R0364

SRC TR 81-504

SECOND DRAFT (REVISED)

# Information Profiles on Potential Occupational Hazards: Aluminum and Compounds

Center for Chemical Hazard Assessment
Syracuse Research Corporation
Merrill Lane
Syracuse, New York 13210

Contract No. 210-79-0030

March 1981

Prepared for:

National Institute for Occupational Safety and Health
5600 Fishers Lane
Rockville, Maryland 20857

## BIBLIOGRAPHIC INFORMATION

PB89-216238

Report Nos: SRC-TR-81-504

Title: Information Profiles on Potential Occupational Hazards: Aluminum and Compounds. Second Draft (Revised).

Date: Mar 81

Performing Organization: Syracuse Research Corp., NY. Center for Chemical Hazard Assessment.

Sponsoring Organization: *National Inst. for Occupational Safety and Health, Rockville, MD.

Contract Nos: PHS-NIOSH-210-79-0030

Supplementary Notes: Sponsored by National Inst. for Occupational Safety and Health, Rockville, MD.

NTIS Field/Group Codes: 57U, 57Y, 94D, 41I, 68G

Price: PC A11/MF A01

Availability: Available from the National Technical Information Service,
Springfield, VA. 22161

Number of Pages: 231p

Keywords: *Aluminum, *Industrial medicine, *Aluminum organic compounds, Exposure, Toxicity, Control equipment, Hazards, Toxicology, Chemical properties, Pathology, *Occupational safety and health, *Toxic substances.

Abstract: Information profiles are working papers used by the National Institute for Occupational Safety and Health to assist the Institute in establishing priorities. The profile summarizes data on organic and inorganic substances containing aluminum as the only metal. Each summary presents data on known and suspected health effects, the extent of worker exposure, physical and chemical properties and the industrial importance of the following aluminum compounds: aluminum metal, aluminum ammonium sulfate, aluminum chlorhydrate, aluminum chloride anhydrous, aluminum chloride hydrous, aluminum distearate, aluminum ethoxide, aluminum fluoride, aluminum hydride, aluminum hydroxide, aluminum nitrate, aluminum oxide, aluminum ortho-phosphate, aluminum potassium sulfate, aluminum silicate, aluminum sodium sulfate, aluminum sulfate, calcium aluminum silicate, diethylaluminum chloride, sodium aluminate, tri-n-butylaluminum, triethylaluminum, tri-n-hexylaluminum, triisobutylaluminum, tri-n-octylaluminum. Detailed literature searches are conducted to identify information to be used in the profile summaries.

# INTRODUCTION

An information profile is a working paper used by the National Institute for Occupational Safety and Health (NIOSH) to assist in establishing Institute priorities. It is an initial step in determining the need to develop comprehensive documents or to initiate research. Each profile summarizes data on known and suspected health effects, the extent of worker exposure, physical and chemical properties, and the industrial importance of individual chemicals and classes of chemicals. The profile may also be used by industry, labor, and the occupational health community as a synopsis of information on each subject and to identify possible health hazards associated with their workplaces.

Although detailed literature searches are conducted using computerized and manual searching techniques to identify pertinent and recent information, not all the literature obtained is incorporated in the report due to the summary nature of the profiles. Further, literature published after 1979 may not be included in these profiles because it was generally unavailable at the time the search was completed.

## TABLE OF CONTENTS

## I. SCOPE OF DOCUMENT AND SUMMARY OF MAJOR FINDINGS

### A. CLASS IDENTIFICATION

The compounds considered for inclusion in this report are all inorganic and organic substances containing aluminum as the only metal. The oxidation state of aluminum in its compounds is 3+ except under certain extreme conditions. All commercial aluminum compounds have an oxidation state of 3+.

### B. CHEMICALS TO BE ADDRESSED

Individual profiles have been prepared for the following aluminum compounds:

- Aluminum metal
- Aluminum ammonium sulfate
- Aluminum chlorhydrate
- Aluminum chloride, anhydrous
- Aluminum chloride, hydrous
- Aluminum distearate
- Aluminum ethoxide
- Aluminum fluoride
- Aluminum hydride
- Aluminum hydroxide
- Aluminum nitrate
- Aluminum oxide
- Aluminum ortho-phosphate
- Aluminum potassium sulfate
- Aluminum silicates
- Aluminum sodium sulfate
- Aluminum sulfate
- Calcium aluminum silicate
- Diethylaluminum chloride
- Sodium aluminate
- Tri-n-butylaluminum
- Triethylaluminum
- Tri-n-hexylaluminum
- Triisobutylaluminum
- Tri-n-octylaluminum

These compounds were deliberately selected for profiles on the basis that each is produced in commercial quantities of at least 1 million pounds per year. Significant biological data are available for only a few of these compounds.

## C. SUMMARY OF BIOLOGICAL ACTIVITY

### 1. Pharmacokinetic Considerations

The biological role of aluminum in mammals has not been clearly established, but aluminum is generally regarded as an essential metal. The pharmacokinetics of aluminum compounds are not well characterized. The presence of aluminum in human organs indicates that absorption of the metal occurs, and, within the range of usual intake, there is an apparent homeostatic regulation of tissue levels. Approximately 1-2% of an ingested dose of aluminum hydroxide is retained by humans, and inhalation exposure to alumina dust has been reported to increase blood aluminum levels 2-3 times the baseline value, but quantitative estimates for absorption of other aluminum compounds have not been published. Once absorbed into the body, aluminum is present in chelated form.

Studies of normal tissue distribution of aluminum in humans indicate that the highest concentrations are found in the lungs (approximately 200-300 mg/kg); most of the other organs are reported to contain 1/10 or less of this value (Norseth, 1979). Aluminum in the lung is probably a result of local deposition from inhaled air. Aluminum has been monitored in fetal and newborn blood, and newborn blood aluminum levels higher than maternal blood levels have been reported (Sorenson _et al_., 1974). If it can be confirmed that bioconcentration of aluminum occurs in the fetus, then this must be taken into consideration in the assessment of health risk for pregnant workers. Various diseases influence the aluminum concentration in organs (Sorenson _et al_., 1974). Elevated bone, brain, and muscle levels of aluminum have been observed in uremic patients on hemodialysis (Allfrey _et al_., 1976; Elliott _et al_., 1978; Ellis _et al_., 1979); in these cases which have limited occupational significance, the main sources of aluminum were its salts in the dialysate water, and aluminum hydroxide administered to control hyperphosphatemia. Crapper _et al_. (1973)

reported high brain levels of aluminum in patients with Alzheimer's disease (presenile dementia).

### 2. Effects of Major Concern

There is a paucity of information on the biological effects of many of the specific aluminum compounds addressed in this report. Several generalizations are evident, however. Excessive exposure to aluminum may result in expression of symptoms of toxicity, but there appear to be no major qualitative differences in the effects of various aluminum compounds (although soluble salts are much more toxic than insoluble compounds). The fact that structurally dissimilar aluminum compounds cause similar biological effects *in vivo* is most likely related to the conversion of the aluminum compound into chelates of similar nature. Animal and human studies suggest that the toxic effects of aluminum may result from phosphate depletion caused by binding of phosphate in the intestine (Ondreicka *et al.*, 1966; Thurston *et al.*, 1972; Sorenson *et al.*, 1974). Gross toxicity seen with high concentrations of aluminum (e.g., retarded growth, bone changes) may result from adverse effects on phosphate metabolism, and biochemical reactions in the body associated with phosphate utilization (particularly glycolysis and phosphorylation) appear to be easily affected by excess aluminum.

### A. Pulmonary Effects

Single intratracheal instillations of aluminum powder, aluminum oxide, and aluminum phosphate have produced pulmonary fibrosis in rodents after 3-6 months, but chronic exposure to aluminum via inhalation does not appear to be fibrogenic. Weekly intratracheal instillation of aluminum oxide dust for 15 weeks also produced lung fibrosis in hamsters. Three intratracheal inoculations of aluminum chlorhydrate at 3-day intervals caused acute respiratory broncholitis in rabbits, but no other histological changes.

Human occupational studies have established that pulmonary fibrosis may develop in workers exposed to aluminum powder, particularly those exposed to fine "pyro" powder. Workers engaged in the manufacture of aluminum oxide have reportedly experienced lung fibrosis accompanied by emphysema, but these effects have not been noted in the recent literature. Pulmonary effects were not noted in paint and ink manufacturing workers exposed to aluminum dust or in workers employed in the grinding of duraluminum propellers with calcined aluminum oxide abrasive. Human pulmonary fibrotic reactions caused specifically by aluminum-containing dusts other than aluminum metal or aluminum oxide have not been reported.

## B. Carcinogenicity, Mutagenicity, and Teratogenicity

Carcinogenic effects have not been observed in rats inoculated intrapleurally with single doses of aluminum oxide suspension or aluminum silicate, in hamsters that received weekly intratracheal instillations of aluminum oxide dust for 15 weeks, or in mice fed aluminum potassium sulfate orally for their lifetimes. Inhalation exposure to aluminum chlorhydrate for 12 months did result in lung irritation and granuloma formation in the lungs of rats and guinea pigs. Aluminum hydroxide and aluminum chlorhydrate have been reported to cause granuloma formation in guinea pigs after intradermal or subcutaneous injection. Injection-site sarcomas developed in mice inoculated with aluminum-dextran (Haddow and Horning, 1960), but this so-called "solid state" phenomenon has long been observed with several other metal complexes and inert materials.

Elemental aluminum and aluminum salts tested for mutagenicity in bacterial or mammalian systems failed to show positive effects.

Aluminum chloride has not shown significant teratogenic effects in rats, but is embryotoxic. Decreased spermatozoa counts and lowered sperm motility have been reported in rats following 6 months' oral exposure to aluminum chloride, and intratesticular injection of aluminum sulfate produced testicular degeneration in the same species.

## C. Other Effects

Elevated serum or tissue levels of aluminum have been correlated with toxic encephalopathy (Allfrey *et al.*, 1976; Elliott *et al.*, 1978) and osteomalacia and impaired bone mineralization (Ellis *et al.*, 1979) in dialysis patients, and with an increased prothrombin time in Bayer-process workers exposed to aluminum oxide dust.

Aqueous solutions of aluminum chloride and nitrate have been shown to be damaging to the skin of rabbits, rats, and guinea pigs following topical application, but aluminum chlorhydrate, hydroxide, and sulfate are without effect. The irritant aluminum solutions are more acid than the non-irritant compounds, but the pH of the test solutions does not appear to contribute to the pathological damage observed following application (Lansdown, 1973). Epidermal damage appears instead to be related directly to the deposition of aluminum in the keratin, which is enhanced by the acid solutions.

Intracranial injections of aluminum hydroxide and aluminum hydroxide gels have produced neurofibrillary degeneration and evidence of epilepsy in experimental mammals, but this route of exposure is difficult to correlate with human exposure.

## II. DATA FOR COMMERCIALLY IMPORTANT CHEMICALS NOT INDIVIDUALLY PROFILED

Other aluminum compounds that have or may have some commercial importance are presented in Tables 1, 2, and 3; these compounds were not treated in individual profiles. Table 1 lists synonyms, CAS numbers, RTECS numbers, and chemical structures; Table 2 presents chemical and physical properties; Table 3 lists production volumes and uses, and summarizes manufacturing processes, and Table 4 lists manufacturers of aluminum compounds.

All aluminum chemicals considered for selection, regardless of their commercial importance, are listed in the Appendix.

## Table 1. Aluminum Compounds

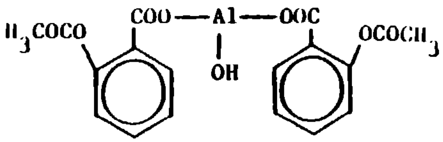
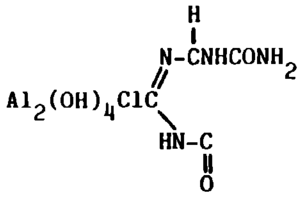
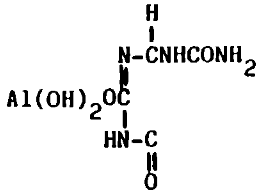
| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Aluminum acetate<br>Acetic acid, aluminum salt | 139-12-8<br>(triacetate)<br>142-03-0<br>(diacetate, subacetate, basic) | --- | $Al(C_2H_3O_2)_3$<br>$Al(OH)(COOCH_3)_2$ |
| Aluminum acetylacetonate<br>Aluminum, tris (2,4-pentanedionato-O,O')-, (OC-6-11)- | 13963-57-0 | BD2230000 | $Al(C_5H_7O_2)_3$ |
| Aluminum acetylsalicylate<br>Aluminum aspirin<br>Aluminum bis(acetylsalicylate)<br>bis[2-(Acetyloxy)-benzoato-O']hydroxyaluminum<br>Aluminum diacetylsalicylate | 147-31-9<br>29825-08-9<br>23413-80-1 | --- |  |
| Aluminum barium oxide<br>Barium aluminum oxide | 12004-04-5 | --- | $BaO \cdot Al_2O_3$ |
| Aluminum benzoate<br>Benzoic acid, aluminum salt | 555-32-8 | --- | $(C_6H_5COO)_3{}^{3-}Al^{3+}$ |
| Aluminum borate | 11121-16-7 | --- | $2Al_2O_3 \cdot B_2O_3$ |
| Aluminum boride<br>Aluminum diboride | 12041-50-8 | --- | $AlB_2$ |
| Aluminum borohydride<br>Aluminum tetrahydroborate | 16962-07-5 | --- | $Al(BH_4)_3$ |

Table 1. **Aluminum** Compounds (Cont'd.)

| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Aluminum sec-butoxide<br>Aluminum sec-butylate<br>2-Butanol, aluminum salt | 2269-22-9 | --- | $Al(OC_4H_9)_3$ |
| Aluminum bromide | 7727-15-3 (anhydrous)<br>7784-11-4 (hexahydrate) | BD0350000 | $AlBr_3$ |
| Aluminum tert-butoxide<br>2-Methyl-2-propanol, aluminum salt<br>2-Propanol, 2-methyl-, aluminum salt | 556-91-2 | --- | $Al(OC_4H_9)_3$ |
| Aluminum carbide | 1299-86-1 | --- | $Al_4C_3$ |
| Aluminum carbonate, basic | 1339-92-0 | --- | variable<br>$\approx Al_2O_3 \cdot CO_2$ |
| Aluminum Chelates:<br>1. Aluminum diisopropoxide acetoacetic ester chelate<br>2. Aluminim isopropoxide bis-(acetoacetic ester chelate)<br>3. Aluminim isopropoxide sterate acetoacetic ester chelate<br>4. Aluminum di-sec-butoxide acetoacetic ester chelate<br>5. Aluminum monoalkoxy chelates | | | |

Table 1. Aluminum Compounds (Cont'd)

| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Aluminum chlorhydroxy allantoinate<br>Alcloxa | 1317-25-5 | --- |  |
| Aluminum chromate(VI)<br>Chromic acid, aluminum salt | 54991-58-1 | --- | $xAl_2O_3 \cdot yCrO_3 \cdot zH_2O$<br>(where $x > y$) |
| Aluminum dihydroxy allantoinate<br>Aldioxa | 5579-81-7 | --- |  |
| Aluminum 2-ethylhexanoate<br>Aluminum octoate<br>α-Ethylcaproic acid, aluminum salt<br>Aluminum ethylhexoate | 6028-57-5 | --- | $[C_4H_9CH(C_2H_5)COO]_3Al$ |
| Aluminum formate<br>Formic acid, aluminum salts | 7360-53-4 (normal)<br>18748-09-0 (dibasic)<br>51575-25-8 (monobasic) | --- | $Al(OOCH)_3$<br>$(HO)_2Al(OOCH)$<br>$(HO)Al(OOCH)_2$ |
| Aluminum formoacetate | 61827-57-4 | --- | $Al(OH)(OOCH)(OOCCH_3)$ |

## Table 1. Aluminum Compounds (Cont'd)

| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Aluminum iodide | 7784-23-8 (anhydrous)<br>10090-53-6 (hexahydrate) | --- | $AlI_3$ |
| Aluminum isopropoxide<br>Aluminum isopropylate<br>2-Propanol, aluminum salt | 555-31-7 | BD0975000 | $Al[OCH(CH_3)_2]_3$ |
| Aluminum magnesium carbonate hydroxide<br>Magnesium aluminum carbonate hydroxide | 14492-59-2 | --- | $AlMg(CO_3)(OH)_3$ |
| Aluminum monostearate<br>Aluminum dihydroxy (octadecanoato-O)-<br>Aluminum monobasic stearate | 7047-84-9 | --- | $[CH_3(CH_2)_{16}COO]Al(OH)_2$ |
| Aluminum naphthenate<br>Naphthenic acid, aluminum salt | --- | --- | --- |
| Aluminum nitride | 24304-00-5 | --- | $AlN$ |
| Aluminum octanoate<br>Octanoic acid, aluminum salt<br>Caprylic acid, aluminum salt | 6028-57-5 | --- | $C_{16}H_{31}AlO_5$ |
| Aluminum oleate<br>Oleic acid, aluminum salt | 688-37-9 | --- | $Al(C_{18}H_{33}O_2)_3$ |
| Aluminum palmitate<br>Hexadecanoic acid, aluminum salt | 555-35-1 | --- | $[CH_3(CH_2)_{14}COO]Al(OH)_2$ |

### Table 1. Aluminum Compounds (Cont'd)

| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Aluminum phenolsulfonate<br>Aluminum sulfocarbolate<br>Aluminum 1-phenol-4-sulfonate | 1300-35-2 | --- | $Al_2(C_6H_4OHSO_3)_6$ |
| Aluminum meta-phosphates<br>Aluminum m-phosphate | 13776-88-0 | --- | $Al(PO_3)_3$ |
| Aluminum phosphide | 20859-73-8 | --- | AlP |
| Aluminum resinate<br>Resin acids, aluminum salt<br>Resin acids, aluminum salt | 61789-65-9 | --- | variable |
| Aluminum tristearate<br>Octadecanoic acid, aluminum salt | 637-12-7 | --- | $Al[OOC(CH_2)_{16}CH_3]_3$ |
| Calcium aluminate<br>Tricalcium aluminate<br>Aluminum calcium oxide | 12042-78-3 | --- | $3CaO \cdot Al_2O_3$ |
| Diethylaluminum ethoxide<br>DEAEO<br>Aluminum, diethylethoxy | 1586-92-1 | --- | $(C_2H_5)_2AlOC_2H_5$ |
| Diethylaluminum fluoride<br>DEAF<br>Aluminum, diethylfluoro- | 367-44-2 | --- | $(C_2H_5)_2AlF$ |
| Diethylaluminum hydride<br>Aluminum, diethylhydro- | 871-27-2 | --- | $(C_2H_5)_2AlH$ |

**Table 1. Aluminum Compounds (Cont'd)**

| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Diethylaluminum iodide<br>DEAI<br>Aluminum, diethyliodo- | 2040-00-8 | --- | $(C_2H_5)_2AlI$ |
| Diisobutylaluminum chloride<br>Aluminum, chlorobis (2-methylpropyl)-<br>DIBAC | 1779-25-5 | --- | $[(CH_3)_2CHCH_2]_2AlCl$ |
| Diisobutylaluminum hydride<br>Aluminum, hydrobis (2-methylpropyl)-<br>DIBAL-H | 1191-15-7 | --- | $[(CH_3)_2CHCH_2]_2AlH$ |
| Dimethylaluminum chloride<br>DMAC<br>Aluminum, chlorodimethyl | 1184-58-3 | --- | $(CH_3)_2AlCl$ |
| Ethylaluminum dichloride<br>EADC<br>Aluminum, dichloroethyl- | 563-43-9 | --- | $C_2H_5AlCl_2$ |
| Ethylaluminum sesquichloride<br>EASC<br>Aluminum, trichlorotriethyldi- | 12075-68-2 | --- | $(C_2H_5)_3Al_2Cl_3$ |
| Isobutylaluminum dichloride<br>IBADC<br>Aluminum, dichloro(2-methylpropyl)- | 1888-87-5 | --- | $[(CH_3)_2CHCH_2]AlCl_2$ |

## Table 1. Aluminum Compounds (Cont'd)

| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Isobutylaluminum sesquichloride<br>IBASC<br>Aluminum, trichlorotriisobutyldi- | --- | --- | $[(CH_3)_2CHCH_2]_3Al_2Cl_3$ |
| Isoprenylaluminum<br>Isoprenyl | --- | --- | --- |
| Lithium aluminate<br>Aluminate, lithium- | 12003-67-7 | --- | $LiAlO_2$ |
| Lithium aluminum hydride<br>Aluminate(1-), tetrahydro-, lithium<br>Lithium alanate<br>Lithium aluminohydride | 16853-85-3 | BD0100000 | $LiAlH_4$ |
| Magnesium aluminum silicate<br>Aluminosilicic acid, magnesium salt<br>Aluminum dimagnesium silicate | 1327-43-1 | --- | $2MgO \cdot Al_2O_3 \cdot SiO_2 \cdot H_2O$<br>(variable) |
| Methylaluminum sesquichloride<br>MASC<br>Aluminum, trichlorotrimethyldi- | 12541-85-7 | --- | $(CH_3)_3Al_2Cl_3$ |
| Sodium aluminum diethyl dihydride<br>OMH-1 Reducing Agent | --- | --- | --- |
| Tri-n-decylaluminum<br>Aluminum, tri-n-decyl<br>Tri-1-decylaluminum | 1726-66-5 | --- | $(C_{10}H_{21})_3Al$ |

**Table 1. Aluminum Compounds (Cont'd)**

| Compound and Synonyms | CAS Number | RTECS Number | Chemical Structure |
|---|---|---|---|
| Trimethylaluminum<br>ATM<br>Aluminum, trimethyl- | 75-24-1 | --- | $(CH_3)_3Al$ |
| Tri-2-methylpentylaluminum<br>Triisohexylaluminum | --- | --- | $(C_6H_{13})_3Al$ |
| Tripropylaluminum<br>Aluminum, tripropyl-<br>Tri-n-propylaluminum | 102-67-0 | --- | $(C_3H_7)_3Al$ |

## Table 2. Aluminum Compounds: Chemical and Physical Properties

| Compound | Description | Boiling Point (°C) | Melting Point (°C) | Vapor Pressure | Water Solubility[a] | Specific Gravity | Molecular Weight |
|---|---|---|---|---|---|---|---|
| Aluminum acetate (tri-) | white solid | ---[b] | decomp. | --- | very sl. sol. | --- | 204.12 |
| Aluminum acetylacetonate | colorless solid | 315 | 189 | --- | insol. | 1.27 | 324.31 |
| Aluminum acetylsalicylate | white to off-white powder or granules | --- | decomp. | --- | nearly insol. | --- | 402.30 |
| Aluminum barium oxide | solid | --- | --- | --- | --- | --- | 255.29 |
| Aluminum benzoate | crystalline powder | --- | --- | --- | very sl. sol. | --- | 390.30 |
| Aluminum borate | white granular powder | --- | 1050 | --- | nearly insol. | --- | 273.56 |
| Aluminum boride | copper-red solid | --- | 975 decomp. | --- | --- | 3.19 | 48.60 |
| Aluminum borohydride | volatile pyrophoric liquid | 44.5 | -64.5 | --- | decomp. | --- | 71.53 |
| Aluminum bromide (anhydrous) | white to yellow solid | 265 | 97.5 | --- | sol. with violence | 3.01 | 266.72 |
| Aluminum bromide (hexahydrate) | white to yellow solid | decomposes | 93 | --- | sol. | 2.54 | 374.80 |
| Aluminum *sec*-butoxide | yellow to white crystals | 160 (0.4 mm Hg) | 88-101.5 | --- | decomp. | 0.9671 | 246.33 |
| Aluminum *tert*-butoxide | powder | --- | sublimes (180°C) | --- | --- | --- | 246.33 |
| Aluminum carbide | yellow crystals or powder | --- | 2100 | --- | decomp. | 2.36 | 143.91 |
| Aluminum carbonate, basic | white solid | --- | --- | --- | insol. | --- | variable |
| Aluminum chlorhydroxy allantoinate | white to off-white powder | --- | --- | --- | insol. | --- | --- |
| Aluminum chromate | yellow amorphous salt | --- | --- | --- | --- | --- | variable |
| Aluminum dihydroxy allantoinate | white to off-white powder | --- | --- | --- | insol. | --- | --- |
| Aluminum 2-ethylhexanoate | solid | --- | --- | --- | --- | --- | 456.50 |
| Aluminum formate (normal) | white crystalline powder | --- | --- | --- | sl. sol. (cold)<br>25% sol. (boiling) | --- | 162.03 |
| Aluminum formoacetate | white powder | --- | --- | --- | sol. | --- | 148.05 |
| Aluminum iodide (anhydrous) | brownish-black pieces commercially | 382-385 | 191 | --- | sol. | 3.9825 | 407.73 |

