reverberatory Furnace, Speciation Data Base. U. S. Environmental Protection Agency. Research Triangle Park, NC, Profile Number 20101, 1989.
8. Secondary Aluminum Plant—General, Speciation Data Base. U. S. Environmental Protection Agency. Research Triangle Park, NC, Profile Number 90009, 1989.