## Table 2. Aluminum Compounds: Chemical and Physical Properties (Continued)

| Compound | Description | Boiling Point (°C) | Melting Point (°C) | Vapor Pressure | Water Solubility[a] | Specific Gravity | Molecular Weight |
|---|---|---|---|---|---|---|---|
| Aluminum isopropoxide | white solid | 138-148<br>(10 mm Hg) | 128-133 | --- | decomp. | 1.035 | 204.25 |
| Aluminum magnesium carbonate hydroxide | solid | --- | --- | --- | --- | --- | 130.31 |
| Aluminum monostearate | fine white to yellowish-white powder | --- | 155 | --- | insol. | 1.020 | 344.5 |
| Aluminum naphthenate | yellow substance, rubbery consistency | --- | --- | --- | --- | --- | --- |
| Aluminum nitride | bluish-white crystals | 2000<br>sublimes | >2200<br>(in $N_2$) | --- | decomp. | 3.26 | 40.99 |
| Aluminum octanoate | solid | --- | --- | --- | --- | --- | 474.4 |
| Aluminum oleate | yellowish-white viscous mass | --- | --- | --- | insol. | --- | 871.36 |
| Aluminum palmitate | white powder | --- | 200 | --- | insol. | 1.072 | 318.41 |
| Aluminum phenolsulfonate | reddish-white powder | --- | --- | --- | sol. | --- | 546.49 |
| Aluminum <u>meta</u>-phosphate, | white powder | --- | 1537 | --- | insol. | 2.779 | 263.90 |
| Aluminum phosphide | dark gray to dark yellow crystals | --- | >1000 | --- | decomp. | 2.85 | 57.96 |
| Aluminum resinate | brown solid | --- | --- | --- | insol. | --- | variable |
| Aluminum tristearate | white powder | --- | 115 | --- | insol. | 1.070 | 877.4 |
| Calcium aluminate | white crystals or powder | --- | decomposes<br>(1535°C) | --- | insol. | 3.038<br>(25°C) | 270.20 |
| Diethylaluminum ethoxide | --- | --- | --- | --- | --- | --- | 130.16 |
| Diethylaluminum fluoride | colorless liquid | 90-100<br>(1-2 mm Hg) | --- | --- | --- | --- | 104.11 |
| Diethylaluminum hydride | colorless pyrophoric liquid | 55-56<br>($10^{-3}$ to $10^{-4}$ mm Hg) | --- | --- | decomp. | 0.808<br>(20°C) | 86.11 |
| Diehylaluminum iodide | colorless liquid | 262 | --- | --- | --- | $1.5_{25}^{25}$ | 212.00 |
| Diisobutylaluminum chloride | colorless liquid | 152<br>(10 mm Hg) | -39.5 | --- | decomp. | 0.905 | 176.66 |

## Table 2. Aluminum Compounds: Chemical and Physical Properties (Continued)

| Compound | Description | Boiling Point (°C) | Melting Point (°C) | Vapor Pressure | Water Solubility[a] | Specific Gravity | Molecular Weight |
|---|---|---|---|---|---|---|---|
| Diisobutylaluminum hydride | colorless pyrophoric liquid | 105<br>(0.2 mm Hg) | -80 | --- | decomp. | 0.799 | 142.22 |
| Dimethylaluminum chloride | colorless liquid | 126-127 | -21 to -45 | --- | --- | 1.00 | 92.50 |
| Ethylaluminum dichloride | clear, yellow pyrophoric liquid | 194<br>(extrapolated) | 32 | --- | decomp. | 1.222 | 126.94 |
| Ethylaluminum sesquichloride | clear, yellow, pyrophoric liquid | 204 | -50 | --- | decomp. | 1.08 | 247.50 |
| Isobutylaluminum dichloride | liquid | 118<br>(10 mm Hg) | -29.8 | --- | --- | 1.1218 | 155.00 |
| Isobutylaluminum sesquichloride | --- | --- | --- | --- | --- | --- | 331.66 |
| Isoprenylaluminum | --- | --- | --- | --- | --- | --- | --- |
| Lithium aluminate | white powder | --- | 1900-2000 | --- | insol. | 2.55<br>(25°C) | 65.92 |
| Lithium aluminum hydride | white crystalline solid | --- | decomposes<br>(125°C) | --- | decomp. | 0.917 | 37.95 |
| Magnesium aluminum silicate | solid | --- | --- | --- | --- | --- | variable |
| Methylaluminum sesquichloride | colorless liquid | 143.7 | 22.8 | --- | decomp. | 1.1629 | 205.42 |
| Sodium aluminum diethyl dihydride | 25% solution in aromatic | --- | 60 | --- | --- | $0.878^{25}_{25}$ | --- |
| Tri-n-decylaluminum | --- | --- | --- | --- | --- | --- | 450.82 |
| Trimethylaluminum | colorless pyrophoric liquid | 126 | 15.4 | --- | --- | 0.752 | 72.09 |
| Tri-2-methylpentylaluminum | --- | --- | --- | --- | --- | --- | 282.49 |
| Tripropylaluminum | colorless pyrophoric liquid | 110<br>(13 mm Hg) | -84 | --- | --- | 0.820 | 156.25 |

[a] decomp. = decomposes; insol. = insoluble; sl. sol. = slightly soluble; sol. = soluble.

[b] "---" = information not readily available.

Table 3. Production Volumes, Uses, and Manufacturing Processes of Various Aluminum Compounds (Cont'd.)

| Compound | Production | Uses | Manufacturing Processes |
|---|---|---|---|
| Aluminum acetates | 1977: >0.1-1.0 million lb (U.S. EPA, 1980)<br>1958: 0.222 million lb (Stewart, 1963) | Water-proofing cloth; mordant in textile dyeing, preparation of lakes; embalming fluids; calico printing; treatment of dermititis (Hawley, 1977). | Reaction of aluminum salt with acetic acid or acetic anhydride and precipitating to obtain solid. An aqueous solution--Burow's solution--is also available (Stewart, 1963). |
| Aluminum acetylacetonate | Not available | Deposition of aluminum; catalyst (Hawley, 1977); chelating agent. | Not available. |
| Aluminum acetylsalicylate | Not available | In medicine as an analgesic and antipyretic (Hawley, 1977; The Merck Index, | Reaction of aluminum hydroxide with acetylsalicylic acid (Hawley, 1977). 1976). |
| Aluminum ammonium sulfate | 1977: 1-10 million lb (U.S. EPA, 1980) | Medicines; mordant in dyeing, water purification; dressing of skins (Darragh, 1978); sizing paper; ingredient in baking powder; food additive (Hawley, 1977). | By crystallization from a mixture of ammonium and aluminum sulfates or by treating aluminum sulfate and $H_2SO_4$ with $NH_3$ (Darragh, 1978). |
| Aluminum barium oxide | 1977: 1-11 thousand lb (U.S. EPA, 1980) | Catalysts; pigments (various patent literature). | By-product of barium metal production via barium oxide plus aluminum powder (Kunesh, 1978). |
| Aluminum benzoate | 1977: >1000 lb (U.S. EPA, 1980) | As an additive to prevent flocculation of copper phthalocyanine pigment (Moser, 1968); also, in gelling of hydrocarbons. | Not available. |
| Aluminum borate | Not available | Catalyst for polymerizations; in glass and ceramic manufacturing (Hawley, 1977; The Merck Index, 1976). | Interaction of $Al(OH)_3$ and boric acid (Hawley, 1977). |
| Aluminum boride | 1977: 0.1-1.0 million lb (U.S. EPA, 1980) | Refractories and cutting tools (Lawler, 1977); nuclear shielding (Hawley, 1977). | Reduction of mixtures of metallic and boron oxides with aluminum followed by purification (Wentorf, 1978). |
| Aluminum borohydride | Not available | Reducing agent; preparation of borohydrides of heavy metals; fuel for jet engines and rockets (The Merck Index, 1976). | (1) Reaction of sodium borohydride and $AlCl_3$ in the presence of tributyl phosphate.<br>(2) Reaction of trimethyl aluminum and diborane (Hawley, 1977). |
| Aluminum bromide | Not available | Bromination, alkylation, and isomerization catalyst in organic syntheses (Hawley, 1977). | Anhydrous--by passing $Br_2$ over heated Al; Hexahydrate--reaction of HBr with $Al(OH)_3$ (Hawley, 1977). |

Table 3. Production Volumes, Uses, and Manufacturing Processes of Various Aluminum Compounds (Cont'd.)

| Compound | Production | Uses | Manufacturing Processes |
|---|---|---|---|
| Aluminum sec-butoxide | Not available | Intermediate (Bretzinger and Josten, 1978). | Not available. |
| Aluminum tert-butoxide | 1977: under 1000 lb (U.S. EPA, 1980) | Reagent for oxidation of alcohols to ketones; in dealcoholation of ortho-esters (The Merck Index, 1976). | Prepared from aluminum tert-butyl alcohol and mercuric chloride (The Merck Index, 1976). |
| Aluminum carbide | Not available | Generating methane; catalyst; metallurgy; drying agent; reducing metal oxides; manufacturing aluminum nitride (Hawley, 1977; The Merck Index, 1976). | Heating $Al_2O_3$ and coke in an electric furnace (Hawley, 1977). |
| Aluminum carbonate, basic | Not available | Mild astringent and styptic (Hawley, 1977). | Not available. |
| Aluminum chelates | Not available | Curing of epoxy, phenolic, castor oil alkyds and high molecular weight polymers which are hydroxyl or carboxyl bearing; textile hydrophobing in solvent-based systems; adhesion promotion (Hawley, 1977). | Not available. |
| Aluminum chlorhydrate | 1977: ca. 11-60 million lb (U.S. EPA, 1980) | Antiperspirant deodorants (Isacoff, 1979); also, water purification and sewage treatment (Hawley, 1977). | Prepared by reacting hydrochloric acid with aluminum or salts (Marstiller, 1978). |
| Aluminum chlorhydroxy allantoinate | Not available | Used in antiperspirant deodorants, after shave lotions, acne and astringent preparations (Mecca, 1970). | Derived from allantoin (Mecca, 1970). |
| Aluminum chromate | 1977: 0-1000 lb (U.S. EPA, 1980) | Ceramic compositions (Hartford, 1979). | Precipitation of $AlCl_3$ with sodium chromate (Hartford and Copson, 1964). |
| Aluminum dihydroxy allantoinate | Not available | Used in diaper rash creams, lotions, compressed powders, talcums, etc. (Mecca, 1970). | Derived from allantoin by dissolving in NaOH and treating with aluminum chloride (Warner, 1978). |
| Aluminum distearate | 1978: 1.694 million lb (USITC, 1979) | Used most extensively as an agent to improve consistency of paints and varnishes; preparation of cosmetic gels and pomades; gasoline gelling agent (Warner, 1978); water repellent; in cement production (Hawley, 1977). | Reaction of sodium sterate with aqueous aluminum sulfate or chloride (Warner, 1978); the precipitate is filtered, washed, and dried. |
| Aluminum 2-ethylhexanoate | See aluminum octanoate | Gelling agent for liquid hydrocarbons as gasoline and common petroleum fractions used in coating thinners (Hawley, 1977). | Derived from 2-ethylhexoic acid (Hawley, 1977). |

Table 3. Production Volumes, Uses, and Manufacturing Processes of Various Aluminum Compounds (Continued)

| Compound | Production | Uses | Manufacturing Processes |
|---|---|---|---|
| Aluminum fluoride | 1978: 182 million lb (Gall, 1980) | Principal use as a make-up ingredient in the molten electrolyte of aluminum reduction cell and in the electrolytic process for refining aluminum; lower volume uses include incorporation into glass, glazes and enamels, and ceramics, in fluxes, in catalysts, and in production of aluminum silicate fiber (Gall, 1980). | Reaction of hydrofluoric acid or HF gas with alumina hydrate (Gall, 1980). |
| Aluminum formate | <1 million lb annually (SRC estimate) | Principal use is waterproofing formulations for textiles and other materials; dyeing mordant; fabric printing (Warner, 1978). | Reaction of 98% formic acid with an aluminum salt (Warner, 1978). |
| Aluminum formoacetate | Not available | In textile water repellents (Hawley, 1977). | Corroding Al metal with aqueous acetic and formic acids containing stabilizers. The solution is filtered and spray-dried (Toubes, 1963). |
| Aluminum iodide | 1977: <2000 lb (U.S. EPA, 1980) | Catalyst in organic reactions (*The Merck Index*, 1976; Marstiller, 1978). | Heating Al and iodine in a sealed tube (Hawley, 1977). |
| Aluminum isopropoxide | 1977: >0.1-1.0 million lb (U.S. EPA, 1980) | Selective reducing agent for aldehydes and ketones; intermediate for making aluminum salt and antiperspirants; paint additive for removing water; water resistance (Anderson and Thomas, 1963). | Reaction of aluminum and isopropyl alcohol in a distillation tower. Isopropoxide is separated and purified via distillation (Bretzinger and Josten, 1978). |
| Aluminum magnesium carbonate hydroxide | 1977: 0.1-1 million lb | Antacid (*The Merck Index*, 1976); in pigments and ceramics. | Not available. |
| Aluminum monostearate | 1974: 0.425 million lb (USITC, 1976) | Gelling agent in medicines; preparation of synthetic greases; in water repellent formulations; preparation of fiber lubricants (Warner, 1978). | Treating an aqueous solution of chlorodihydroxy aluminum with a sodium stearate solution (Warner, 1978). Precipitate is filtered, washed, and dried. |
| Aluminum naphthenate | Not available | Paint and varnish drier and bodying agent; detergent in lube oils (Hawley, 1977). | Reaction of an aluminum salt with an alkali naphthenate in aqueous solution (Hawley, 1977). |
| Aluminum nitride | 1977 import: 0-3000 lb (U.S. EPA, 1980) | In semiconductor electronics; in steel manufacturing (*The Merck Index*, 1976). | Arcing high-purity aluminum electrodes in a nitrogen atmosphere (Anderson and Haupin, 1978). |

Table 3. Production Volumes, Uses, and Manufacturing Processes of Various Aluminum Compounds (Continued)

| Compound | Production | Uses | Manufacturing Processes |
|---|---|---|---|
| Aluminum octanoate | 1977: >0.11-1.1 million lb<br>1977: 1-10 thousand lb (import)<br>(U.S. EPA, 1980) | Gelling agent (Warner, 1978). | Reaction of sodium 2-ethylhexanoate with aluminum sulfate (Warner, 1978). |
| Aluminum oleate | Not available | Waterproofing; paint drier; lube oil thickener; medicines; metal lacquer, plastic lubricant; food additive (Hawley, 1977). | Heating aluminum hydroxides, water, and oleic acid; then filtering and drying (Hawley, 1977). |
| Aluminum palmitate | <1 million lb annually (SRC Estimate) | Gelling agent (Warner, 1978); waterproofing; thickening lubricating oils, paints, and inks; production of high gloss on leather and paper; varnish component; food additive (Hawley, 1977). | Refluxing an isopropanol solution of aluminum isopropoxide and palmatic acid Warner, 1978). |
| Aluminum phenolsulfonate | Not available | Medicine (Hawley, 1977). | Not available. |
| Aluminum *meta*-phosphate | 1977: 10-100 thousand lb (U.S. EPA, 1980) | The *meta*-phosphate has uses as a constituent of glazes, enamels and glasses, and high temperature insulating cement (Hawley, 1977). | Not available. |
| Aluminum phosphide | 1977: 0.1-1.0 million lb (U.S. EPA, 1980) | Major use--fumigant; other--insecticide, source of phosphine, in semiconductor research (Hawley, 1977; *The Merck Index*, 1976). | Prepared from red phosphorus and aluminum powder (*The Merck Index*, 1976). |
| Aluminum resinate | 1977: >0.1-1.0 million lb (U.S. EPA, 1980) | Drier for varnishes (Hawley, 1977). | Heating soluble aluminum salts and resin (Hawley, 1977). |
| Aluminum tristearate | 1977: 297 thousand lb (USITC, 1978) | Gelling agent in cosmetics, pharmaceuticals, paints, greases, lubricants and petroleum fractions; dye improver; waterproofing cements and porous materials (Warner, 1978); additive for chewing gums (Hawley, 1977). | Reaction of aluminum isopropoxide and stearic acid in anhydrous pyridine; the tristearate precipitates as a pyridine complex and the pyridine is removed under vacuum (Warner, 1978). |
| Calcium aluminate | 1977: 1-10 thousand lb (U.S. EPA, 1980) | In refractory cements (Hawley, 1977) | Not available. |

## Table 3. Production Volumes, Uses, and Manufacturing Processes of Various Aluminum Compounds (Continued)

| Compound | Production | Uses | Manufacturing Processes |
|---|---|---|---|
| Diethylaluminum ethoxide | Not available | Catalyst in manufacturing of polyolefins and polydiolefins. | Not available. |
| Diethylaluminum fluoride | Not available | Catalyst. | Not available. |
| Diethylaluminum hydride | Not available | Catalyst reducing agent (Hawley, 1977). | Action of ethylene and hydrogen on aluminum (Hawley, 1977). |
| Diethylaluminum iodide | Not available | Catalyst | Not available. |
| Diisobutylaluminum chloride | 1974: 3.5 million lb for all isobutyl aluminum compounds (Cosslett and Gerry, 1976) | Polymerization co-catalysts in the manufacture of polybutadiene, polyisoprene, and polypropylene, 70%; alpha-olefin manufacture and transalkylations, 30% (Cosslett and Gerry, 1976). | Action of high purity isobutylene, hydrogen, and aluminum (Cosslett and Gerry, 1976). |
| Diisobutylaluminum hydride | 1974: 3.5 million lb for all isobutyl aluminum compounds (Cosslett and Gerry, 1976) | Polymerization co-catalysts in the manufacture of polybutadiene, polyisoprene, and polypropylene, 70%; alpha-olefin manufacture and transalkylations, 30% Cosslett and Gerry, 1976). | Action of high purity isobutylene, hydrogen, and aluminum (Cosslett and Gerry, 1976). |
| Dimethylaluminum chloride | Not available | Polymerization catalyst. | Prepared from methylaluminum sesquichloride (Anderson, 1963). |
| Ethylaluminum dichloride | Not available | Catalyst for olefin polymerization, aromatic hydrogenation; intermediate (Hawley, 1977). | Reaction of aluminum chloride with ethylaluminum sesquichloride (Hawley, 1977). |
| Ethylaluminum sesquichloride | Not available | Catalyst for olefin polymerization, aromatic hydrogenation; intermediate (Hawley, 1977). | Reaction of ethylchloride and aluminum (Hawley, 1977). |
| Isobutylaluminum dichloride | Not available | Catalyst. | Not available. |
| Isobutylaluminum sesquichloride | Not available | Catalyst; organoaluminum synthesis | Not available. |
| Isoprenylaluminum | Not available | Catalyst. | Not available. |
| Lithium aluminate | Not available | As a flux in high-refractory procelain enamels (Hawley, 1977). | Not available. |

Table 3. Production Volumes, Uses, and Manufacturing Processes of Various Aluminum Compounds (Continued)

| Compound | Production | Uses | Manufacturing Processes |
|---|---|---|---|
| Lithium aluminum hydride | 1977 import: 1-10 thousand lb (U.S. EPA, 1980) | Reducing agent for over 60 different functional groups, especially for pharmaceutical, perfume, and fine organic chemicals; converts esters, aldehydes, and ketones to alcohols, and nitriles to amines; sources of hydrogen; propellant; catalyst in polymerizations (Hawley, 1977). | Addition of a diethyl ether solution of $AlCl_3$ to a slurry of lithium hydride (Sullivan and Wade, 1980). |
| Magnesium aluminum silicate | 1977: 1-10 thousand lb (U.S. EPA, 1980) | Antacid (*The Merck Index*, 1976); in pigments and ceramics. | Not available. |
| Methylaluminum sesquichloride | Not available | Catalyst (Hawley, 1977); organoaluminum synthesis. | Prepared from methyl chloride and aluminum (Anderson, 1963). |
| Sodium aluminum diethyl dihydride | Not available | Reducing agent. | Not available. |
| Tri-n-decylaluminum | Not available | Catalyst; organic synthesis. | Not available. |
| Trimethylaluminum | Not available | Catalyst intermediate for polymerization of olefins, especially ethylene; pyrophoric fuels; production of alpha-olefins and long chain alcohols; gas plating of aluminum (Hawley, 1977). | By sodium reduction of dimethylaluminum chloride (Hawley, 1977). |
| Tri-2-methylpentylaluminum | Not available | Catalyst for polyolefins (Hawley, 1977). | Reaction of 2-methylpentane and isobutylaluminum (Hawley, 1977). |
| Tripropylaluminum | Not available | Polyolefin catalyst (Hawley, 1977). | Reaction of propylene and isobutylaluminum (Hawley, 1977). |

Table 4. Manufacturers of Aluminum Compounds (SRI International, 1980; U.S. EPA, 1980)

| Compound | Manufacturers |
|---|---|
| Aluminum acetate | American Cyanamid Co. (Woodbridge, NJ)<br>Union Carbide Corp. (Niagara Falls, NY)<br>CP Chemicals (Sewaren, NJ) |
| Aluminum acetylacetonate | MacKenzie Chem. Works (Bush, LA)<br>Shepherd Chem. Co. (Cincinnati, OH)<br>Chattem Chem. (Chattanooga, TN) |
| Aluminum acetylsalicylate | --- |
| Aluminum barium oxide | Barium and Chemicals (Steubenville, OH)<br>Great Western Inorganics (Golden, CO) |
| Aluminum benzoate | Exxon (Pittsburg, PA)<br>Harmon Colors Corp. (Hawthorne, NJ)<br>Chemetron Pigments (Holland, MI)<br>DuPont (Newark, NJ) |
| Aluminum boride | Shieldalloy Corp. (Newfield, NJ)<br>Cabot Corp. (Boyertown, PA)<br>Thiokol Corp. (Danvers, MA) |
| Aluminum borate | --- |
| Aluminum borohydride | --- |
| Aluminum bromide | Boulder Sci. (Boulder, CO)<br>Halocarbon Products (Hackensack, NJ) |
| Aluminum _sec_-butoxide | Chattem Chem. (Chattanooga, TN) |
| Aluminum _tert_-butoxide | Columbia Organics (Columbia, SC) |
| Aluminum carbide | --- |
| Aluminum carbonate | Revlon, Reheis Chem. (Berkeley Hgts., NJ) |
| Aluminum chelates | Chattem Chem. (Chattanooga, TN) |
| Aluminum chlorhydroxy allantionate | Carroll Prod., Schuylkill Chem. (Philadelphia, PA) |
| Aluminum chromate | Sermetel Inc. (Limerick, PA) |
| Aluminum dihydroxy allantoinate | Carroll Prod., Schuylkill Chem. (Philadelphia, PA) |
| Aluminum formate | Eastern Color and Chem. (Providence, RI)<br>Union Carbide Corp. (Niagara Falls, NY)<br>American Cyanamid (Woodbridge, NJ) |
| Aluminum formoacetate | --- |
| Aluminum iodide | Deepwater Chem. (Compton, CA) |
| Aluminum isopropoxide | Chattem Chem. (Chattanooga, TN)<br>Joseph Ayers Inc. (Bethlehem, PA) |

Table 4. Manufacturers of Aluminum Compounds (Cont'd.)
(SRI International, 1980; U.S. EPA, 1980)

| Compound | Manufacturers |
|---|---|
| Aluminum magnesium carbonate hydroxide | Reheis Chem. (Berkeley Heights, NJ) |
| Aluminum monostearate | Chattem Chem. (Chattanooga, TN; Fort Worth, TX)<br>Diamond Shamrock (Cedartown, GA)<br>Norac, Mathe Div. (Lodi, NJ)<br>Smith Chem. and Color (Jamaica, NY)<br>Tenneco (Piscataway, NJ)<br>Witco Chem. (Clearing, IL; Lynwood, CA; Perth Amboy, NJ)<br>Synthetic Products (Cleveland, OH) |
| Aluminum naphthenate | The Shepherd Chem. Co. (Cincinnati, OH) |
| Aluminum nitride | Thiokol, Ventron-Alfa (Danvers, MA) |
| Aluminum octanoate | Norac, Mathe Div. (Lodi, NJ)<br>Troy Chem. Co. (Newark, NJ)<br>Diamond Shamrock (Cedartown, GA)<br>Witco Chem. (Clearing, IL; Lynwood, CA) |
| Aluminum 2-ethylhexanoate | Witco Chem. (Clearing, IL; Lynwood, CA)<br>Diamond Shamrock (Cedartown, GA)<br>Norac, Mathe Div. (Lodi, NJ) |
| Aluminum palmitate | Diamond Shamrock (Cedartown, GA)<br>Synthetic Products (Cleveland, OH) |
| Aluminum phenolsulfonate | Salsbury Lab (Charles City, IA) |
| Aluminum oleate | — |
| Aluminum <u>meta-</u>phosphate | Chicago Heights Plant (Chicago Hgts., IL) |
| Aluminum resinate | Eastman Kodak (Rochester, NY)<br>Hercules (Glen Falls, NY) |
| Aluminum tristearate | CPC, Penick (Newark, NJ)<br>Dart Ind., Synthetic Prod. (Cleveland, OH)<br>Diamond Shamrock (Cedartown, OH)<br>Tenneco (Piscataway, NJ)<br>Witco Chem. (Clearing, IL; Lynwood, CA; Perth Amboy, NJ)<br>Eastman Kodak (Rochester, NY)<br>H and S Chem. (Wallington, NJ)<br>Barrier Ind. (Port Jervis, NY)<br>Charles S. Tanner Co. (Greenville, SC)<br>Norac, Mathe Div. (Lodi, NJ)<br>Chattem Chem. (Chattanooga, TN) |
| Calcium aluminate | United Catalysts (Louisville, KY) |
| Diethylaluminum ethoxide | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. |

Table 4. Manufacturers of Aluminum Compounds (Cont'd.)
(SRI International, 1980; U.S. EPA, 1980)

| Compound | Manufacturers |
|---|---|
| Diethylaluminum fluoride | Texas Alkyls (Deer Park, TX) |
| Diethylaluminum hydride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. |
| Diethylaluminum iodide | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC) |
| Diisobutylaluminum chloride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC) |
| Diisobutylaluminum hydride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC; Pasadena, TX) |
| Dimethylaluminum chloride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. |
| Ethylaluminum dichloride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC) |
| Ethylaluminum sesquichloride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC)<br>Hercules Inc. (Lake Charles, LA) |
| Isobutylaluminum dichloride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC) |
| Isobutylaluminum sesquichloride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC; Pasadena, TX) |
| Isoprenylaluminum | Texas Alkyls (Deer Park, TX) |
| Lithium aluminate | Lithium Corp. of America (Bessemer City, NC) |
| Lithium aluminum hydride | Belmont Metals (Brooklyn, NY)<br>Thiokol Corp-Ventron (Beverly, MA) |
| Magnesium aluminum silicate | NL Industries (Perth Amboy, NJ)<br>Mason Color and Chem. (East Liverpool, OH) |
| Methylaluminum sesquichloride | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC; Pasadena, TX) |
| Sodium aluminum diethyl dihydride | Ethyl Corp. |
| Tri-n-decylaluminum | Texas Alkyls (Deer Park, TX) |
| Trimethylaluminum | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. (Orangeburg, SC) |
| Tri-2-methylpentylaluminum | Texas Alkyls (Deer Park, TX) |
| Tri-n-propylaluminum | Texas Alkyls (Deer Park, TX)<br>Ethyl Corp. |

# III. INFORMATION PROFILES

## A. ALUMINUM METAL

1. Chemical Name: Aluminum (metal)

2. Chemical Structure: Al

3. Synonyms: Aluminum
Pigment metal I
C.I. 77000

4. Chemical Abstracts Service (CAS) Number: 7429-90-5

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:
BD0330000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | silvery white crystalline solid |
| Molecular Weight: | 26.9815 |
| Boiling Point: | 2450°C |
| Melting Point: | 660°C |
| Vapor Pressure: | 1 mm Hg (1284°C) |
| Solubility: | insoluble in water, nitric acid, hot acetic acid<br>soluble in sulfuric and, hydrochloric acids, alkalis |
| Specific Gravity: | 2.708 |
| Stability: | fine powders form flammable and explosive mixtures with air; metal surfaces gradually oxidize in moist air; corrodes rapidly in contact with other metals because it is strongly electropositive |

7. Production

U.S. production (manufacture) of primary aluminum metal and secondary recovery aluminum has been as follows (Anderson and Haupin, 1978; Stamper and Kurtz, 1976; PEDCo Environmental, 1978):

| Year | Primary Production (thousand short tons) | Secondary Recovery (thousand short tons) |
|---|---|---|
| 1976 | 4250 | 1155 |
| 1975 | 3879 | --- |
| 1974 | 4903 | 304 |
| 1973 | 4529 | 265 |
| 1972 | 4122 | 250 |
| 1965 | 2754 | 205 |
| 1960 | 2015 | --- |

U.S. demand for aluminum metal is projected to increase at an annual average growth rate of 5.1% until 1985, based upon 1973 figures (Stamper and Kurtz, 1976).

Data available from the U.S. EPA (1980) regarding producers of aluminum metal and production volumes are presented in Table 5.

8. Use

The distribution of end-use shipment of aluminum products in 1976 was the following (PEDCo Environmental, 1978):

|  | Quantity (thousand short tons) | Percentage |
|---|---|---|
| Building and construction | 1478 | 23.2 |
| Transportation | 1227 | 19.2 |
| Containers and packaging | 1284 | 20.2 |
| Electrical | 664 | 10.4 |
| Consumer durables | 449 | 8.1 |
| Machinery and equipment | 452 | 7.1 |
| Exports | 421 | 6.6 |
| Other | 328 | 5.2 |
|  | 6303 |  |

Other uses, as mentioned above, include non-recoverable applications of aluminum (Stamper and Kurtz, 1976). Examples are the use of aluminum powders and flakes in decorative and insulating paints, in explosives, in pyrotechnics, and in rocket fuels.

Many grades of aluminum powder are available ranging from coarse granules to the finest pyro dusts. Inhalation potential to the user increases

Table 5. Producers of Aluminum Metal and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 7429-90-5) |
|---|---|---|
| Foote Mineral Co. | | |
| Cambridge, OH | Manufacturer | 0.1-1.0 million lb |
| New Haven, WV | Manufacturer | zero |
| Engelhard Industries | | |
| Newark, NJ | Manufacturer | 10-100 thousand lb |
| Eastalco Aluminum Co. | | |
| Frederick, MD | Manufacturer | 100-500 million lb |
| Haven Chemical | | |
| Philadelphia, PA | Manufacturer | confidential |
| Intalco Aluminum Corp. | | |
| Ferndale, WA | Manufacturer | 100-500 million lb |
| Consolidated Aluminum Corp. | | |
| Lake Charles, LA | Manufacturer | 50-100 million lb |
| Waverly, TN | Manufacturer | 100-500 million lb |
| Valumet Processing Corp. | | |
| Sayreville, NJ | Manufacturer | 10-100 thousand lb |
| Ormet Corp. | | |
| Hannibal, OH | Manufacturer | 100-500 million lb |
| Aluminum Company of America | | |
| Palestine, TX | Manufacturer | 1-10 million lb |
| Alcoa, TN | Manufacturer | confidential |
| Wenatchee, WA | Manufacturer | confidential |
| Newburgh, IN | Manufacturer | confidential |
| Vancouver, WA | Manufacturer | confidential |
| Rockdale, TX | Manufacturer | confidential |
| Massena, NY | Manufacturer | confidential |
| Badin, NC | Manufacturer | confidential |
| Point Comfort, TX | Manufacturer | confidential |
| ABC Compounding Co. | | |
| Atlanta, GA | Manufacturer | 10-100 thousand lb |
| The Anaconda Co. | | |
| Columbia Falls, MT | Manufacturer | 100-500 million lb |
| Near Sebree, KY | Manufacturer | 100-500 million lb |
| Martin Marietta, Aluminum | | |
| The Dalles, OR | Manufacturer | 100-500 million lb |
| Goldendale, WA | Manufacturer | 100-500 million lb |

Table 5. Producers of Aluminum Metal and Production Ranges (U.S. EPA, 1980) (Cont'd.)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 7429-90-5) |
|---|---|---|
| National Aluminum | | |
| Hawesville, KY | Manufacturer | 100-500 million lb |
| Noranda Aluminum | | |
| New Madrid, MO | Manufacturer | 100-500 million lb |
| National Southwire Aluminum Co. | | |
| Hawesville, KY | Manufacturer | 100-500 million lb |
| Revere Aluminum Reduction | | |
| Scottsboro, AL | Manufacturer | 100-500 million lb |
| Kaiser Aluminum | | |
| Ravenswood, WA | Manufacturer | 100-500 million lb |
| Tacoma, WA | Manufacturer | 100-500 million lb |
| Chalmette, LA | Manufacturer | 100-500 million lb |
| Spokane, WA | Manufacturer | 100-500 million lb |
| Oakland, CA | Importer | over 1 billion lb |
| Reynolds Metals Co. | | |
| Sheffield, AL | Manufacturer | 100-500 million lb |
| Massena, NY | Manufacturer | 100-500 million lb |
| Troutdale, OR | Manufacturer | 100-500 million lb |
| Arkadelphia, AR | Manufacturer | 100-500 million lb |
| Gregory, TX | Manufacturer | zero |
| Longview, WA | Manufacturer | 100-500 million lb |
| Malvern, AR | Manufacturer | 100-500 million lb |
| Republic Foil | | |
| Salisbury, NC | Manufacturer | 10-50 million lb |
| Ross Aluminum Foundries | | |
| Sidney, OH | Manufacturer | 0.1-1.0 million lb |
| United Minerals and Chemical | | |
| NYC, NY | Importer | 0.1-1.0 million lb |
| Cominco American Inc. | | |
| Spokane, WA | Importer | 10-100 thousand lb |
| Henley and Co. | | |
| NYC, NY | Importer | confidential |
| Intsel Corp. | | |
| NYC, NY | Importer | 10-50 million lb |
| Revelli Chemicals | | |
| Yonkers, NY | Importer | 0.1-1.0 million lb |

Table 5. Producers of Aluminum Metal and Production Ranges (U.S. EPA, 1980) (Cont'd.)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 7429-90-5) |
|---|---|---|
| Dow Chemical<br>Midland, MI | Importer | 50-100 million lb |
| IMC<br>Libertyville, IL | Importer | 10-100 thousand lb |
| BASF Wyandotte Corp.<br>Parsippany, NJ | Importer | 1-10 thousand lb |
| Asarco Inc.<br>Tacoma, WA | Importer | 1-10 million lb |
| NYC, NY | Importer | 1-10 million lb |
| Alusuisse Metals Inc.<br>Fort Lee, NJ | Importer | confidential |
| HC Starck Inc.<br>NYC, NY | Importer | zero |
| F.W. Myers and Co.<br>Rouses Pt., NY | Importer/<br>Small Manufacturer | 0-1000 lb |
| Philipp Brothers<br>NYC, NY | Importer | confidential |
| Magnesium Elektron Inc.<br>Flemington, NJ | Importer | confidential |
| Hummel Chemical Co.<br>South Plainfield, NJ | Importer/<br>Small Manufacturer | 1-10 thousand lb |
| General Motors Corp.<br>Detroit, MI | Importer | 0.2-2.0 million lb |
| Xerox Corp.<br>Rochester, NY | Importer | 10-100 thousand lb |
| Degussa Corp.<br>Teterboro, NJ | Importer | 1-10 thousand lb |
| Indussa, Div. of<br>African Metals<br>NYC, NY | Importer | 0-1000 thousand lb |
| Kawecki Berylco Ind.<br>Reading, PA | Importer | 1-10 million lb |
| Alcan Aluminum Corp.<br>Cleveland, OH | Importer | 100-500 million lb |
| Amalgamet Inc.<br>NYC, NY | Importer | zero |

with a decrease in aluminum particle size. The pyro dusts, which may be less than 400 mesh in particle size, are used primarily in explosives (military) and civilian fireworks. The most used and most reactive pyro powder for fireworks is made by charring a special lacquered paper backing on aluminum foil and then powdering the foil in a stamp mill; the product contains a certain percentage of carbon matter, which gives the powder a blackish appearance. This grade of pyro powder has been obtained from Germany in the past but has become available domestically in recent years. The fireworks industry consumes on the order of several thousands of tons of pyro powder per year (SRC estimate). Fireworkers are exposed directly to the airborn dust during mixing operations; dust masks are commonly worn by the workers involved.

### 9. Manufacturers and Distributors

The primary aluminum manufacturers are listed in Table 6. Producers cited by the U.S. EPA (1980) are listed in Table 5. Approximately 28% of the primary manufacturing capacity is located in the state of Washington; the remaining capacity is spread among 15 states from coast to coast.

The distributors of aluminum and aluminum products are too numerous to identify or list; however, the manufacturers are likely to be major distributors.

### 10. Manufacturing Processes

Most of the world's aluminum is derived by converting bauxite ore to aluminina via the Bayer process, followed by electrolytic reduction of the alumina to the metal (Anderson and Haupin, 1978).

Figure 1 diagrams the bauxite to alumina operations. Figure 2 diagrams the electrolytic operations.

In 1976, Alcoa began producing aluminum metal at their Palestine, TX, plant by electrolysis of aluminum chloride (Treskon, 1976b).

Table 6. Primary Aluminum Manufacturing Plant Locations and Capacity (Parsons, 1977)

| Producer and Location | Capacity[a] |
|---|---|
| Aluminum Company of America | |
| Alcoa, TN | 265 |
| Badin, NC | 115 |
| Massena, NY | 130 |
| Point Comfort, TX | 184 |
| Rockdale, TX | 280 |
| Vancouver, WA | 100 |
| Warrick, IN | 225 |
| Wenatchee, WA | 175 |
| Anaconda Aluminum Company | |
| Columbia Falls, MT | 180 |
| Sebree, KY | 120 |
| Consolidated Aluminum Corp. | |
| New Johnsonville, TN | 140 |
| Lake Charles, LA | 35 |
| Eastalco Aluminum Company | |
| Frederick, MD | 87 |
| Martin-Marietta Aluminum Inc. | |
| The Dalles, OR | 91 |
| Goldendale, WA | 110 |
| Intalco Aluminum Co. | |
| Ferndale, WA | 265 |
| Kaiser Aluminum and Chem. Corp. | |
| Chalmette, LA | 260 |
| Mead, WA | 206 |
| Ravenswood, WV | 163 |
| Tacoma, WA | 81 |
| National-Southwire Aluminum Co. | |
| Hawesville, KY | 180 |
| North West Aluminum Co. | |
| Astoria, OR | 68 |
| Noranda Aluminum, Inc. | |
| New Madrid, MO | 70 |
| Ormet Corporation | |
| Hannibal, OH | 250 |
| Revere Copper and Brass, Inc. | |
| Scottsboro, AL | 112 |

Table 6. Primary Aluminum Manufacturing Plant Locations and Capacity (Parsons, 1977) (Cont'd)

| Producer and Location | Capacity[a] |
|---|---|
| Reynolds Metals Co. | |
| Arkadelphia, AR | 63 |
| Jones Mills, AR | 122 |
| Listerhill, AL | 221 |
| Longview, WA | 190 |
| Massena, NY | 128 |
| Corpus Christi, TX | 111 |
| Troutdale, OR | 140 |
| TOTAL 32 plants | 4868 |

[a] Capacity is a variable value. Stated values are estimates expressed in 1000 short tons.

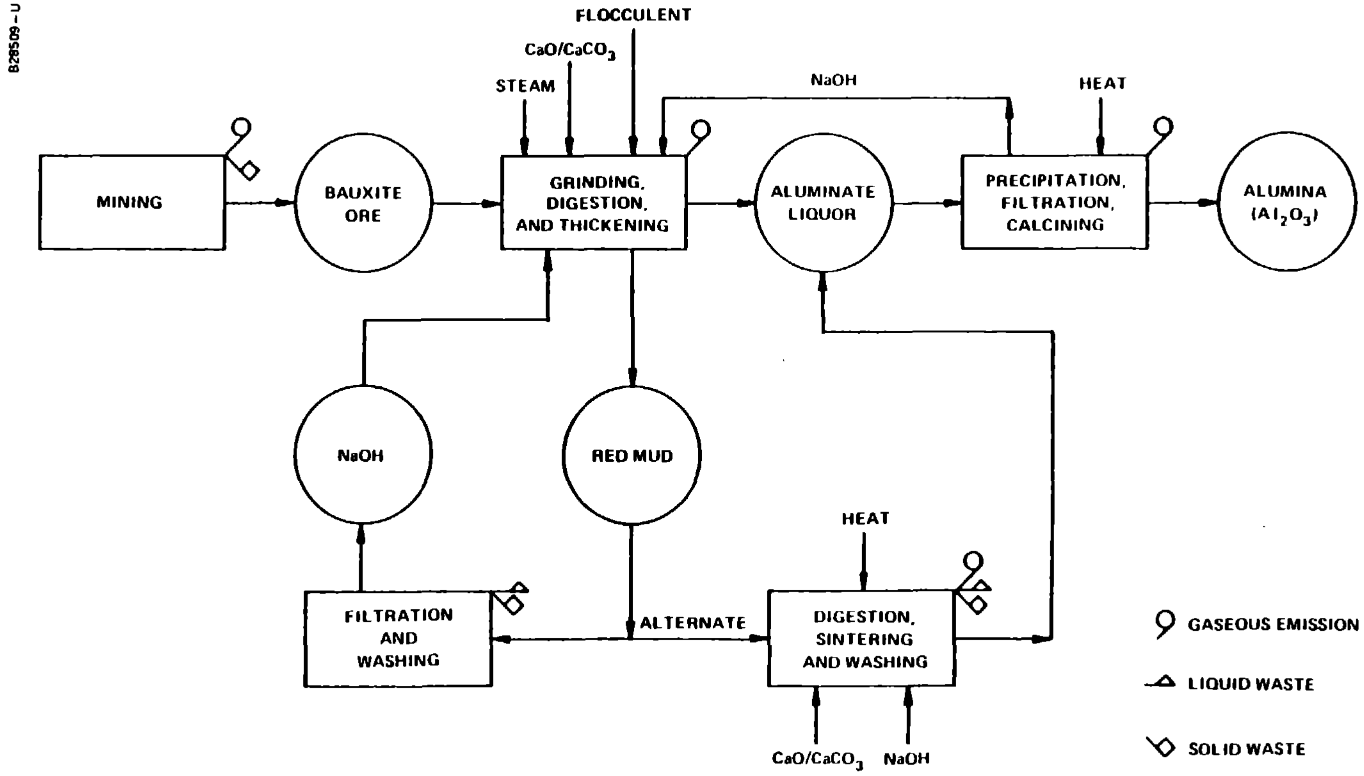


Figure 1. Bauxite Processing to Alumina (Parsons, 1977).

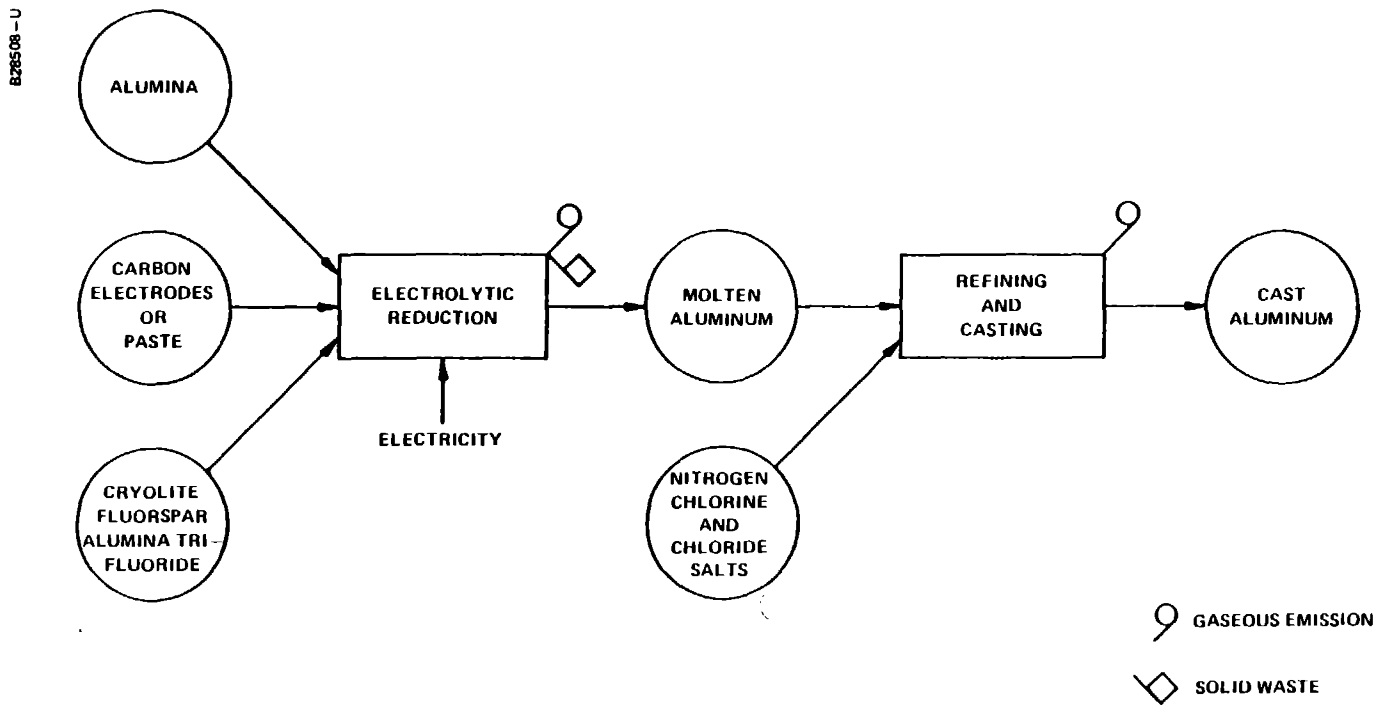


Figure 2. Electrolytic Reduction of Alumina to Aluminum (Parsons, 1977)

### 11. Impurities or Additives

Molten aluminum removed from electrolytic cells is normally 99.6-99.9% pure. The principal impurities are Fe, Si, Ti, V, and Mn, largely from the anode, but also from the impurities in the alumina (Anderson and Haupin, 1978).

Many aluminum alloys are produced commercially (Anderson and Haupin, 1978). Aluminum is commonly alloyed with magnesium, silicon, copper, nickel, zinc, and other metals.

### 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 684,231 and 31,333 workers are potentially exposed to aluminum metal and C.I. 77000 (powdered aluminum), respectively.

### 13. Control Technology and Work Practices

Concern has been expressed by the Russian, Konstantinov (1979), over the use of electrodes in which coal tar is used as the binder. He suggests that electrolyzers with roasted anodes be used in the aluminum industry.

In Japan, a gas and vapor suction unit is placed on a horizontally moving platform to collect gas and vapor evolved during the resetting of pins in electrodes of upright Soderberg electrolytic aluminum extractors (Yamori *et al.*, 1977).

Uporov (1972) has reported that in a building for aluminum refining, electrolyzers are enclosed in a special housing with a gas-evacuation system to reduce emissions of fluoride compounds.

### 14. Biological Effects

#### a. Animal Studies

##### (1) Acute Exposures

The intratracheal instillation of 100 mg of metallic aluminum powder produced nodular fibrosis in the lungs of rats after 60 days

(King *et al*, 1958). By 210 days, the nodules were large, acellular, and composed of thick reticulin and collagen. Corrin (1963) similarly found that high intratracheal doses (100 mg) of stamped aluminum powders (oil-coated or uncoated "pyro" powder, produced by the stamping of cold aluminum metal) caused severe nodular fibrosis in rats, but that a granular aluminum powder (produced by atomizing molten aluminum metal) caused only minimal fibrosis after 12 months and was considered to be biologically inert. The pulmonary fibrogenic action of aluminum powders was confirmed by Gross *et al*. (1973), who showed that this intratracheal response was dose dependent in rats; no fibrosis occurred in the lungs of hamsters injected intratracheally with the same powders.

### (2) Subchronic Exposures

Greenberg (1977) implanted small aluminum wires (3 mm x 0.25 mm) into the lungs of Swiss mice for 1-45 days. Following a response of edema and congestion, consequent to the introduction of the wire, a fibrosis developed after 30 days that reportedly was not consistent with the size of the original injury. It was suggested that accompanying mononuclear cell infiltration may have been indicative of a hypersensitivity reaction to the metal.

### (3) Chronic Exposures

Although pulmonary fibrosis has been demonstrated in rats following intratracheal injection of aluminum powders (see Acute Exposures), Gross *et al*. (1973) could not produce fibrosis in rats, hamsters, or guinea pigs by exposing them via inhalation to atomized aluminum pyro aluminum or aluminum oxide at levels of 15-100 $mg/m^3$ for 6-12 months. Alveolar proteinosis developed in all three species, although it was more pronounced in rats.

### (4) Carcinogenicity

No information was found in the literature searched.

(5) Mutagenicity

Elemental aluminum (0.1 mg dissolved in dimethyl sulphoxide) failed to produce mutagenic effects in Salmonella typhimurium strains TA98, TA1535, and TA1538 in an Ames assay (Milvy and Kay, 1978).

(6) Teratogenicity

No information was found in the literature searched.

(7) Reproductive Effects

No information was found in the literature searched.

(8) Other Relevant Information

No information was found in the literature searched.

b. Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

McLaughlin et al. (1962) described a patient employed as a ball-mill operator in an aluminum flake-powder factory in whom an encephalopathy developed that had many of the features of dialysis encephalopathy syndrome, including an elevated brain concentration of aluminum.

The inhalation of metallic aluminum powder (particle diameter $>1.2\ \mu m$) appears to be effective in the prevention and therapy of silicosis (Sorenson et al., 1974). Upon generation, the particles become oxidized to $Al_2O_3$, which is considered to be the active $SiO_2$-inhibiting agent. Aluminum powder treatment has been used with apparent effectiveness in the gold mining and ceramic industries, but there is, however, no unequivocal evidence that the procedure is of clinical utility. A lack of controlled clinical studies suggested to Sorenson and coworkers (1974) the possibility that the improved health experienced by the treated workers may be due to improved mine hygiene and air cleaning rather than to aluminum inhalation. The therapeutic use of aluminum dust has no effect on reversing established silcotic disease.

### (3) Target Organ Toxicity

Clinical reports of pulmonary fibrosis in British workers exposed to stearin-coated aluminum flake powder ("pyro") have been described by McLaughlin et al. (1962) and Mitchell et al. (1961). Based on animal studies, Gross et al. (1973) have suggested that the size of inhaled aluminum particles and the formation of aggregates influence the development of fibrosis.

### (4) Epidemiology

A study of 27 British workers exposed to aluminum flakes ("pyro") and aluminum powder during the production of explosives and fireworks revealed 6 cases of pulmonary fibrosis (Mitchell et al., 1961). The mean exposure level recorded for time periods of 30-90 minutes per shift was 95 $mg/m^3$ respirable dust (exposure levels varied from 19 to 114 $mg/m^3$), and the duration of exposure varied from 1 to 9 years. The investigators concluded that exposure to fine "pyro" powder presented a greater risk than did exposure to the coarse aluminum powder (Mitchell et al., 1961). Goralewski (1947) summarized findings of pulmonary fibrosis in 163 of 628 workers employed in the manufacture of aluminum powder ("pyro") for explosives, but details of exposure levels and duration were unavailable. Symptoms of exposure included dyspnea, spontaneous pneumothorax, cough, and sputum.

No adverse respiratory system effects were found in an investigation of 125 aluminum workers exposed to aluminum powder used in the manufacture of paint and ink (Crombie et al., 1944). Exposure of this cohort to aluminum dust ranged from 6 to 26 years, but exposure levels were not reported.

Aluminum smelter workers involved in the electrolytic reduction of aluminum have been reported to develop an asthma-like condition and to show an excess risk of lung cancer and some types of leukemia and lymphoma (Aluminum Association, 1977; Gibbs and Horowitz, 1979; Milham, 1979). These effects appear, however, to be due primarily to exposure to coal tar pitch volatiles emitted during the manufacturing process. Sulfur dioxide and fluorine compounds, particularly hydrogen fluoride, may also constitute major hazards to aluminum plant workers (Sorenson et al., 1974; Norseth, 1979). Fluorides evolve from the use of cryolite ($Na_3AlF_6$), either natural or synthetic, as a flux in the electrolytic reduction of alumina to aluminum.

## 15. Ongoing Studies

An epidemiological investigation of aluminum reduction workers is under way to assess cancer risk and other mortality causes (Brown et al., 1980).

## 16. Exposure Standards

The ACGIH has recommended a Time-Weighted Average (TWA) occupational exposure limit for aluminum metal of 10 $mg/m^3$, based on consideration of the metal as an inert dust (ACGIH, 1979). For alumnum pyro powders, a Threshold Limit Value (TLV) of 5 $mg/m^3$ as Al is recommended; this limit is intended to protect against lung changes. The recommended TLV for aluminum fume as developed in arc welding is 5 $mg/m^3$.

## 17. Sources of Additional Relevant Information

The following relevant NIOSH publications were identified:

| Title | Publication No. | |
|---|---|---|
| Environmental Surveys of Aluminum Reduction Plants | NIOSH | 74-101 |
| Molten Aluminum - Water Explosion Initiation Mechanism Study | CONTR | HSM-95-73-27 |
| Health Hazard Evaluation, Alcan Aluminum Corp., Fairmont, WV | HHE | 78-88-533 |
| Health Hazard Evaluation, Amax Aluminum Mill Products Co., Riverside, CA | HHE | 73-187-151 |

| | | |
|---|---|---|
| Health Hazard Evaluation, American Concrete Division, Union Metal Co., Waukegan, IL | HHE | 78-47-570 |
| Health Hazard Evaluation, Chalfant Manufacturing Co., Elyria, OH | HHE | 78-32-507 |
| Health Hazard Evaluation, Conalco, Hannibal, OH | HHE | 72-32-459 |
| Health Hazard Evaluation, FMC Corp. Chain Div., Indianapolis, IN | HHE | 76-97-430 |
| Health Hazard Evaluation, Franklin Electric Co., Bluffton, IN | HHE | 75-124-382 |
| Health Hazard Evalution, General American Transportation Corp., Masury, OH | HHE | 77-41-505 |
| Health Hazard Evaluation, Gerico, Inc., Boulder, CO | HHE | 78-14-476 |
| Health Hazard Evaluation, Gorsuch Foundry Co., Inc., Jeffersonville, IN | HHE | 73-27-200 |
| Health Hazard Evaluation, Kaiser Aluminum and Chemical Corp., Ravenswood, WV | HHE | 74-25-267 |
| Health Hazard Evaluation, Melroe Division of Clark Equipment Co., Gwinner, ND | HHE | 78-87-573 |
| Health Hazard Evaluation, Prefinish Metals, Inc., Elk Grove Village, IL | HHE | 77-78-466 |
| Health Hazard Evaluation, Steiger Tractor, Inc., Fargo, ND | HHE | 77-58-428 |
| Health Hazard Evaluation, Superior Metals Products, Inc., Lima, OH | HHE | 73-3-65 |
| Health Hazard Evaluation, Willard Bronze Co., Cincinnati, OH | HHE | 72-7-10 |

## 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum metal as an occupational hazard was found in the literature searched.

## B. ALUMINUM AMMONIUM SULFATE

1. Chemical Name: Aluminum Ammonium Sulfate

2. Chemical Structure: $NH_4Al(SO_4)_2 \cdot 12H_2O$

3. Synonyms:
   - Ammonia alum
   - Ammonium aluminum sulfate
   - Ammonium alum
   - Sulfuric acid, aluminum ammonium salt

4. Chemical Abstracts Service (CAS) Numbers:
   7784-25-0 (anhydrous)
   7784-26-1 (dodecahydrate)

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   Not listed.

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | colorless crystals |
| Molecular Weight: | 453.33 (dodecahydrate) |
| Boiling Point: | decomposes above 280°C |
| Melting Point: | 94.5°C |
| Vapor Pressure: | --- |
| Solubility: | 15 g/100 cc water (20°C)<br>soluble in glycerine<br>insoluble in alcohol |
| Specific Gravity: | 1.645 |
| Stability: | noncombustible |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum ammonium sulfate and production volumes are presented in Table 7. Darragh (1978) estimates the annual production to be several thousand metric tons.

8. Use

Aluminum ammonium sulfate is used in medicine, as a mordant in dyeing, in water purification, in paper sizing, and in the dressing of skins

Table 7. Producers of Aluminum Ammonium Sulfate and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 7784-25-0) |
|---|---|---|
| Allied Chemical Corp.<br>Claymont, DE | Manufacturer | 1-10 million lb |
| ABC Chemical Corp.<br>Naipahu, HI | Manufacturer | 0-1000 lb |
| J.T. Baker Chemical Co.<br>Phillipsburg, NJ | Manufacturer | 1-10 thousand lb |
| United Mineral and Chemical Corp.<br>NYC, NY | Importer | 0-1000 lb |
| ICI Americas Inc.<br>Wilmington, DE | Importer | zero |

(Darragh, 1978). It also has uses as a food additive, as an ingredient in baking powders, in the manufacture of pigments, lakes, artificial gems, paper, vegetable glue, marble and porcelain cements, in fireproofing, and in electrolytic copperplating (Hawley, 1977; *The Merck Index*, 1976).

### 9. Manufacturers and Distributors

SRI International (1980) lists Allied Chemical Corp. (Claymont, DE, and Marcus Hook, PA) as the only manufacturer.

Data available from the U.S. EPA (1980) regarding producers of aluminum ammonium sulfate and production volumes are presented in Table 7.

The distributors in addition to the manufacturers, include (*1980-81 OPD Chemical Buyers Directory*, 1980; *Chemical Week: 1981 Buyers Guide Issue*, 1980); *Chem Sources--USA*, 1980):

Alfa Prod.
Aldrich Chem.
Anachemia Chem.
Ashland Chem.
Atomergic Chemetals
Cooper Chem.
Chem. Services
Delmar Inc.
EM Labs.
Fisher Sci.
Gallard-Schelsinger Chem.
Independent Chem. Corp.
LaPine Sci.
Laporte Ltd.
Mallinckrodt
MCB Reagents
Orion Chem.
Pioneer Salt and Chem.
E.M. Sergeant Pulp and Chem. Co.
Sigma Chem.
Thompson-Hayward Chem.
Van Waters and Rogers

### 10. Manufacturing Processes

Aluminum ammonium sulfate is manufactured by crystallization from a mixture of ammonium sulfate and aluminum sulfate or by treating aluminum sulfate and sulfuric acid with ammonia gas. It is sold commercially in several forms including lumps, granular, and powder (Darragh, 1978).

### 11. Impurities or Additives

Aluminum ammonium sulfate is sold in N.F. and technical grades.

## 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 26,952 workers are potentially exposed to aluminum ammonium sulfate.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum ammonium sulfate were not found in the literature searched.

## 14. Biological Effects

No information regarding the biological effects of aluminum ammonium sulfate was found in the literature searched.

## 15. Ongoing Studies

No current toxicological or environmental studies of aluminum ammonium sulfate were found.

## 16. Exposure Standards

The ACGIH (1979) currently recommends a Threshold Limit Value (TLV) of 2 $mg/m^3$ as Al for the soluble salts of aluminum. The TLV for these soluble salts, such as the chloride and sulfate, is based on the amount of hydrolyzed acid and the corresponding TLV. On the basis that 3 mol of HCl, with a TLV of 5 ppm, hydrolyze from 1 mol of $AlCl_3$, a TLV of 2 $mg/m^3$ as Al is recommended to provide the same degree of freedom from irritation that is provided by the TLV for HCl. As the acute toxicity from $Al_2(SO_4)_3$ is only slightly greater than that of $AlCl_3$, and the toxicity of the alums is considerably less, the 2 $mg/m^3$ is considered to be suitable for the soluble salts of aluminum (ACGIH, 1979).

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum ammonium sulfate as an occupational hazard was found in the literature searched.

## C. ALUMINUM CHLORHYDRATE

1. Chemical Name: Aluminum Chlorhydrate

2. Chemical Structure: $[Al_2(OH)_5Cl]_x$ or $Al_2(OH)_5Cl \cdot 2H_2O$

3. Synonyms:
ACH
Aluminum chloride hydroxide
Aluminum hydroxy chloride
Aluminum chlorhydroxide
Aluminum chlorohydroxide
Aluminum chlorhydrol
Astringen
Chlorhydrol, granular
Chlorhydrol, impalpable
Locron extra
Locron Flakes
Locron powder
Locron solution
Micro dry
Wickenol 303
Wickenol 321
Wickenol 323
Wickenol 324

4. Chemical Abstracts Service (CAS) Numbers: 12042-91-0
1327-41-9

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:
BD0550000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | glassy solid |
| Molecular Weight: | variable |
| Boiling Point: | --- |
| Melting Point: | --- |
| Vapor Pressure: | --- |
| Solubility: | dissolves in water, forming slightly turbid colloidal solution (up to 55% w/w) |
| Specific Gravity: | --- |
| Stability: | noncombustible |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum chlorhydrate and production volumes are presented in Table 8.

8. Use

Aluminum chlorhydrate is a widely used ingredient in deodorants and antiperspirants (Isacoff, 1979). It is also used for water purification and

Table 8. Producers of Aluminum Chlorhydrate and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range |
|---|---|---|
| For CAS No. 1327-41-9: | | |
| Reheis Chemical Co.<br>Berkeley Heights, NJ | Manufacturer | 10-50 million lb |
| Wicken Products, Inc.<br>Huguenot, NY | Manufacturer/ Produced Site Limited | 10-100 thousand lb |
| Huguenot, NY | Manufacturer | 0.12-1.2 million lb |
| American Hoechst Corp.<br>Bridgewater, NJ | Importer | confidential |
| For CAS No. 12042-91-0: | | |
| Summit Research Laboratories<br>Franklin TWSP, NJ | Manufacturer | 1-10 million lb |
| Robinson Wagner Co.<br>Mamaroneck, NY | Manufacturer | 0.1-1 million lb |
| Wicken Products, Inc.<br>Huguenot, NY | Manufacturer | 1.2-12 million lb |
| Struktol C. of America<br>Akron, OH | Small Manufacturer/<br>Importer | confidential<br>confidential |

treatment of sewage and plant effluent (Hawley, 1977). A variety of patent literature indicates that aluminum chlorhydrate is useful as a binder for refractories and ceramics and as a paper sizing agent.

### 9. Manufacturers and Distributors

SRI International (1980) lists the following manufacturers of aluminum chlorhydrate:

| | |
|---|---|
| Revlon (Reheis Chem. Co.) | Berkeley Heights, NJ |
| Robinson-Wagner Co. | Guilford, NJ |

Data available from the U.S. EPA (1980) regarding producers of aluminum chlorhydrate and production volumes are presented in Table 8.

In addition to the manufacturers listed above and in Table 8, the distributors include (1980-81 OPD Chemical Buyers Directory, 1980; Chem Sources--USA, 1980):

American Hoechst Corp.
Orion Chem.
Pfaltz and Bauer
Santell Chem. Co.
Universal Preservachem.

### 10. Manufacturing Processes

Aluminum chlorhydrate is commercially produced by reacting hydrochloric acid with aluminum metal or an aluminum salt (such as the hydroxide, oxide, or chloride) at various temperature and pressure conditions. Bellan and Deneke (1972) describe the process as trickling HCl solution over Al chips in a solid bed with air exclusion, continuous replacement of consumed Al, and removal of hydrogen gas; the lower part of the column is heated to give an aluminum chlorhydrate solution. Danner and Krieg (1974) describe the process as mixing $Al(OH)_3$ (65% $Al_2O_3$) and aqueous HCl and heating the mixture to a boil; the resultant product is filtered to obtain the chlorhydrate.

Aluminum chlorhydrate has also been prepared experimentally by electrolysis of aluminum chloride solution (Ringk and Theimer, 1978).

11. Impurities or Additives

No information was found in the literature searched.

12. Occupational Exposure

The National Occupational Hazard Survey indicates that 37,709 workers are potentially exposed to aluminum chlorhydrate.

13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum chlorhydrate were not found in the literature searched.

14. Biological Effects

a. Animal Studies

(1) Acute Exposures

Martin et al. (1966) determined a mouse oral LD50 value of 8.4 g/kg for an antiperspirant product (Rehydrol A.S.C.) that contains 93-100% aluminum chlorhydrate-propylene glycol complex. When 10 rats were exposed via inhalation to 320 mg/l of this product for 1 hour, 1 death occurred within a 14-day observation period.

Intratracheal inoculation of aluminum chlorhydrate (10 mg suspended in 3 ml of saline, administered three times at 3-day intervals) induced respiratory bronchiolitis in rabbits (Stankus et al., 1978); 0.1 mg and 1.0 mg inoculations did not result in significant bronchopulmonary histopathology. No well-defined pulmonary granulomas were evident in any of these exposure groups, and, 28 days after the last intratracheal injection, the inflammatory response observed at the 10-mg dose had subsided. With an in vitro phagocytic assay, an increase in bacterial phagocytosis following the intratracheal inoculations was demonstrated. An absence of demonstrable delayed skin reactivity after intradermal injection or migration inhibition factor production in the inoculated rabbits suggested that the bronchopulmonary macrophage activation was non-immunological (Stankus et al., 1978).

Prior and Cronk (1959) reported that single percutaneous applications of 22% aluminum chlorhydrate to rabbit ears (applied on saturated cotton pads) caused slight redness that faded with 24 hours. The antiperspirant product, Rehydrol A.S.C., did not irritate rabbit skin (Draize test) at a concentration of 30% after a single exposure for 24 hours (Martin et al., 1966).

Intradermal injection of aluminum chlorhydrate (5 mg, 0.5 mg, or 0.05 mg) produced granulomatous lesions in the skin of guinea pigs after 14 days (Turk and Parker, 1977). These changes were succeeded by intense fibrosis. A total of 1.4 mg of aluminum chlorhydrate injected intradermally over a 6-week period in rabbits produced granulomas at the injection site, but was not sensitizing (Kang et al., 1977). Subcutaneous injection of 110 mg aluminum chlorhydrate into rabbit back skin caused fibrotic lesions at the injection sites and a few granulomas in the dermis after 7 weeks (Prior and Cronk, 1959); when aluminum chlorhydrate (110 mg) was injected a second time 7 weeks after the original experiment, multiple granulomas were produced. Single or repeated (after 7 weeks) intracutaneous injections of 22 mg aluminum chlorhydrate into the ears of rabbits resulted in slight irritation, but no lesions (Prior and Cronk, 1959).

When the antiperspirant product Rehydrol A.S.C. was instilled (0.1 ml) at a concentration of 30% into the eyes of rabbits (Draize procedure), mild conjunctival irritation resulted (Martin et al., 1966). The irritation cleared in 2 to 4 days.

### (2) Subchronic Exposures

Lansdown (1973) found that 10% and 25% aluminum chlorhydrate did not produce any visible or microscopic changes to the uncovered back skin of mice, rabbits, or guinea pigs when applied daily for 5 consecutive days. When a 15% solution of an antiperspirant product containing 93-100% aluminum chlorhydrate-propylene glycol complex was injected intracutaneously into guinea pigs every other day for a total of 10 injections, with an 11th injection 2 weeks later, sensitization did not occur. The first and 11th injections were 0.05 ml, and the remaining injections were 0.1 ml; reaction readings were made 24 hours after each injection.

### (3) Chronic Exposures

When groups of Fischer rats and Hartley strain guinea pigs were exposed to 0.25, 2.5, or 25 $mg/m^3$ of aluminum chlorhydrate for 6 hours/day, 5 days/week, for 6 months, depressed body weight, increased lung-body weight ratios, multifocal granulomatous pneumonia, and increases in lung aluminum concentrations were observed (Cavender et al., 1978). The pneumonia was characterized by a macrophagic reaction in the alveoli near the terminal bronchioles. After 12 months of exposure, granulomas were present in the lungs and peribronchial lymph nodes in both the rats and guinea pigs exposed to 2.5 $mg/m^3$ aluminum chlorhydrate. Aluminum concentrations in the lung in all exposure groups had further increased at this time, and numerous unspecified changes in the free-cell population of the lungs of both species were reported.

### (4) Carcinogenicity

No information was found in the literature searched.

### (5) Mutagenicity

No information was found in the literature searched.

(6) Teratogenicity

No information was found in the literature searched.

(7) Reproductive Effects

No information was found in the literature searched.

(8) Other Relevant Information

Aluminum chlorhydrate is toxic to guinea pig peritoneal macrophages and fibroblasts _in vitro_ and is hemolytic (Badenoch-Jones _et al_., 1978).

b. Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

Aluminum chlorhydrate (50%), when applied to scarified skin (occlusive conditions) once a day for of 3 days, was mildly irritating at the end of the exposure (Frosch and Kligman, 1976).

Extensive consumer experience in the use of antiperspirant preparations containing aluminum chlorhydrate suggests that this compound is unlikely to prove irritating to human skin except in people with extremely sensitive skin (Lansdown, 1974). Aluminum chlorhydrate has not been implicated as a sensitizing agent in humans (Stankus _et al_., 1978).

(3) Target Organ Toxicity

No information was found in the literature searched.

(4) Epidemiology

No information was found in the literature searched.

15. _Ongoing Studies_

No current toxicological or environmental studies of aluminum chlorhydrate were found.

16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum chlorhydrate were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of aluminum chlorhydrate as an occupational hazard was found in the literature searched.

## D. ALUMINUM CHLORIDE, ANHYDROUS

1. Chemical Name: Aluminum Chloride, Anhydrous

2. Chemical Structure: $AlCl_3$

3. Synonyms: Aluminum trichloride
   Trichloroaluminum
   Aluminum chloride (1:3)
   Aluminum(III) chloride

4. Chemical Abstracts Service (CAS) Number: 7446-70-0

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:
   BD0525000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white or yellowish crystals |
| Molecular Weight: | 133.34 |
| Boiling Point: | sublimes at 178°C |
| Melting Point: | 190°C (2.5 atm) |
| Vapor Pressure: | 1 mm Hg (100°C) |
| Solubility: | 69.9 g/100 cc (15°C) with violence<br>100 g/100 cc absolute alcohol (12.5°C)<br>0.072 g/100 cc chloroform (25°C)<br>freely soluble in benzophenone, benzene, nitrobenzene, carbon tetrachloride, and many organic solvents<br>soluble in ether<br>slightly soluble in benzene |
| Specific Gravity: | 2.44 (25°C) |
| Stability: | can react violently with water; noncombustible |

7. Production

During 1965-1975, annual production of anhydrous aluminum chloride ranged from 29 to 40 thousand short tons (Treskon, 1976c). In 1976, production increased sharply when Alcoa brought on-stream a plant for the captive use of aluminum chloride to make aluminum metal (Marstiller, 1978); in 1977, this plant produced between 5 and 25 thousand tons of aluminum chloride (U.S. EPA, 1980), and it has, at present, a total capacity of 200 thousand tons per year (CMR, 1980a).

CMR (1980a) estimates the future growth of demand to be 2.5% per year through 1984; this is exclusive of Alcoa's aluminum chloride to aluminum plant, which is captive. CMR (1980a) also reports that the Alcoa plant has yet to resolve the problems of particle size and PCB contamination in its material.

Data available from the U.S. EPA (1980) regarding producers of aluminum chloride and production volumes are presented in Table 9.

8. Use

The following tabulation presents the percentage of the total amount of anhydrous aluminum chloride produced that is used in each of the applications listed (exclusive of that used in aluminum metal production) (CMR, 1980a):

| | Percentage of Total |
|---|---|
| Detergent alkylate | 18 |
| Ethylbenzene catalyst | 15 |
| Hydrocarbon resins | 12 |
| Titanium dioxide processing | 10 |
| Dyestuff intermediate | 10 |
| Miscellaneous (including cosmetic and pharmaceutical applications, butyl rubber and polybutenes, ethyl chloride) | 35 |

Since 1976, the major single use of anhydrous aluminum chloride has been in the electrolytic production of aluminum (Marstiller, 1978).

9. Manufacturers and Distributors

The following companies manufacture aluminum chloride (CMR, 1980a):

Table 9. Producers of Anhydrous Aluminum Chloride and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 7446-70-0) |
|---|---|---|
| Eastman Kodak | | |
| Rochester, NY | Manufacturer | 0.1-1.0 million lb |
| Baton Rouge Plant | | |
| Baton Rouge, LA | Manufacturer | 10-100 thousand lb |
| Allied Chemical Corp. | | |
| Chicago, IL | Manufacturer | 1-10 million lb |
| Ransomville, NY | Manufacturer | 10-50 million lb |
| Dow Chemical | | |
| Freeport, TX | Manufacturer | 1-10 million lb |
| Engelhard Industries | | |
| Newark, NJ | Manufacturer | 10-100 thousand lb |
| E.I. duPont de Nemours | | |
| East Chicago, IN | Manufacturer | zero |
| Linden, NJ | Manufacturer | 1-10 million lb |
| Pennwalt Corp. | | |
| Delaware, OH | Manufacturer | 0-1 thousand lb |
| Los Angeles, CA | Manufacturer | 0-1 thousand lb |
| Montgomery, AL | Manufacturer | 0-1 thousand lb |
| Calumet City, IL | Manufacturer | 0-1 thousand lb |
| Cornwall Heights, PA | Manufacturer | 0-1 thousand lb |
| Orange, CA | Manufacturer | 0-1 thousand lb |
| Monsanto | | |
| Texas City, TX | Manufacturer | 1-10 million lb |
| Vanchlor Chemical Co. | | |
| Lockport, NY | Manufacturer | 1-10 million lb |
| Aluminum Co. of America | | |
| Alcoa, TN | Manufacturer | confidential |
| Palestine, TX | Manufacturer | 10-50 million lb |
| Shell Chemical Co. | | |
| Axis, AL | Manufacturer | 1-10 million lb |
| Pearsall Chemical Corp. | | |
| Phillipsburg, NJ | Manufacturer | 10-50 million lb |
| Laporte, TX | Manufacturer | 10-50 million lb |
| Oxirane Chemical Co. | | |
| Channelview, TX | Manufacturer | 0.1-1.0 million lb |
| Reheis Chemical Co. | | |
| Berkeley Heights, NJ | Manufacturer | 10-100 thousand lb |

Table 9. Producers of Anhydrous Aluminum Chloride and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 7446-70-0) |
|---|---|---|
| Great Western Inorganics<br>Golden, CO | Manufacturer | 0-1 thousand lb |
| Process Div. UOP Inc. | | |
| Shreveport, LA | Manufacturer | confidential |
| McCook, IL | Manufacturer | confidential |
| Continental Oil Co.<br>Baltimore, MD | Manufacturer | 10-50 million lb |
| CP Chemicals Inc.<br>Sewaren, NJ | Manufacturer | confidential |
| Chattem Chemical<br>Chattanooga, TN | Manufacturer | confidential |
| Degussa Corp.<br>Theodore, AL | Manufacturer/<br>Produced Site Limited | 0.1-1.0 million lb |
| United Mineral and Chemical Corp.<br>NYC, NY | Importer | 0-1 thousand lb |
| Fallek Chemical<br>NYC, NY | Importer | 1-10 thousand lb |
| American Hoechst Corp.<br>Bridgewater, NJ | Importer | confidential |
| Tridom Chemical Inc.<br>Hauppauge, NY | Importer/<br>Small Manufacturer | confidential |
| Southeastern Adhesives Co.<br>Lenoir, NC | Importer | 10-100 thousand lb |
| Rohm and Haas Co.<br>Philadelphia, PA | Importer | 0.1-1.0 million lb |
| Carey Industries<br>Danbury, CT | Importer | zero |

|  |  | Annual Capacity (in Tons) |
|---|---|---|
| ACL Industries | Elkton, MD | 2,500 |
| Alcoa | Palestine, TX | 100,000[a] |
| Allied Chem. | Ransomville, NY | 10,000 |
| Ascension | Tonawanda, NY | 4,000 |
|  | Huntsville, TX | 3,000 |
| Van De Mark | Lockport, NY | 4,800 |
| Witco (Peavsall) | LaPorte, TX | 7,000 |
|  | Phillipsburg, NJ | 12,000 |
|  |  | 143,300 |

[a] Alcoa alternates production between twin units.

Producers cited by the U.S. EPA (1980) are listed in Table 9; however, some of the manufacturers listed in Table 9 are actually reprocessers of spent $AlCl_3$ catalyst and do not make $AlCl_3$ from raw materials.

In addition to the manufacturers, the distributors include (1980-81 OPD Chemical Buyers Directory, 1980; Chemical Week: 1981 Buyers' Guide Issue, 1980; Chem Sources--USA, 1980):

- Aldrich Chem.
- Alfa Products
- Anachemia Chem.
- Apache Chem.
- Atomergic Chemetals
- J.T. Baker Chem.
- Bodman Chem.
- Brown Chem.
- Cationics Inc.
- Cerac Inc.
- Chem Services
- Columbia Organics
- Cortlic Chem.
- Eastern Chem.
- EM Labs
- Fallek Chem.
- Fisher Sci.
- Gallard-Schelsinger
- Gulbrandsen Co.
- J.F. Henry Co.
- Hetako Chem.
- Hudson Labs
- ICN/K and K
- LaPine Sci.
- Mallinckrodt
- MCB Reagents
- Nippon Soda
- Noah Chem.
- Orbis Prod.
- Orion Chem.
- Pfaltz and Bauer
- Pioneer Salt and Chem.
- Prior Chem.
- Sigma Chem.
- Spex Ind.
- Suburban Chem.
- T.R. America
- Tridom Chem.
- Joseph Turner and Co.
- George Uhe Co.
- Vanchlor Co.
- VWR Sci.

### 10. Manufacturing Processes

Anhydrous aluminum chloride is produced commercially by reacting chlorine with either molten aluminum or with alumina (Marstiller, 1978). In the first method, scrap aluminum or a mixture of scrap and pig aluminum is charged to a refractory crucible furnace in which it is melted. Dry chlorine is passed into the molten charge and forms aluminum chloride, which vaporizes and leaves the furnace through a vapor duct in the top. The vapors are then passed into air-cooled condensers, where aluminum chloride sublimes and is periodically removed (Lowenheim and Moran, 1975). The condensed product is crushed, sized, and packaged under an atmosphere of dry air or nitrogen. Overall purity of the aluminum chloride produced by this process is >98% (Marstiller, 1978). This process is outlined in Figure 3.

Alcoa prepares high-purity aluminum chloride for electrolytic reduction to aluminum (Marstiller, 1978). The starting material is Bayer's process alumina which is coked or impregnated with carbon and reacted with chlorine at 600°C in a a fluidized-bed reactor. The effluent gases from the reactor are cooled but maintained above the condensation temperature of aluminum chloride and filtered. Materials retained on the filter are returned in controlled amounts to the reactor to improve efficiency. The gas stream, containing essentially pure $AlCl_3$ and carbon oxides, is conducted to a desublimer, where the aluminum chloride vapor can be condensed on solid particles of aluminum chloride. This process is outlined in Figure 4.

### 11. Impurities or Additives

Typical specifications of anhydrous aluminum chloride are as follows (Marstiller, 1978):

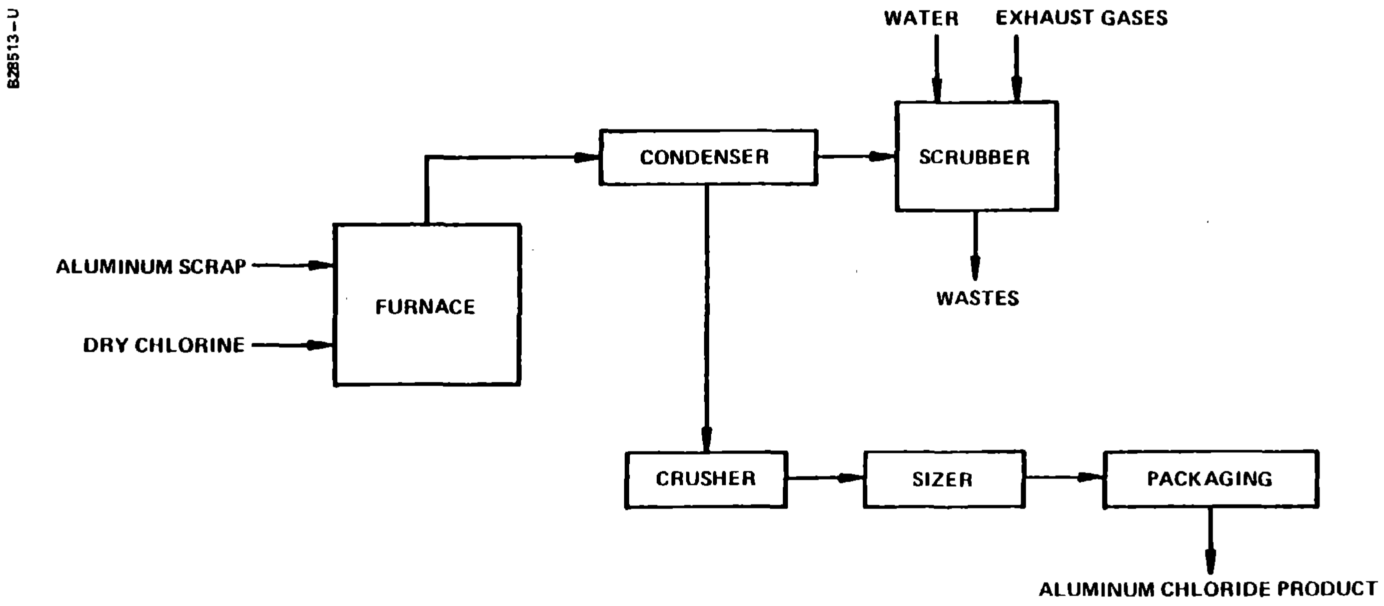


Figure 3. Aluminum Chloride from Molten Aluminum and Chlorine

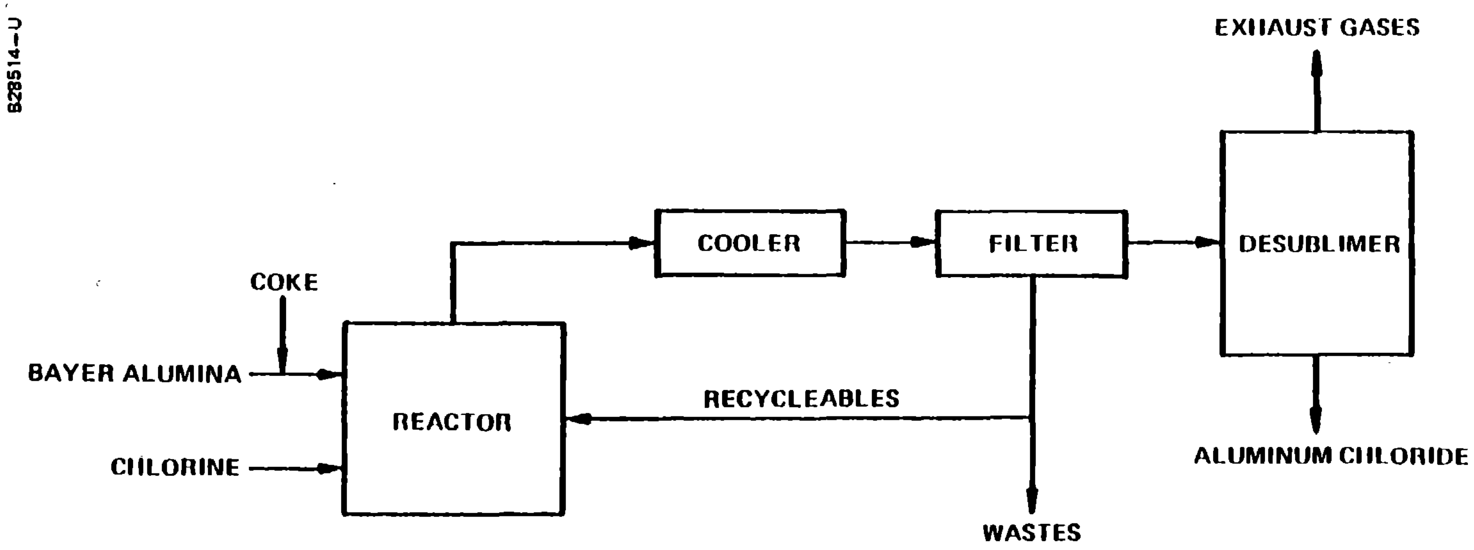


Figure 4. Aluminum Chloride from Alumina and Chlorine

| | |
|---|---|
| $AlCl_3$,% | 99.8 |
| $FeCl_3$,% | 0.08 |
| $SiCl_4$,% | 0.05 |
| NaCl,% | 0.02 |
| sublimate, % | 99.7 |
| water-insoluble material, % | 0.05 |
| nonvolatile material, % | 0.29 |

## 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 178,148 workers are potentially exposed to anhydrous aluminum chloride.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to anhydrous aluminum chloride were not found in the literature searched.

## 14. Biological Effects

Most of the reports on the biological effects of aluminum chloride do not state whether the test compound is in the anhydrous or the hydrated form. It may be assumed that anhydrous $AlCl_3$ was employed in studies where the state of hydration was not mentioned (only two studies were found in which hydrated $AlCl_3$ was specified), but it must be emphasized that anhydrous $AlCl_3$ is rapidly hydrated upon contact with water, both in test solution and _in vivo_. Exposure to atmospheric moisture is sufficient to cause rapid hydration. Therefore, because the the two forms of this compound are indistinguishable at the point of absorption into the body and consequently have identical biological effects, studies involving both compounds are summarized in this profile.

### a. Animal Studies

#### (1) Acute Exposures

The results of oral administration of aluminum chloride to several animal species (Table 10) indicate that this compound has a low level of toxicity, which may be due in part to poor absorption of the compound from the gastrointestinal tract (Ondreicka _et al_., 1966). The administration of oral

Table 10. Acute Toxicity of Aluminum Chloride

| Route | Species | Dose | Response | Reference |
|---|---|---|---|---|
| oral | rats | 250 | 0/5 deaths | Berlyne *et al.*, 1972 |
| oral | rats | 380 | LD50 | Krasovskii *et al.*, 1979 |
| oral | rats | 3700 | LD50 | *The Merck Index*, 1968 |
| oral | mice | 770 | LD50 | Ondreicka *et al.*, 1966 |
| oral | guinea pigs | 400 | LD50 | Krasovskii *et al.*, 1979 |
| oral | rabbits | 400 | LD50 | Krasovskii *et al.*, 1979 |

lethal doses of 1% $AlCl_3$ to rats that were nephrectomized resulted in symptoms of lethargy, anorexia, and orbital bleeding (Berlyne et al., 1972). It was noted that these signs of aluminum intoxication could also be induced in normal rats.

Benett et al. (1975) reported that intraperitoneal injection of pregnant rats with 75, 100, or 200 mg/kg aluminum chloride on days 9 to 13 or 14 to 18 of gestation resulted in ascites, adhesions between organs, perihepatic granulomas, and signs of centrilobular necrosis. A high incidence of maternal deaths followed treatment at the higher (100 and 200 mg/kg) dose levels.

Inhalation of a propylene glycol complex of aluminum-chloride-hydroxide (alchlor, an antiperspirant preparation compound) at an average concentration of 164 $mg/m^3$ for 4-6 hours/day for 3 days produced broncho-pneumonia, alveolar wall thickening, and small granulomatous foci in the lungs of hamsters (Drew et al., 1974). Lung irritation was also observed in rabbits following similar exposures to alchlor.

(2) Subchronic Exposures

When aluminum chloride was given orally for 20-30 days to rats and guinea pigs (6, 17, or 50 mg/kg) and rabbits (3, 9, or 27 mg/kg), the kidneys of these animals were reported to show moderate dystrophy of protein in the epithelium of the proximal tubules (Krasovskii et al., 1979). In addition, an increase in desquamation of the epithelium, pyknosis, and epithelial hyperplasia of the medullar rays were noted.

Ellis et al. (1979) noted that when rats were given daily intraperitoneal injections of aluminum chloride (approximately 2 increasing to 12 mg/kg x 52 days; approximately 0.8 increasing to 8 mg/kg x 48-85 days), there was an accumulation of aluminum in bone. After 53 days of aluminum treatment, rats developed osteomalacia that increased in severity with continued injections. The increased bone aluminum and osteomalocia persisted after injections had been stopped for up to 49 days, although endochondial ossification was restored to normal.

Lansdown (1973) found evidence of skin irritation when the uncovered back skin of mice, rabbits, and guinea pigs was treated daily for 5 consecutive days with 10% solutions of aluminum chloride. Epidermal changes consisting of hyperplasia, microabscess formation, dermal inflammatory cell infiltration, and occasionally ulceration were apparent in all three species. Macroscopic changes consisted of erythema, thickening, and scaling. A high degree of aluminum deposition was present in the epidermal keratin of the damaged skin. When mice were treated with 2.5, 5, 10, and 25% solutions of aluminum chloride, the degree of macroscopic and microscopic skin damage and aluminum deposition in the keratin was found to be directly related to the dose (no damage at 2.5%).

Following inhalation exposures to 50 mg/m$^3$ levels of a propylene glycol complex of aluminum-chloride-hydroxide (alchlor) for 6 hours/day, 5 days/week, for 10-30 exposure days, granulomas were observed in the lungs of hamsters (Drew et al., 1974). The reversibility of these lesions was not determined.

### (3) Chronic Exposures

Marked growth retardation has been reported in the second and third generations of mice treated with 19.3 mg/kg levels of aluminum chloride in drinking water for 180-390 days (Ondreicka et al., 1966).

When rats were exposed orally to 2.5 mg/kg levels of aluminum chloride for 6 months, decreased alkaline phosphatase in the blood and a slow down in development and reinforcement of conditioned reflexes were noted (Krasovskii et al., 1979).

### (4) Carcinogenicity

No information was found in the literature searched.

### (5) Mutagenicity

Testing of aluminum chloride in two strains of recombination-deficient Bacillus subtilis (H17 and M45) did not indicate any mutagenic effects in the rec assay (Nishioka, 1975; Kanematsu et al., 1980).

Chromosomal aberrations were detected in the bone marrow cells of mice following the intraperitoneal injection of 100 mol/l of aluminum chloride (Manna and Das, 1972). Aberrations included chromatid and subchromatid breaks, translocations, gaps, and constrictions.

Aluminum chloride failed to enhance the transformation of Syrian hamster embryo cells by simian adenovirus SA7 (Casto et al., 1979).

### (6) Teratogenicity

Aluminum chloride injected intraperitoneally at 75-200 mg/kg levels for days 9-13 or 14-18 of gestation produced embryotoxic effects (decreased fetal weight and crown-rump length, increased incidence of resorptions in rats) (Benett et al., 1975). At the 100 mg/kg level, gross fetal abnormalities (wavy and missing ribs, abnormal digits, poor ossification) were noted. A high incidence of dead fetuses was observed in mothers that had been treated with 200 mg/kg aluminum chloride on days 9-13 of gestation.

Dietary administration of aluminum chloride at levels of 500 or 1000 ppm on days 6-19 of gestation (McCormack et al., 1979) or intraperitoneal injection of 40 mg/kg on days 9 or 13 of gestation (Benett et al., 1975) did not produce embryotoxic or teratogenic effects in rats. In mice, teratogenic or embryotoxic effects were not seen following the administration of 19.3 mg/kg aluminum chloride for 180-390 days in the drinking water (Ondreicka et al., 1966).

Injection of high levels (15 mg) of aluminum chloride into the yolk sac or chorioallantoic membrane of developing chick embryos produced toxic effects but failed to show teratogenic effects (Ridgway and Karnofsky, 1952).

(7) Reproductive Effects

The inclusion of hydrated aluminum chloride in the drinking water of male rats at levels as high as 500 ppm for periods up to 90 days had no effect on reproductive capacity as measured by histopathological evaluation, plasma gonadotropin levels, and mating index (Dixon _et al._, 1979).

Decreased spermatozoa counts and lowered sperm motility have been reported in rats following a 6-month oral exposure to 2.5 mg/kg levels of alminum chloride (Krasovskii _et al._, 1979).

(8) Other Relevant Information

Intracranial injection of cats with solutions of aluminum chloride has been reported to produce neurofibrillary degeneration (NFD) with progressive encephalopathy (King _et al._, 1975). Even at brain concentrations of 5 to 6 times that found in the cat, however, aluminum chloride-injected rats did not display evidence of NFD (Crapper _et al._, 1973).

(b) Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

Aluminum chloride ($AlCl_3 \cdot 6H_2O$) (2.5%), when applied to scarified skin (occlusive conditions) once daily for 3 days, was mildly irritating at the end of the exposure (Frosch and Klingman, 1976). Hydrated aluminum chloride (5%) resulted in marked irritation in the same test.

### (3) Target Organ Toxicity

In skin tests on the forearms of 20 experimental subjects, Papa and Kligman (1967) found that the occlusive application of 20% aqueous $AlCl_3$ for 18 hours resulted in reduced perspiration, but in most cases no histological damage to the sweat apparatus. Three subjects showed miliaria rubra confined to the aluminum treated sites, but it was noted that these changes were not typical of aluminum anidrosis.

### (4) Epidemiology

No information was found in the literature searched.

## 15. Ongoing Studies

No current toxicological or environmental studies of anhydrous aluminum chloride were found.

## 16. Exposure Standards

The ACGIH (1979) currently recommends a Threshold Limit Value (TLV) of 2 mg/m$^3$ as Al for the soluble salts of aluminum. The TLV for these soluble salts, such as the chloride and sulfate, is based on the amount of hydrolyzed acid and the corresponding TLV. On the basis that 3 mol of HCl, with a TLV of 5 ppm, hydrolyze from 1 mol of $AlCl_3$, a TLV of 2 mg/m$^3$ as Al is recommended to provide the same degree of freedom from irritation that is provided by the TLV for HCl. As the acute toxicity from $Al_2(SO_4)_3$ is only slightly greater than that of $AlCl_3$, and the toxicity of the alums is considerably less, the 2 mg/m$^3$ is considered to be suitable for the soluble salts of aluminum (ACGIH, 1979).

## 17. Sources of Additional Relevant Information

A NIOSH Health Hazard Evaluation (HHE) relating to aluminum chloride has been conducted at Dawes Laboratories, Chicago Heights, IL (HHE No. 77-75-494).

## 18. Other Pertinent Data

No other information that would aid in the assessment of anhydrous aluminum chloride as an occupational hazard was found in the literature searched.

## E. ALUMINUM CHLORIDE, HYDROUS

1. **Chemical Name**: Aluminum Chloride, Hydrous

2. **Chemical Structure**: $AlCl_3 \cdot 6H_2O$

3. **Synonyms**: Aluminum chloride, hexahydrate
   Aluminum trichloride, hexahydrate

4. **Chemical Abstracts Service (CAS) Number**: 7784-13-6

5. **Registry of Toxic Effects of Chemical Substances (RTECS) Number**:

   BD0530000

6. **Chemical and Physical Properties**:

| | |
|---|---|
| Description: | white or yellowish deliquescent crystalline powder |
| Molecular Weight: | 241.43 |
| Boiling Point: | decomposes |
| Melting Point: | decomposes |
| Vapor Pressure: | --- |
| Solubility: | soluble in water (1 g/9 ml), ether, alcohol |
| Specific Gravity: | 2.4 (solid)<br>1.28 (commercial aqueous liquid) |
| Stability: | noncombustible |

7. **Production**

Production of hydrous aluminum chloride ranged from 3.2 to 8.1 thousand tons per year from 1950-1971 (Treskon, 1976c) on a 100% $AlCl_3$ basis. More recent, specific figures are not available.

CMR (1980b) estimates demand for hydrous $AlCl_3$ to be 5.6 thousand tons (100% $AlCl_3$ basis) in both 1979 and 1980. CMR (1980b) also projects future growth to 2.5% per year through 1984.

8. **Use**

CMR (1980b) reports that hydrous aluminum chloride is used in the following applications: cosmetics and pharmaceuticals, 60% (of total amount produced); miscellaneous, including pigments, roofing, specialty papers and photography, 40% (of total amount produced).

Hydrous aluminum chloride is normally available as a solution. It is employed in antiperspirant and deodorant preparations. Roofing granules and mineral aggregates for bituminous products are treated with the solution to improve adhesion of the asphalt. It is used in textile finishing to impart crease recovery and non-yellowing properties to cotton fabrics and antistatic characteristics to polyester, polyamide, and acrylic fabrics and to improve the flammability rating of nylon (Marstiller, 1978).

## 9. Manufacturers and Distributors

The manufacturers of hydrous aluminum chloride are the following (CMR, 1980b; SRI International, 1980):

| | | Annual Capacity (100% $AlCl_3$ Basis) (thousand of tons) |
|---|---|---|
| Allied Chemical | Chicago, IL | 2.2 |
| Chattem Chemical | Chattanooga, TN | 1.4 |
| Cortlic Chemical | Baltimore, MD | 1.4 |
| DuPont | Linden, NJ | 1.7 |
| Revlon (Reheis Chem.) | Berkeley Heights, NJ | 5.6 |
| | | 12.3 |

In addition to the manufacturers, the distributors include (*Chemical Week: 1981 Buyers' Guide Issue*, 1980); *Chem Sources--USA*, 1980):

American Hoechst
J.T. Baker Chem.
Barker Industries
Fisher Scientific
Mallinckrodt
Tridom Chem.
United Mineral and Chem.

## 10. Manufacturing Processes

Hydrous aluminum chloride is usually made by dissolving aluminum hydroxide, $Al(OH)_3$, in concentrated hydrochloric acid. When the acid is depleted, the solution is cooled to 0°C and gaseous hydrogen chloride is introduced. Crystalline aluminum chloride hydrate is precipitated, filtered from the liquor, washed with ethyl ether, and dried (Marstiller, 1978). This process is shown in Figure 5.

Alternatively, anhydrous $AlCl_3$ may be hydrolyzed in chilled dilute hydrochloric acid (Marstiller, 1978).

### 11. Impurities or Additives

A typical specification is 97.2% $AlCl_3 \cdot 6H_2O$, 30 ppm Fe, and 0.01% insoluble (Gottlieb, 1963).

### 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to hydrated aluminum chloride.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to hydrous aluminum chloride were not found in the literature searched.

### 14. Biological Effects

Most of the reports on the biological effects of aluminum chloride do not state whether the test compound is in the anhydrous or hydrated form. Only two studies were found in which the use of hydrated $AlCl_3$ was specifically stated, but it must be noted that anhydrous $AlCl_3$ is rapidly hydrated upon contact with water, both in test solution and *in vivo*. Exposure to atmospheric moisture is sufficient to cause rapid hydration. Therefore, because the two forms of the compound are indistinguishable at the point of absorption into the body and consequently have identical biological effects, studies involving both compounds are summarized in this profile.

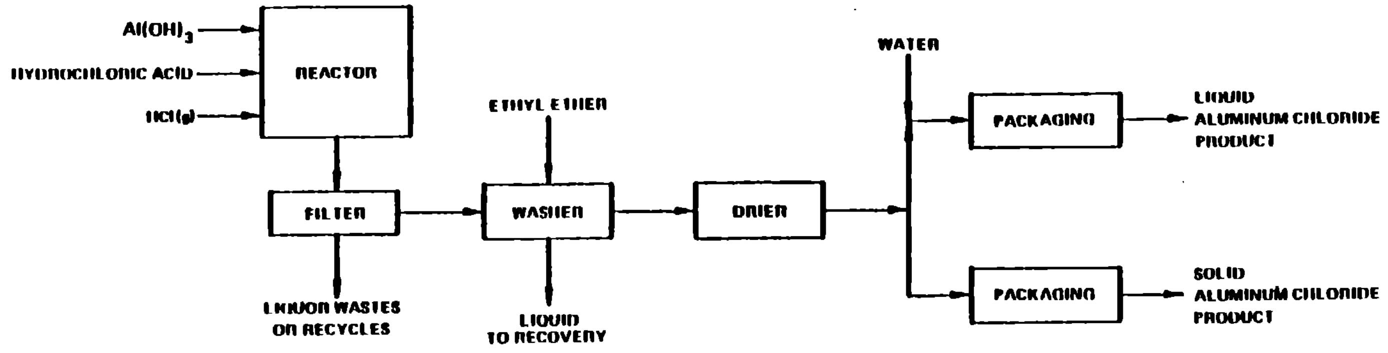


Figure 5. Manufacture of Hydrous Aluminum Chloride

### a. Animal Studies

#### (1) Acute Exposures

The results of oral administration of aluminum chloride to several animal species (Table 10, p. 65) indicate that this compound has a low level of toxicity, which may be due in part to poor absorption of the compound from the gastrointestinal tract (Ondreicka et al., 1966). The administration of oral lethal doses of 1% $AlCl_3$ to rats that were nephrectomized resulted in symptoms of lethargy, anorexia, and orbital bleeding (Berlyne et al., 1972). It was noted that these signs of aluminum intoxication could also be induced in normal rats.

Benett et al. (1975) reported that intraperitoneal injection of pregnant rats with 75, 100, or 200 mg/kg aluminum chloride on days 9 to 13 or 14 to 18 of gestation resulted in ascites, adhesions between organs, perihepatic granulomas, and signs of centrilobular necrosis. A high incidence of maternal deaths followed treatment at the higher (100 and 200 mg/kg) dose levels.

Inhalation of a propylene glycol complex of aluminum-chloride-hydroxide (alchlor, an antiperspirant preparation compound) at an average concentration of 164 mg/m$^3$ for 4-6 hours/day for 3 days produced bronchopneumonia, alveolar wall thickening, and small granulomatous foci in the lungs of hamsters (Drew et al., 1974). Lung irritation was also observed in rabbits following similar exposures to alchlor.

#### (2) Subchronic Exposures

When aluminum chloride was given orally for 20-30 days to rats and guinea pigs (6, 17, or 50 mg/kg) and rabbits (3, 9, or 27 mg/kg), the kidneys of these animals were reported to show moderate dystrophy of protein in the epithelium of the proximal tubules (Krasovskii et al., 1979). In addition, an increase in desquamation of the epithelium, pyknosis, and epithelial hyperplasia of the medullar rays were noted.

Ellis et al. (1979) noted that when rats were given daily intraperitoneal injections of aluminum chloride (approximately 2 increasing to 12 mg/kg x 52 days; approximately 0.8 increasing to 8 mg/kg x 48-85 days), there was an accumulation of aluminum in bone. After 53 days of aluminum treatment, rats developed osteomalacia that increased in severity with continued injections. The increased bone aluminum and osteomalocia persisted after injections had been stopped for up to 49 days, although endochondial ossification was restored to normal.

Lansdown (1973) found evidence of skin irritation when the uncovered back skin of mice, rabbits, and guinea pigs was treated daily for 5 consecutive days with 10% solutions of aluminum chloride. Epidermal changes consisting of hyperplasia, microabscess formation, dermal inflammatory cell infiltration, and occasionally ulceration were apparent in all three species. Macroscopic changes consisted of erythema, thickening, and scaling. A high degree of aluminum deposition was present in the epidermal keratin of the damaged skin. When mice were treated with 2.5, 5, 10, and 25% solutions of aluminum chloride, the degree of macroscopic and microscopic skin damage and aluminum deposition in the keratin was found to be directly related to the dose (no damage at 2.5%).

Following inhalation exposures to 50 $mg/m^3$ levels of a propylene glycol complex of aluminum-chloride-hydroxide (alchlor) for 6 hours/day, 5 days/week, for 10-30 exposure days, granulomas were observed in the lungs of hamsters (Drew et al., 1974). The reversibility of these lesions was not determined.

### (3) Chronic Exposures

Marked growth retardation has been reported in the second and third generations of mice treated with 19.3 mg/kg levels of aluminum chloride in drinking water for 180-390 days (Ondreicka et al., 1966).

When rats were exposed orally to 2.5 mg/kg levels of aluminum chloride for 6 months, decreased alkaline phosphatase in the blood and a slow down in development and reinforcement of conditioned reflexes were noted (Krasovskii et al., 1979).

### (4) Carcinogenicity

No information was found in the literature searched.

### (5) Mutagenicity

Testing of aluminum chloride in two strains of recombination-deficient *Bacillus subtilis* (H17 and M45) did not indicate any mutagenic effects in the rec assay (Nishioka, 1975; Kanematsu et al., 1980).

Chromosomal aberrations were detected in the bone marrow cells of mice following the intraperitoneal injection of 100 mol/l of aluminum chloride (Manna and Das, 1972). Aberrations included chromatid and subchromatid breaks, translocations, gaps, and constrictions.

Aluminum chloride failed to enhance the transformation of Syrian hamster embryo cells by simian adenovirus SA7 (Casto et al., 1979).

### (6) Teratogenicity

Aluminum chloride injected intraperitoneally at 75-200 mg/kg levels for days 9-13 or 14-18 of gestation produced embryotoxic effects (decreased fetal weight and crown-rump length, increased incidence of resorptions in rats) (Benett et al., 1975). At the 100 mg/kg level, gross fetal abnormalities (wavy and missing ribs, abnormal digits, poor ossification) were noted. A high incidence of dead fetuses was observed in mothers that had been treated with 200 mg/kg aluminum chloride on days 9-13 of gestation.

Dietary administration of aluminum chloride at levels of 500 or 1000 ppm on days 6-19 of gestation (McCormack et al., 1979) or intraperitoneal injection of 40 mg/kg on days 9 or 13 of gestation (Benett et al., 1975) did not produce embryotoxic or teratogenic effects in rats. In mice, teratogenic or embryotoxic effects were not seen following the administration of 19.3 mg/kg aluminum chloride for 180-390 days in the drinking water (Ondreicka et al., 1966).

Injection of high levels (15 mg) of aluminum chloride into the yolk sac or chorioallantoic membrane of developing chick embryos produced toxic effects but failed to show teratogenic effects (Ridgway and Karnofsky, 1952).

### (7) Reproductive Effects

The inclusion of hydrated aluminum chloride in the drinking water of male rats at levels as high as 500 ppm for periods up to 90 days had no effect on reproductive capacity as measured by histopathological evaluation, plasma gonadotropin levels, and mating index (Dixon et al., 1979).

Decreased spermatozoa counts and lowered sperm motility have been reported in rats following a 6-month oral exposure to 2.5 mg/kg levels of aluminum chloride (Krasovskii et al., 1979).

### (8) Other Relevant Information

Intracranial injection of cats with solutions of aluminum chloride has been reported to produce neurofibrillary degeneration (NFD) with progressive encephalopathy (King et al., 1975). Even at brain concentrations of 5 to 6 times that found in the cat, however, aluminum chloride-injected rats did not display evidence of NFD (Crapper et al., 1973).

(b) Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

Aluminum chloride ($AlCl_3 \cdot 6H_2O$) (2.5%), when applied to scarified skin (occlusive conditions) once daily for 3 days, was mildly irritating at the end of the exposure (Frosch and Kligman, 1976). Hydrated aluminum chloride (5%) resulted in marked irritation in the same test.

(3) Target Organ Toxicity

In skin tests on the forearms of 20 experimental subjects, Papa and Kligman (1967) found that the occlusive application of 20% aqueous $AlCl_3$ for 18 hours resulted in reduced perspiration, but in most cases no histological damage to the sweat apparatus. Three subjects showed miliaria rubra confined to the aluminum treated sites, but it was noted that these changes were not typical of aluminum anidrosis.

(4) Epidemiology

No information was found in the literature searched.

15. Ongoing Studies

No current toxicological or environmental studies of hydrous aluminum chloride were found.

16. Exposure Standards

The ACGIH (1979) currently recommends a Threshold Limit Value (TLV) of 2 $mg/m^3$ as Al for the soluble salts of aluminum. The TLV for these soluble salts, such as the chloride and sulfate, is based on the amount of hydrolyzed acid and the corresponding TLV. On the basis that 3 mol of HCl, with a TLV of 5 ppm, hydrolyze from 1 mol of $AlCl_3$, a TLV of 2 $mg/m^3$ as Al is recommended to provide the same degree of freedom from irritation that is provided by the TLV for HCl. As the acute toxicity from $Al_2(SO_4)_3$ is only slightly greater than that of $AlCl_3$, and the toxicity of the alums is considerably less, the 2 $mg/m^3$ is considered to be suitable for the soluble salts of aluminum (ACGIH, 1979).

### 17. Sources of Additional Relevant Information

A NIOSH Health Hazard Evaluation (HHE) relating to aluminum chloride has been conducted at Dawes Laboratories, Chicago Heights, IL (HHE No. 77-75-494).

### 18. Other Pertinent Data

No other information that would aid in the assessment of hydrous aluminum chloride as an occupational hazard was found in the literature searched.

## F. ALUMINUM DISTEARATE

1. Chemical Name: Aluminum Distearate

2. Chemical Structure: $Al(OH)(C_{18}H_{35}O_2)_2$

3. Synonyms: Aluminum, hydroxybis(octadecanoato-O)-

4. Chemical Abstracts Service (CAS) Number: 300-92-5

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number: Not listed.

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white powder |
| Molecular Weight: | 610.9 |
| Boiling Point: | --- |
| Melting Point: | 145°C |
| Vapor Pressure: | --- |
| Solubility: | insoluble in water |
| Specific Gravity: | 1.009 |
| Stability: | combustible |

7. Production

Production of aluminum distearate in recent years is as follows (USITC, 1979, 1978, 1977a, 1977b):

| Year | Production (in millions of pounds) |
|---|---|
| 1978 | 1.694 |
| 1977 | 3.005 |
| 1976 | 2.419 |
| 1975 | 1.943 |

Data available from the U.S. EPA (1980) regarding producers of aluminum distearate and production volumes are presented in Table 11.

8. Use

Aluminum distearate is used most extensively as an agent to improve the consistency of linseed alkyd resin paints and varnishes. It has wide applications in the cosmetics industry in the preparation of clear cosmetic gels

Table 11. Producers of Aluminum Distearate and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 300-92-5) |
|---|---|---|
| Joseph Ayers Inc. | | |
| Bethlehem, PA | Manufacturer | 0-1000 lb |
| Tenneco Chemicals Inc. | | |
| Piscataway, NJ | Manufacturer | 1-10 million lb |
| Elizabeth, NJ | Manufacturer | zero |
| Synthetic Products Co. | | |
| Cleveland, OH | Manufacturer | confidential |
| Penick Corp. | | |
| Newark, NJ | Manufacturer | confidential |

and pomades. It is also used as a gasoline gelling agent and may find use in the melt spining of polypropylene to enhance the dyeability and weatherability of the fiber (Warner, 1978).

Other uses include thickener in greases, water repellent, lubricant in plastics and ropes, and cement production (Hawley, 1977).

### 9. Manufacturers and Distributors

SRI International (1980) lists the following manufacturers:

| | |
|---|---|
| Chattem Inc. (Petrochems Co.) | Fort Worth, TX |
| CPC International (Penick Corp.) | Newark, NJ |
| Dart Industries (Synthetic Prod.) | Cleveland, OH |
| Diamond Shamrock Corp. | Cedartown, GA |
| Tenneco Inc. | Piscataway, NJ |
| Witco Chem. Corp. | Clearing, IL |
| | Lynwood, CA |
| | Perth Amboy, NJ |

USITC (1979) lists Diamond Shamrock, Joseph Ayers Inc., Norac Co., Synthetic Prod., and Witco as manufacturers.

Data available from the U.S. EPA (1980) regarding producers of aluminum distearate and production volumes are presented in Table 11.

In addition to the manufacturers, distributors include (*1980-81 OPD Chemical Buyers Directory*, 1980; *Chemical Week: 1981 Buyers' Guide Issue*, 1980):

Ashland Chem.
C.P. Hall Co.
Harshaw Chem.
International Commodities Export Corp.
Kraft Chem.
Mallinckrodt
Pacific Gateway
Pennwalt Corp.
Phillips Bro. Chem.
Ruger Chem.
Sattva Trading Co.
Sea Land Chem.
Smith Chem. and Color
Sobin Chem.
Thompson-Hayward Chem.
Joseph Turner and Co.
Universal Preservachem.

### 10. Manufacturing Processes

Aluminum distearate is prepared by the reaction of a solution of sodium stearate at pH 7.3 with an aqueous solution of aluminum sulfate or aluminum chloride (Warner, 1978).

The commercial process can be either batch or continuous operations. The process begins by dissolving caustic soda in water and adding stearic acid to form the sodium stearate. A solution of aluminum sulfate is then slowly charged to the reactor, causing the aluminum distearate to precipitate. The resulting slurry is filtered and washed in plate and frame filter presses, vacuum filters, or centrifugal separators. The partially dried filter cakes are placed in tray dryers and the remaining water is removed. The dried product may then be ground and separated to produce a uniform particle size powder (Whitaker, 1965).

### 11. Impurities and Additives

No information was found in the literature searched.

### 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 8,282 workers are potentially exposed to aluminum distearate.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum distearate were not found in the literature searched.

### 14. Biological Effects

No information regarding the biological effects of aluminum distearate was found in the literature searched.

### 15. Ongoing Studies

No current toxicological or environmental studies of aluminum distearate were found.

## 16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum distearate were found.

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum distearate as an occupational hazard was found in the literature searched.

## G. ALUMINUM ETHOXIDE

1. Chemical Name: Aluminum Ethoxide

2. Chemical Structure: $Al(OC_2H_5)_3$

3. Synonyms: Ethanol, aluminum salt

4. Chemical Abstracts Service (CAS) Number: 555-75-9

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white solid |
| Molecular Weight: | 162.15 |
| Boiling Point: | 189°C (at 3 mm Hg); 200°C (6-8 mm Hg) |
| Melting Point: | 140°C |
| Vapor Pressure: | --- |
| Solubility: | decomposed by water<br>slightly soluble in hot xylene; chlorobenzene, and other high boiling solvents |
| Specific Gravity: | --- |
| Stability: | --- |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum ethoxide and production volumes are presented below:

Continental Oil Co. (Westlake, LA)
Manufacturer - Not distributed
1977 Production: 1-10 million lb

Eastman Kodak (Rochester, NY)
Manufacturer
1977 Production: under 1000 lb

8. Use

The only commercial manufacturer uses its production captively (see data from U.S. EPA above). Aluminum ethoxide can be used as a catalyst in organic reactions and polymerizations, in the reduction of aldehydes and ketones

(Hayes, 1963; The Merck Index, 1976), and as a chemical intermediate (Bretzinger and Josten, 1978).

## 9. Manufacturers and Distributors

The manufacturers are listed above in Section 7.

Distributors include (Chem Sources--USA, 1980):

Columbia Organics
Chem Services
Fisher Sci.
ICN/K and K
Orion Chem.
Pflatz and Bauer
Reliable Chem.

## 10. Manufacturing Processes

The commercial process is unavailable. Aluminum ethoxide can, however, be prepared by reacting aluminum powder with absolute alcohol (ethanol) in xylene using small amounts of mercuric chloride and iodine as catalysts (The Merck Index, 1976).

## 11. Impurities or Additives

No information was found in the literature searched.

## 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to aluminum ethoxide.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum ethoxide were not found in the literature searched.

## 14. Biological Effects

No information regarding the biological effects of aluminum ethoxide was found in the literature searched.

15. Ongoing Studies

No current toxicological or environmental studies of aluminum ethoxide were found.

16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum ethoxide were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of aluminum ethoxide as an occupational hazard was found in the literature searched.

## H. ALUMINUM FLUORIDE

1. **Chemical Name**: Aluminum Fluoride
2. **Chemical Structure**: $AlF_3$
3. **Synonyms**: Aluminum trifluoride
4. **Chemical Abstracts Service (CAS) Number**: 7784-18-1
5. **Registry of Toxic Effects of Chemical Substances (RTECS) Number**: BD2100000
6. **Chemical and Physical Properties**:

| | |
|---|---|
| Description: | white crystalline solid |
| Molecular Weight: | 83.98 |
| Boiling Point: | --- |
| Melting Point: | sublimes at 1272°C |
| Vapor Pressure: | 1 mm Hg (1238°C) |
| Solubility: | 0.559 g/100 cc water<br>insoluble in most organic solvents<br>sparingly soluble in acids and alkalis |
| Specific Gravity: | $2.882^{25}_{4}$ |
| Stability: | not combustible |

7. **Production**

The following production figures for aluminum fluoride are available (MCA, 1975):

| Year | Production (in short tons) |
|---|---|
| 1973 | 140,187 |
| 1972 | 138,853 |

Gall (1980) has estimated that the volume of production in 1978 was about 91,000 tons, excluding recycled material or production from fluorosilicic acid.

Data available from the U.S. EPA (1980) regarding producers of aluminum fluoride and production volumes are presented in Table 12.

Table 12. Producers of Aluminum Fluoride and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 7784-18-1) |
|---|---|---|
| Kawecki Berylco Industries | | |
| Boyertown, PA | Manufacturer | 0-1000 lb |
| Greens Bayou Plant | | |
| Houston, TX | Manufacturer | 10-50 million lb |
| Allied Chemical Co. | | |
| Geismar, LA | Manufacturer | 50-100 million lb |
| Aluminum Co. of America | | |
| Forte Meade, FL | Manufacturer | confidential |
| Point Comfort, TX | Manufacturer | confidential |
| Pittsburg, PA | Importer | 1-10 million lb |
| Process Div. UOP Inc. | | |
| Shreveport, LA | Manufacturer | confidential |
| Shreveport, LA | Importer | confidential |
| Pennwalt Corp. | | |
| Cornwall Heights, PA | Manufacturer | 0-1000 lb |
| Tulsa, OK | Manufacturer | 1-10 thousand lb |
| E.I. DuPont De Nemours and Co. | | |
| Newark, NJ | Manufacturer | confidential |
| Kaiser Chemicals | | |
| Gramercy, LA | Manufacturer | 50-100 million lb |
| Oakland, CA | Importer | 1-10 million lb |
| United Mineral and Chem. Corp. | | |
| NYC, NY | Importer | 0-2000 lb |
| Amalgamet, Inc. | | |
| NYC, NY | Importer | zero |
| Bulkley Dunton and Co. | | |
| NYC, NY | Importer | 0-1000 lb |
| Revere Copper and Brass, Inc. | | |
| Rome, NY | Importer | 1-10 million lb |
| Alcan Aluminum Corp. | | |
| Cleveland, OH | Importer | 0.1-1 million lb |

The demands for aluminum fluoride can be expected to grow more slowly than the volume of aluminum production, because of greater efficiency in recycling fluorine and reduction of fluoride losses. The demand for aluminum fluoride may be reduced if the chloride process for aluminum metal production becomes widely used (Gall, 1980).

### 8. Use

The principal use of aluminum fluoride is as a make-up ingredient in the molten electrolyte of the aluminum reduction cell and in the electrolytic process for refining aluminum. Lower volume uses for aluminum fluoride include incorporation into glass (optical, laser, and electrically conducting), in low-melting glazes and enamels, and ceramics (electrical resistors), in fluxes (for casting, welding, brazing, and soldering), in catalyst compositions as inhibitors in fermentation processes, and in the manufacture of aluminum silicate fiber (Gall, 1980).

### 9. Manufacturers and Distributors

SRI International (1980) lists the following manufacturers of aluminum fluoride:

| | |
|---|---|
| Allied Chem. Corp. | Geismar, LA |
| Aluminum Co. of America | Fort Meade, FL |
| | Point Comfort, TX |
| Kaiser Aluminum and Chem. | Gramercy, LA |
| Pennwalt (Ozark-Mahoning) | Tulsa, OK |

Data available from the U.S. EPA (1980) regarding producers of aluminum fluoride and production volumes are presented in Table 12.

In addition to the manufacturers, the distributors include (*1980-81 OPD Chemical Buyers Directory*, 1980; *Chemical Week: 1981 Buyers' Guide Issue*, 1980; *Chem Sources--USA*, 1980):

Alcan Aluminum Corp.
Aldrich Chem.
Alfa Products (Thiokol/Ventron)
American Fluoride Corp.
American Hoechst Corp.
Apache Chem.
Atomergic Chemetals Corp.
Bodman Chem.
Cerac Inc.
Chem. Service
City Chem.
Engelhard Ind.
Five Seas Trading Co.
Gallard-Schlesinger Chem.
Hudson Labs
ICN K and K
Intsel Corp.
Jayar-Hoag Chem.
LaPine Sci.
MCB Reagents
Mitsui and Co. (USA)
Noah Chem.
Orion Chem.
Pfaltz and Bauer
Signo Trading
Spex Ind.
Stauffer Chem.
Ultra Pure Chem.

### 10. Manufacturing Processes

Gall (1980), in the *Kirk-Othmer Encyclopedia of Chemical Technology*, describes the manufacturing processes as follows:

> In a typical wet process, alumina hydrate is added to aqueous 15% hydrofluoric acid in makeup tanks of steel lined with rubber and carbon brick using HF-resistant mortar. Solution of the alumina hydrate and formation of crystalline $AlF_3 3H_2O$ takes place in continuous-flow crystallizers with the slurry held for about 3 hours at 93°C with continuous agitation. Continuous dewatering on rubber-lined rotary suction filters gives a washed cake with ca 10% moisture. The product is calcined in rotating horizontal kilns. In a similar process, employing continuous reation of hydrate and acid, hydrofluoric acid of higher concentration is used.
>
> In a dry process, partially dehydrated alumina hydrate reacts with HF gas at elevated temperature. The alumina may be packed in pellet form into vertical contact towers, but fluidized beds are more commonly used. Fluidization is maintained by the hydrogen fluoride gas and by the steam produced in the reaction. In one reported installation, the reactor is made of Inconel, divided into three superimposed zones by two horizontal sieve plates. Alumina trihydrate is fed into the top zone, and spent gases (water, hydrogen fluoride, silicon tetrafluoride, and dust) leave at this point. These gases may be used in the manufacture of cryolite. Hydrogen fluoride enters the bottom zone and receives heat from the departing aluminum trifluoride. The major reaction occurs in the middle zone to maintain a high temperature.
>
> Aluminum trifluoride may also be made from fluorine values gained from waste gases from phosphate rock acidulation in fertilizer manufacture. The silicon tetrafluoride in the gas is first converted to fluorosilicic acid which then reacts with alumina hydrate:

$$H_2SiF_6 + 2Al(OH)_3 \longrightarrow 2AlF_3 \cdot 3H_2O + SiO_2$$

For economic operation loss of aluminum trifluoride to the filter cake must be low, and phosphorus contamination must be avoided. The conditions of operation are critical. The alumina is added slowly to fluorosilicic acid which should contain excess silica, with the F/Si ratio ca 5. With slow addition, a well-filterable silica is obtained, but the reaction time should not be long enough for conversion of alpha alumina hydrate, formed first, to the less soluble beta form. After removal of the precipitated silica, seed crystals are added and beta aluminum trifluoride crystallizes at an elevated temperature (Gall, 1980).

## 11. Impurities and Additives

Commercial technical aluminum trifluoride usually has the following composition:

| | |
|---|---|
| assay as $AlF_3$, typical | 90.0% |
| free alumina as $Al_2O_3$, typical | 9.5 |
| silica as $SiO_2$, max | 0.1 |
| iron as $Fe_2O_3$, max | 0.1 |
| sulfur as $SO_2$, max | 0.32 |

## 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 1757 workers are potentially exposed to aluminum fluoride.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum fluoride were not found in the literature searched.

## 14. Biological Effects

### a. Animal Studies

#### (1) Acute Exposures

Oral doses of 600 mg/kg and subcutaneous doses of 300 mg/kg have been reported to cause death in 48 hours in adult guinea pigs (Waldbott, 1963).

#### (2) Subchronic Exposures

No information was found in the literature searched.

(3) Chronic Exposures

No information was found in the literature searched.

(4) Carcinogenicity

No information was found in the literature searched.

(5) Mutagenicity

No information was found in the literature searched.

(6) Teratogenicity

No information was found in the literature searched.

(7) Reproductive Effects

No information was found in the literature searched.

(8) Other Relevant Data

No information was found in the literature searched.

b. Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

No information was found in the literature searched.

(3) Target Organ Toxicity

No information was found in the literature searched.

(4) Epidemiology

No information was found in the literature searched.

15. Ongoing Studies

No current toxicological or environmental studies of aluminum fluoride were found.

16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum fluoride were found.

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

Exposure to fluorides may occur during the manufacture and use of aluminum fluoride. The toxicity of fluoride ion has been extensively reviewed by many sources, including NIOSH (1975). It has been recommended (NIOSH, 1975; ACGIH, 1977) and promulgated (OSHA, 1976) that occupational exposure to fluoride be controlled to concentrations no greater than 2.5 mg/m$^3$ (as F) determined as a time-weighted average (TWA) exposure for up to a 10-hour work day, 40-hour work week.

## I. ALUMINUM HYDRIDE

1. Chemical Name: Aluminum Hydride

2. Chemical Structure: $AlH_3$

3. Synonyms: None available

4. Chemical Abstracts Service (CAS) Number: 7784-21-6

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number: BD0930000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white to gray powder |
| Molecular Weight: | 29.99 |
| Boiling Point: | --- |
| Melting Point: | decomposes (160°C) |
| Vapor Pressure: | --- |
| Solubility: | decomposes with water |
| Specific Gravity: | --- |
| Stability: | dangerous fire and explosion risk |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum hydride and production volumes are presented below:

Continental Oil Co. (Westlake, LA)
Manufacturer - Not distributed
1977 Production: 1-10 million lb

8. Use

The only manufacturer (listed above) uses its production captively. Aluminum hydride can be used in the production of catalysts for polymerizations and elastomers (Tucker and Horne, 1979), in the production of triisobutyl aluminum (Hoff et al., 1978), in electroless coatings on plastics, textiles, fibers, and other metals, and as a possible rocket fuel (Hawley, 1977).

## 9. Manufacturers and Distributors

See Section 7.

## 10. Manufacturing Processes

The commercial method is not available. Aluminum hydride can be prepared by treating an ether solution of lithium hydride with aluminum chloride (The Merck Index, 1976) or by treating an ether solution of lithium aluminum hydride with aluminum chloride (Sullivan and Wade, 1980).

## 11. Impurities or Additives

No information was found in the literature searched.

## 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to aluminum hydride.

## 13. Control Technology

Specific factors that may contribute to or prevent employee exposure to aluminum hydride were not found in the literature searched.

## 14. Biological Effects

No information regarding the biological effects of aluminum hydride was found in the literature searched.

## 15. Ongoing Studies

No current toxicological or environmental studies of aluminum hydride were found.

## 16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum hydride were found.

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum hydride as an occupational hazard was found in the literature searched.

## J. ALUMINUM HYDROXIDE

1. Chemical Name: Aluminum Hydroxide

2. Chemical Structure: $Al(OH)_3$ or $Al_2O_3 \cdot 3H_2O$

3. Synonyms:

Aluminum trihydrate
Aluminum hydrate
Aluminum hydroxide trihydrate
Hydrated alumina
Hydrated aluminum oxide
α-Trihydrate
Mylanta
Maalox
Kudrox
Amberol ST 140F
Aluminum trihydroxide
Alusal
Haijiraito
Algelium
Gelusil
Amphajel
Co-lu-gel
Creamalin
Aluminic acid
C 4D
Kolantyl gel
Oxaine-M
Silain-gel
Wingel
British Aluminum AF-260
Trihydroxyaluminum
CI 77002
Higilite
Hydral 705
Hychol 705

4. Chemical Abstracts Service (CAS) Number: 21645-51-2

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

BD0940000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white crystalline powder, balls, or granules |
| Molecular Weight: | 78.01 |
| Boiling Point: | decomposes |
| Melting Point: | decomposes |
| Vapor Pressure: | --- |
| Solubility: | practically insoluble in water and alcohol<br>soluble in mineral acids and caustic soda |
| Specific Gravity: | 2.42 |
| Stability: | noncombustible |

7. Production

The most recent production figures for aluminum hydroxide (alumina trihydrate) are the following (Treskon, 1976a):

| Year | Production ($Al_2O_3 \cdot 3H_2O$ basis) (thousand of tons) |
|---|---|
| 1974 | 532 |
| 1973 | 607 |
| 1972 | 529 |
| 1971 | 476 |
| 1970 | 364 |

Data available from the U.S. EPA (1980) regarding producers of aluminum hydroxide and production volumes are presented in Table 13.

In 1978, 48.6 thousand tons of aluminum hydroxide were exported (USDC, 1979).

8. Use

In 1976, the major market for aluminum hydroxide (α-trihydrate) in the United States was as a flame-retardant filler for carpet backing, plastics, and building board. When a product filled with trihydrate is exposed to fire, the hydrate decomposes endothermically (releasing most of its chemically-bound water) and acts as a heat sink to absorb the heat of the fire (MacZura et al., 1978).

Other major markets include the manufacture of aluminum sulfate, sodium aluminate, aluminum fluoride, other aluminum compounds, and catalysts as well as pigments for paper, rubber, and paint (MacZura et al., 1978). Extensive amounts are used in the manufacture of glass, vitreous enamels, pottery, and china glazes. Fine grades are used as a base for cosmetic powders (Papee and Tertian, 1963) and as a constituent in toothpaste and pharmaceutical stomach antacids (MacZura et al., 1978).

Table 13. Producers of Aluminum Hydroxide and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 21645-51-2) |
|---|---|---|
| H. Kohnstamm and Co. | | |
| Brooklyn, NY | Manufactuer | confidential |
| Chevron USA | | |
| Richmond, CA | Manufacturer | zero |
| Keystone Color Works | | |
| York, PA | Manufacturer | 10-100 thousand lb |
| Katalco Corp. | | |
| Chicago, IL | Manufacturer/<br>Produced Site Limited | confidential |
| Engelhard Industries | | |
| Newark, NJ | Manufactuer | 1.1-11 million lb |
| Newark, NJ | Importer | 1-10 million lb |
| Aluminum Co. of America | | |
| Bauxite, AZ | Manufacturer | confidential |
| Mobile, AL | Manufacturer | confidential |
| Point Comfort, TX | Manufacturer | confidential |
| United Catalysts Inc. | | |
| Louisville, KY | Manufacturer/<br>Produced Site Limited | 1-10 thousand lb |
| Nalco Chemical Co. | | |
| Chicago, IL | Manufacturer<br>Produced Site Limited | confidential |
| The Mearl Corp. | | |
| Peekskill, NH | Manufacturer | 0-1 thousand lb |
| Hercules Inc. | | |
| Glen Falls, NY | Manufacturer | confidential |
| Harmons Colors Corp. | | |
| Hawthorne, NJ | Manufactuer | zero |
| The Harshaw Chemical Co. | | |
| Louisville, KY | Manufacturer/<br>Produced Site Limited | 10-100 thousand lb |
| Reheis Chemical Co. | | |
| Berkely Heights, NJ | Manufacturer | 10-50 million lb |
| Pennwalt Corp. | | |
| Homer, NY | Manufacturer | 1-10 thousand lb |

Table 13. Producers of Aluminum Hydroxide and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 21645-51-2) |
|---|---|---|
| CP Chemicals, Inc.<br>Sewaren, NJ | Manufacturer | confidential |
| Cattem Chemicals<br>Chattenooga, TN | Manufacturer | confidential |
| Allusuisse Metals, Inc.<br>Fort Lee, NJ | Importer | 10-100 thousand lb |
| Napp Chemicals<br>Lodi, NJ | Importer | 1-10 thousand lb |
| Alcan Aluminum Corp.<br>Cleveland, OH | Importer | 10-50 million lb |

The following tabulation presents the percentage of the total amount of aluminum hydroxide marketed that is used in each of the applications listed (SRC estimate):

| | Percentage of Total |
|---|---|
| Flame retardant | 50 |
| Aluminum sulfate (iron-free) | 15 |
| Other aluminum compounds | 5-10 |
| Cosmetics | 5 |
| Miscellaneous (pigments, catalysts, glass, etc.) | 20-25 |

9. Manufacturers and Distributors

SRI International (1980) lists the following manufacturers:

| | |
|---|---|
| Aluminum Co. of America | Bauxite, AR<br>Mobile, AL<br>Point Comfort, TX |
| Barcroft Co. | Lewes, DE |
| H. Kohnstamm and Co. | Camden, NJ |
| Revlon (Reheis) | Berkeley Heights, NJ |
| Reynolds Metals | Bauxite, AR |
| Solem Industries | Benton, AR<br>Fairmount, GA |
| Sterling Drug | Glenbrook, CT |

Other producers are listed in Table 13.

In addition to the manufacturers, the distributors include (Chemical Week: 1981 Buyers' Guide Issue, 1980); 1980-81 OPD Chemical Buyers Directory, 1980; Chem Sources--USA, 1980):

Accurate Chem.
Alcan Aluminum
Alfa Chem.
AluChem
Anachemia Chem.
Apache Chem.
Atomergic Chemetals
Austin Chem.
J.T. Baker Chem.
Bodman Chem.
R.E. Carroll Inc.
Chemical Dynamics
Kaiser Chem.
Kraft Chem.
LaPine Sci.
MCB Reagents
Mutchler Chem.
MWM Chem.
Noah Chem.
Orion Chem.
Pacific Gateway
Pfaltz and Bauer
Reliable Chem.
Rhone-Poulenc

Chem. Services
Delmar Inc.
EM Labs
Fisher Sci.
Gallard-Schlesinger
Hammill and Gillespie Inc.
Harrison and Crosfield
Hudspeth Corp.
Intsel Corp.
Roussel Corp.
H.M. Royal Inc.
E.M. Sergeant Pulp and Chem.
S.S.T. Corp.
Superior Materials
Tridom Chem.
George Uhe Co.
Willow Chem.
Willow Labs.
Young Chem.

### 10. Manufacturing Processes

The crystallized, naturally-occurring compound, known as gibbsite or hydragillite, is the principal constituent of tropical bauxites. Industrially, the $\alpha$-trihydrate (aluminum hydroxide) is obtained directly by the Bayer process, which consists of treating the bauxite with sodium hydroxide under pressure, followed by decomposition of the resulting sodium aluminate solution and seeding with previously formed hydrate (MacZura *et al*., 1978). The Bayer process is shown in Figure 6.

### 11. Impurities or Additives

The main impurity in the hydroxide obtained from the Bayer process is sodium (0.35-0.5% $Na_2O$); a few hundred parts per million of iron oxides and silicon oxides are also present (Papee and Tertian, 1963).

### 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 97,273 workers are potentially exposed to aluminum hydroxide.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum hydroxide were not found in the literature searched.

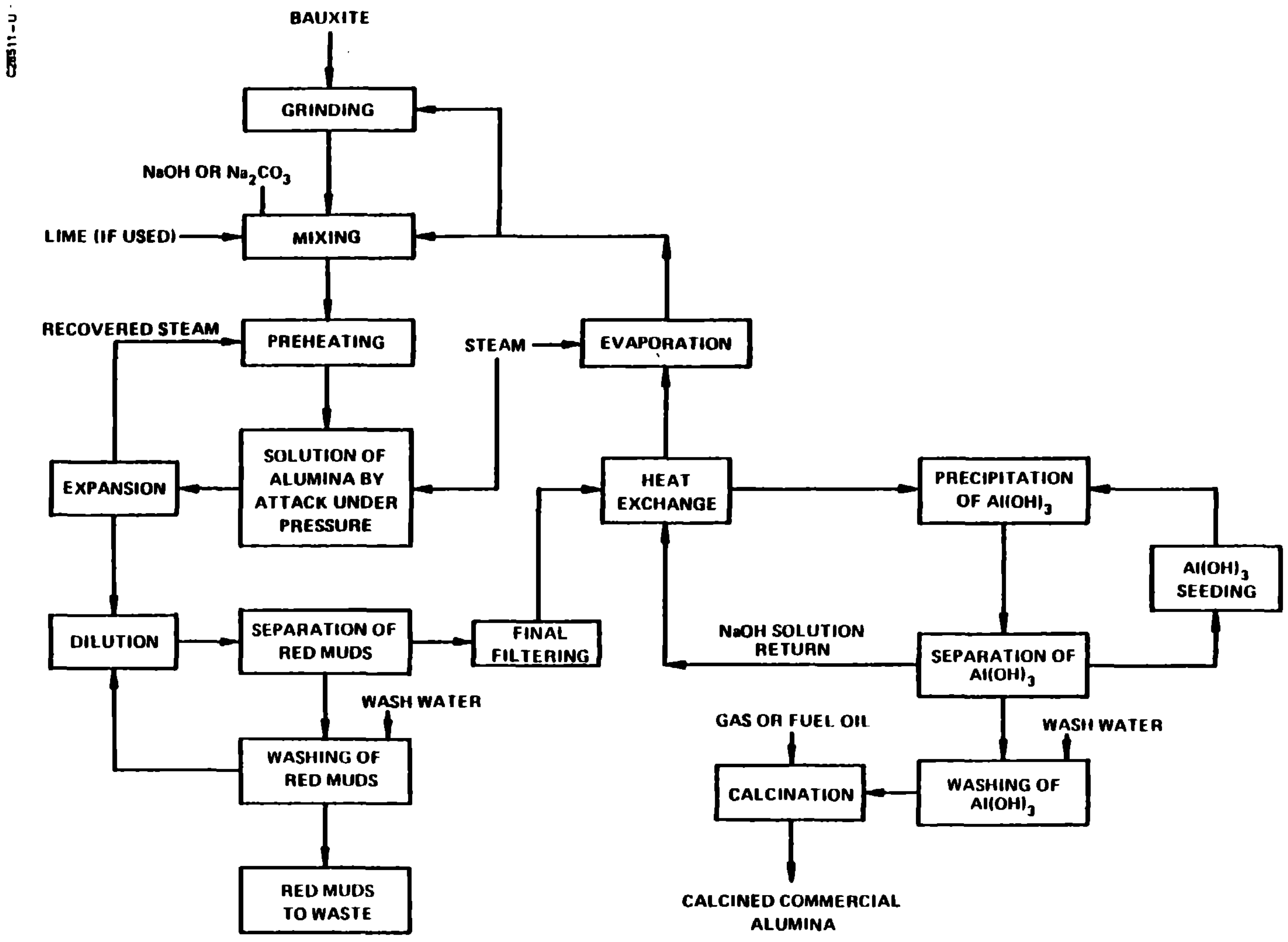


Figure 6. The Bayer Process (Anderson and Haupin, 1978)

## 14. Biological Effects

### a. Animal Studies

#### (1) Acute Exposures

The acute toxicity of aluminum hydroxide is summarized in Table 14. The administration of lethal oral and intraperitoneal doses of aluminum hydroxide to rats that were 5/6 nephrectomized resulted in symptoms of lethargy, anorexia, and orbital bleeding (Berlyne et al., 1972). It was noted that these signs of aluminum intoxication could also be induced in normal rats.

Intradermal injection of aluminum hydroxide (6.5, 0.65, or 0.065 mg) produced severe granulomas in the skin of guinea pigs, but no evidence of fibrosis (Turk and Parker, 1977).

#### (2) Subchronic Exposures

Thurston et al. (1972) reported that retarded growth and rachitic bone changes occurred in weanling rats that were fed a diet with aluminum hydroxide (3.2 g/kg added) for a 4-week period; these effects were corrected by the addition of dietary phosphate supplements.

Lansdown (1973) found that 10% aluminum hydroxide did not produce any visible or microscopic changes to the uncovered back skin of mice, rabbits, or guinea pigs when applied daily for 5 consecutive days.

#### (3) Chronic Exposures

No information was found in the literature searched.

#### (4) Carcinogenicity

No information was found in the literature searched.

#### (5) Mutagenicity

Mammalian mutagenic effects were evaluated in several animal species following single intraperitoneal injections of aluminum hydroxide (Nashed, 1975). At levels of 5-40 mg/kg, aluminum hydroxide produced no increase

Table 14. Acute Toxicity of Aluminum Hydroxide

| Route[a] | Species | Dose (mg/kg) | Response | Reference |
|---|---|---|---|---|
| gavage | rats | 150 mg Al/kg/day | 0/5 deaths x 5 days | Berlyne _et_ _al_., 1972 |
| i.p. | rats | 150 mg Al/kg/day | 5/5 deaths x 5 days | Berlyne _et_ _al_., 1972 |
| s.c. | rats | 150 mg Al/kg/day | 0/8 deaths x 5 days | Berlyne _et_ _al_., 1972 |

[a] i.p. = intraperitoneal; s.c. = subcutaneous.

in chromosome aberrations, but did stimulate mitosis in peritoneal cells of mice, rats, and hamsters.

(6) Teratogenicity

No information was found in the literature searched.

(7) Reproductive Effects

No information was found in the literature searched.

(8) Other Relevant Information

Aluminum hydroxide is toxic to guinea pig peritoneal macrophages and fibroblasts *in vitro*, and is hemolytic (Badenoch-Jones *et al*., 1978).

Intracranial injection of aluminum hydroxide and aluminum hydroxide gels (alumina cream) have produced electroencephalographic and clinical signs of epilepsy and neurofibrillary degeneration in dogs, cats, monkeys, and other mammalian species (Crapper *et al*., 1973; Sorenson *et al*., 1974; King *et al*., 1975; Feria-Velasco *et al*., 1980).

b. Human Studies

(1) Pharmacokinetics

Approximately 1-2% of an ingested dose of aluminum hydroxide is retained in the human body (Berlyne and Rubin, 1977). Patients with renal failure show higher gastrointestinal absorption of aluminum hydroxide (Berlyne *et al*., 1970), with values as high as 15% absorption reported (Clarkson *et al*., 1972).

Elevated bone, brain and muscle levels of aluminum have been observed in uremic patients or hemodialysis patients (Alfrey *et al*., 1976; Elliott *et al*., 1978; Ellis *et al*., 1979). One main source of this aluminum is aluminum hydroxide, which is administered to control hyperphosphatemia.

Metabolic balance studies in patients whose diets were supplemented with antacids containing 1-3 g of aluminum (as the hydroxide) per day for 7-21 6-day periods indicated an average positive daily balance of 23 to 303 mg of aluminum (Gorsky _et al._, 1979). The largest source of elimination of aluminum was through the feces, with small amounts (<1%) excreted in the urine.

### (2) Health Effects

High brain levels of aluminum in dialysis patients maintained on aluminum hydroxide treatment have been correlated with incidences of fatal encephalopathy (Crapper _et al._, 1973; Alfrey _et al._, 1976). Symptoms included the development of a progressive dementia with paranoia, confusion, speech disorders, delirium, and electroencephalographic abnormalities. Cerebral gray matter was found to contain aluminum at a level of 25 ppm in victims of this neurological syndrome (Alfrey _et al._, 1976).

Osteomalacia and impaired bone mineralization in renal dialysis patients have been correlated with increased bone levels of aluminum (Ellis _et al._, 1979); based on animal experiments, these authors do not believe that this defect is the result of altered phosphate levels.

### (3) Target Organ Toxicity

No information was found in the literature searched.

### (4) Epidemiology

No information was found in the literature searched.

## 15. Ongoing Studies

Metabolic studies of aluminum in renal disease patients and normal controls are in progress (Kaehny, 1980).

## 16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum hydroxide were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of aluminum hydroxide as an occupational hazard was found in the literature searched.

## K. ALUMINUM NITRATE

1. Chemical Name: Aluminum Nitrate

2. Chemical Structure: $Al(NO_3)_3 \cdot 9H_2O$

3. Synonyms: Aluminum nitrate, nonahydrate
   Nitric acid, aluminum salt

4. Chemical Abstracts Service (CAS) Number: 7784-27-2 (nonahydrate)
   13473-90-0 (anhydrous)

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   BD1050000 (nonahydrate)
   BD1040000 (anhydrous)

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white crystalline solid |
| Molecular Weight: | 375.19 |
| Boiling Point: | decomposes (150°C) |
| Melting Point: | 73.5°C |
| Vapor Pressure: | --- |
| Solubility: | 63.7 g/100 cc water (25°C)<br>soluble in alcohol, acetone, nitric acid<br>almost insoluble in ethylacetate and pyridine |
| Specific Gravity: | --- |
| Stability: | strong oxidizing agent--do not store near combustible materials |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum nitrate and production volumes are presented in Table 15.

8. Use

Only aluminum nitrate nonahydrate has commercial significance. It is used primarily as a salting-out agent in the solvent extraction of actinides in the recovery of spent nuclear fuel (Marstiller, 1978; Anderson, 1963).

Table 15. Producers of Aluminum Nitrate and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 13473-90-0) |
|---|---|---|
| Mineral Research and Dev. Corp. Concord, NC | Manufacturer | confidential |
| Wasatch Chem. (Entrada) Salt Lake City, UT | Manufacturer | 1-10 million lb |
| Eastman Kodak Rochester, NY | Manufacturer | 10-100 thousand lb |
| Katalco Corp. Chicago, IL | Manufacturer/ Produced Site Limited | confidential |
| J.T. Baker Chem. Phillipsburg, NJ | Manufactuer | 10-100 thousand lb |
| W.R. Grace and Co. Curtis Bay, MD | Manufacturer/ Produced Site Limited | 0.1-1.0 million lb |
| GTE Sylvania Inc. Towanda, PA | Manufacturer | 1-10 thousand lb |
| Dan River Inc. Danville, VA | Manufacturer | zero |
| Pennwalt Corp. Cornwall Heights, PA | Manufacturer | 0-1 thousand lb |
| CP Chemicals Sewaren, NJ | ManufactuRer | confidential |
| Chevron Chemical Kennewick, WA | Manufacturer | confidential |
| United Mineral and Chem. New York, NY | Importer | 0-1 thousand lb |
| EM Laboratories Inc. Elmsford, NY | Importer | 1-10 thousand lb |
| American Hoechst Corp. Bridgewater, NJ | Importer | confidential |

Aluminum nitrate is also used as a source of alumina in the preparation of insulating papers, on transformer core laminates, and in cathode ray tube heating elements (Marstiller, 1978). Other applications include textile mordant, leather tanning, and catalyst in petroleum refining (Hawley, 1977). At one time, some hundreds of tons per year were used in catalyst production (Schliffer, 1947).

### 9. Manufacturers and Distributors

SRI International (1980) lists the following manufacturers:

| | |
|---|---|
| J.T. Baker Chem. | Phillipsburg, NJ |
| MCB Reagents | Norwood, OH |
| Mineral Research and Dev. Corp. | Concord, NC |
| United Catalysts | Louisville, KY |

Other producers are listed in Table 15.

Distributors include (1980-81 OPD Chemical Buyers Directory, 1980; Chemical Week: 1981 Buyers' Guide Issue, 1980; Chem Sources--USA, 1980):

Alfa Prod.
American Hoechot Corp.
American Sci.
Anachemia Chem.
Apache Chem.
Aran Isles Chem.
Barker Ind.
Campbell Chem.
Chem. Services
Delamar Inc.
E.M. Labs
Fisher Sci.
Gallard-Schlesinger
Hetako
LaPine Sci.
Mallinckrodt
MCB Reagents
Orion Chem.
Pfaltz and Bauer
Reliable Chem.
Sattva Trading Co.
G. Fredrick Smith Co.
Spex Ind.
United Mineral and Chem.

### 10. Manufacturing Processes

Aluminum nitrate is prepared by dissolving aluminum or aluminum hydroxide in dilute nitric acid, and crystallizing the aluminum nitrate from the resulting aqueous solution. Commercially, aluminous materials (such as bauxite), and nitric acid can be used (Marstiller, 1978). Prior to the crystallization, impurities in the crude nitrate are removed (Anderson, 1963).

11. Impurities or Additives

Aluminum nitrate is available in technical grade, C.P. grade, and 99.75% (Hawley, 1977).

12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to aluminum nitrate.

13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum nitrate were not found in the literature searched.

14. Biological Effects

a. Animal Studies

(1) Acute Exposures

Nekipelov (1966) determined an oral LD50 of 264 mg/kg for rats. The effect of aluminum nitrate on the rats was expressed by general sluggishness, reduced motor activity, somnolence, and profuse salivation; some of the rats developed "neurotic" tendencies. Gross examination of the rats that died during the experiment revealed necrotic tissue in the gastric mucosa (in which deposits of aluminum nitrate were found) and ulcerations. Histological examination of the internal organs of the rats that had received aluminum nitrate doses of up to 250 mg/kg revealed fatty degeneration of the liver and reticuloendothelial hyperplasia with marked accumulation of megakaryocytes in the spleen.

A single oral dose of 10 mg/kg to rats had no significant effect on the oxygen uptake of rats, but doses of 40 and 100 mg/kg reduced uptake an average of 70-80% (Nekipelov, 1966).

### (2) Subchronic Exposures

When mice and rats were injected intraperitoneally with aluminum nitrate for 10 consecutive days, the following lethal dose levels were reported (Hart and Adamson, 1971):

| | LD50* (mg/kg) | LD10* (mg/kg) |
|---|---|---|
| $CDF_1$ male mice | 320 | 213 |
| Sprague-Dawley female rats | 327 | 240 |

* the observation period totaled 30 days from first injection.

The oral administration of aluminum nitrate in doses of 25, 50, and 100 mg/kg for 10 days reduced the "working capacity" of rats and rabbits, as determined by the "spinning test" (Nekipelov, 1966). The same doses of aluminum nitrate were also reported to adversely affect reflex responses in rabbits.

Daily peroral doses of 0.1, 1, and 10 mg/kg aluminum nitrate for 6 months had no effect on the general condition, behavior, weight, blood pattern, gastic secretion, or functional state of the nervous system of rats, although a significant reduction in oxygen uptake was observed at 10 mg/kg (Nekipelov, 1966). In rabbits, aluminum nitrate doses of 0.1 and 1 mg/kg had no effect on general condition, weight, duration of "narcotic state," gastric secretion, or blood pattern. At 10 mg/kg, however, changes in gastric secretions (total acidity decreased by 47%, the content of free hydrochloric acid decreased by 21%, and the digestive capacity of the gastric juice decreased by 15%) and decreases in weight, red blood cell counts and hemoglobin, and duration of the "narcotic stage" were observed.

Lansdown (1973) found evidence of skin irritation when the uncovered back skin of mice, rabbits, and guinea pigs was treated daily for 5 consecutive days with 10% aluminum nitrate. Epidermal changes consisting of hyperplasia, microabscess formation, dermal inflammatory cell infiltration, and occasionally ulceration were apparent in all three species. A high degree of aluminum deposition was present in the epidermal keratin of the damaged skin.

(3) Chronic Exposures

No information was found in the literature searched.

(4) Carcinogenicity

No information was found in the literature searched.

(5) Mutagenicity

No information was found in the literature searched.

(6) Teratogenicity

No information was found in the literature searched.

(7) Reproductive Effects

No information was found in the literature searched.

(8) Other Relevant Information

No information was found in the literature searched.

b. Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

No information was found in the literature searched.

(3) Target Organ Toxicity

No information was found in the literature searched.

(4) Epidemiology

No information was found in the literature searched.

15. Ongoing Studies

No current toxicological or environmental studies of aluminum nitrate were found.

## 16. Exposure Standards

The ACGIH (1979) currently recommends a Threshold Limit Value (TLV) of 2 $mg/m^3$ as Al for the soluble salts of aluminum. The TLV for these soluble salts, such as the chloride and sulfate, is based on the amount of hydrolyzed acid and the corresponding TLV. On the basis that 3 mol of HCl, with a TLV of 5 ppm, hydrolyze from 1 mol of $AlCl_3$, a TLV of 2 $mg/m^3$ as Al is recommended to provide the same degree of freedom from irritation that is provided by the TLV for HCl. As the acute toxicity from $Al_2(SO_4)_3$ is only slightly greater than that of $AlCl_3$, and the toxicity of the alums is considerably less, the 2 $mg/m^3$ is considered to be suitable for the soluble salts of aluminum (ACGIH, 1979).

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum nitrate as an occupational hazard was found in the literature searched.

## L. ALUMINUM OXIDE

1. Chemical Name: Aluminum Oxide

2. Chemical Structure: $Al_2O_3$

3. Synonyms: Alumina

4. Chemical Abstracts Service (CAS) Number: 1344-28-1

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number: BD1200000

6. Chemical and Physical Properties (pure compound):

| | |
|---|---|
| Description: | white solid |
| Molecular Weight: | 101.96 |
| Boiling Point: | 2980°C |
| Melting Point: | 2045°C |
| Vapor Pressure: | 1 mm Hg (2148°C) |
| Solubility: | insoluble in water<br>very slightly soluble in acids and alkalis<br>practically insoluble in non-polar solvents |
| Specific Gravity: | $3.965^{25}$ |
| Stability: | very stable under ambient conditions; noncombustible |

7. Production

Treskon (1976a) lists the following production volumes for aluminum oxide:

| Year | Production - (in thousands of short tons) |
|---|---|
| 1974 | 6950 |
| 1973 | 6751 |
| 1972 | 6204 |
| 1971 | 6445 |

Current industry capacity to produce aluminum oxide is 7930 thousand tons per year (SRI International, 1980).

Data available from the U.S. EPA (1980) regarding producers of aluminum oxide and production volumes are presented in Table 16.

### 8. Use

About 90% of the produced alumina is used in the production of aluminum metal. The remainder is consumed in other applications such as flame retardant fillers, preparation of aluminum compounds, pigments, adsorbents, catalysts, ceramics, refractories, and abrasives (MacZura et al., 1978).

Various types of commercial alumina are produced; these include calcined, fused, activated, tabular (sintered), and various low sodium grades. The calcined alumina market consumes slightly more than 50% of the chemical alumina production; these markets are shown in Table 17 (MacZura et al., 1978).

North American fused alumina production has stabilized at an average not exceeding 200 kilotons/year. It is used in refractories, abrasives, and production of alumina-silica fibers (MacZura et al., 1978).

United States production of activated aluminas is 20-25 kilotons/year. They are widely used in adsorption for the drying of gases and liquids and in catalysis applications such as Claus converters, alcohol dehydration, and isomerization of olefins (MacZura et al., 1978).

Tabular alumina is used primarily in refractories and ceramics but also has applications in molten metal filter media, ground filler for epoxy and polyester resins, inert supporting beds for adsorbents or catalysts, and heat exchange media, among others (MacZura et al., 1978).

### 9. Manufacturers and Distributors

The manufacturers of aluminum oxide, as listed by SRI International (1980), are shown in Table 18. A substantial percentage of the domestic capacity is located in Texas and Louisiana.

Table 16. Producers of Aluminum Oxide and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1344-28-1) |
|---|---|---|
| Springhill Mill | | |
| Springhill, LA | Manufacturer | 50-100 million lb |
| Chervon | | |
| Richmond, CA | Manufacturer | confidential |
| Kerr-McGee Chemical Corp. | | |
| Hamilton, MS | Manufacturer | 1.2-12 million lb |
| Katalco Corp. | | |
| Chicago, IL | Manufacturer | confidential |
| Engelhard Industries | | |
| Newark, NJ | Manufacturer | 2-20 million lb |
| Newark, NJ | Importer | 10-50 million lb |
| Haven Chemical | | |
| Philadelphia, PA | Manufacturer | confidential |
| Monsanto Co. | | |
| Texas City, TX | Manufacturer | 0.1-1 million lb |
| St. Louis, MO | Importer | 10-100 thousand lb |
| Ferro Corp. | | |
| Cleveland, OH | Manufacturer/ Produced Site Limited | 1-10 thousand lb |
| Valumet Processing Corp. | | |
| Sayreville, NJ | Manufacturer | 1-10 thousand lb |
| Ormet Corp. | | |
| Burnside, LA | Manufacturer | over 1 billion lb |
| Aluminum Co. of America | | |
| Bauxite, AZ | Manufacturer | confidential |
| Mobile, AL | Manufacturer | confidential |
| Pittsburgh, PA | Manufacturer | 1 billion lb |
| Point Comfort, TX | Manufacturer | confidential |
| Armak Catalysts | | |
| Pasadena, TX | Manufacturer | confidential |
| American Cyanamid | | |
| Wayne, NJ | Manufacturer | zero |
| Fort Worth, TX | Importer | confidential |
| Michigan City, IN | Manufacturer | confidential |
| Stamford, CT | Manufacturer | 0.1-1 million lb |
| Willow Island, WV | Manufacturer | confidential |
| Adrian Joyce Works | | |
| Baltimore, MD | Manufacturer | confidential |

Table 16. Producers of Aluminum Oxide and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1344-28-1) |
|---|---|---|
| United Catalysts Inc. | | |
| Louisville, KY | Manufacturer | 1.2-12 million lb |
| Louisville, KY | Manufacturer | 0.3-3 million lb |
| Union Carbide Corp. | | |
| Chickasaw, AL | Manufacturer | 0.1-1 million lb |
| Dresser Industries | | |
| Niagara Falls, NY | Manufacturer | confidential |
| W.R. Grace and Co. | | |
| Chattanooga, TN | Manufacturer | 0.1-1 million lb |
| Curtis Bay, MD | Manufacturer | 0.1-1 million lb |
| General Refractories Co. | | |
| Philadelphia, PA | Manufacturer | confidential |
| Process Div. UOP Inc. | | |
| Shreveport, LA | Manufacturer/ | confidential |
| Importer | confidential | |
| McCook, IL | Manufacturer | confidential |
| Chemical Products Plant | | |
| Cleveland, OH | Manufacturer | 0-1000 lb |
| Continental Oil Co. | | |
| Westlake, LA | Manufacturer | 10-50 million lb |
| Chattem Chemical | | |
| Chattanooga, TN | Manufacturer | confidential |
| Kaiser Chemicals | | |
| Gramercy, LA | Manufacturer | over 1 billion lb |
| Baton Rouge, LA | Manufacturer | over 1 billion lb |
| Oakland, CA | Importer | over 1 billion lb |
| Reynolds Metal Co. | | |
| Bauxite, AZ | Manufacturer | 500-1000 million lb |
| Gregory, TX | Manufacturer | over 1 billion lb |
| Troutdale, OR | Importer | 1-10 million lb |
| Longview, WA | Importer | 500-1000 million lb |
| Alumax Extrusions Inc. | | |
| Plant City, FL | Manufacturer | 0.1-1 million lb |
| St. Charles, IL | Manufacturer | 0.1-1 million lb |
| Hernando, MS | Manufacturer | 0.1-1 million lb |
| Alumax Mill Products | | |
| Morris, IL | Manufacturer | 1-10 million lb |
| Riverside, CA | Manufacturer | 1-10 million lb |

Table 16. Producers of Aluminum Oxide and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1344-28-1) |
|---|---|---|
| Alumax Foils | | |
| St. Louis, MO | Manufacturer | 0.1-1 million lb |
| V.E. Anderson | | |
| Rome, GA | Manufacturer | 1-10 thousand lb |
| Apex International Alloys | | |
| Carson, CA | Manufacturer | 1-10 million lb |
| Checotah, OK | Manufacturer | 1-10 million lb |
| Cleveland, OH | Manufacturer | 1-10 million lb |
| Chicago, IL | Manufacturer | 1-10 million lb |
| United Mineral and Chem. Corp. | | |
| NYC, NY | Importer | 0-1000 lb |
| Cincinnati Milacron Prod. | | |
| Cincinnati, OH | Importer | confidential |
| Intsel Corp. | | |
| NYC, NY | Importer | 2-20 thousand lb |
| Universal Grindingwheel Co. | | |
| Philadelphia, PA | Importer | 10-100 thousand lb |
| Allied Chemical | | |
| Charlotte, NC | Importer | 1-10 thousand lb |
| E.I. DuPont De Nemours and Co. | | |
| Cleveland, OH | Manufacturer | confidential |
| Texas Instruments Inc. | | |
| Sherman, TX | Manufacturer | zero |
| C.E. Minerals | | |
| Greeneville, TN | Manufacturer | 10-100 thousand lb |
| SCM Corp. | | |
| Astabula, OH | Manufacturer | confidential |
| Martin Marietta | | |
| St. Croix, VI | Manufacturer | over 1 billion lb |
| The Dalles, OR | Importer | 100-500 million lb |
| Goldendale, WA | Importer | 100-500 million lb |
| Mobile Oil Corp. | | |
| Paulsboro, NJ | Manufacturer | 1-10 million lb |
| Nalco Chemical Co. | | |
| Chicago, IL | Manufacturer | 1-10 million lb |

Table 16. Producers of Aluminum Oxide and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1344-28-1) |
|---|---|---|
| Porocel Corp. | | |
| Little Rock, AR | Manufacturer | 0.1-1 million lb |
| The Harshaw Chemical Co. | | |
| Cleveland, OH | Manufacturer | 0.1-1 million lb |
| Elyria, OH | Manufacturer | 0.1-1 million lb |
| Cleveland, OH | Importer | 0.1-1 million lb |
| The Exolon Co. | | |
| Tonawanda, NY | Importer | confidential |
| E.M. Laboratories | | |
| Elmsford, NY | Importer | 1-10 thousand lb |
| Eastalco Aluminum Co. | | |
| Fredrick, MO | Importer/ Produced Site Limited | 500-1000 million lb |
| Exxon Co. | | |
| Houston, TX | Importer | 0.1-1 million lb |
| Great Lakes Carbon Corp. | | |
| NYC, NY | Importer | 1-10 million lb |
| Ferroxcube Amperex Corp. | | |
| Saugerties, NY | Importer | 1-10 thousand lb |
| Intalco Aluminum Corp. | | |
| Ferndale, WA | Importer | 500-1000 million lb |
| Stauffer Chemical Co. | | |
| Portland, OR | Importer | 10-50 million lb |
| Bulkley Dunton and Co. | | |
| NYC, NY | Importer | 1-10 thousand lb |
| The Carborundum Corp. | | |
| Niagara Falls, NY | Importer | 50-100 million lb |
| Imperial Wallpaper Mills | | |
| Plattsburgh, NY | Importer | 10-100 thousand lb |
| Consolidated Aluminum Co. | | |
| St. Louis, MO | Importer | 100-500 million lb |
| BASF Wyandotte Corp. | | |
| Parsippany, NJ | Importer | zero |
| Aceto Chemical Co. | | |
| Flushing, NY | Importer | 0.1-1 million lb |

Table 16. Producers of Aluminum Oxide and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1344-28-1) |
|---|---|---|
| Alusuisse Metals Inc.<br>Fort Lee, NJ | Importer | confidential |
| Atlantic Richfield Co.<br>Los Angeles, CA | Importer | over 1 billion lb |
| The Anaconda Co.<br>Louisville, KY | Importer | over 1 billion lb |
| Adolf Meller Co.<br>Providence, RI | Importer | confidential |
| Uniroyal<br>Naugatuck, CT | Importer | 10-100 thousand lb |
| Superior Materials<br>NYC, NY | Importer | 0.1-1 million lb |
| Sumitomo Shoji America<br>NYC, NY | Importer | 1-10 thousand lb |
| H.C. Starck Inc.<br>NYC, NY | Importer | 0-1000 lb |
| Billiton Metals and Ores<br>NYC, NY | Importer | 2-20 million lb |
| Bodman Chemicals<br>Aston, PA | Importer | 1-10 thousand lb |
| Lukens Chemical Co.<br>Cambridge, MA | Importer | 0.1-1 million lb |
| Montedisan USA<br>NYC, NY | Importer | 0-1000 lb |
| Norton Co.<br>Worcester, MA | Importer | confidential |
| Titanium Pigment Div.<br>South Amboy, NJ | Importer | 1-10 million lb |
| Mead Corp.<br>Dayton, OH | Importer | 10-100 thousand lb |
| Petro-Tex Chem. Corp.<br>Houston, TX | Importer | zero |
| GTE Sylvania<br>Towanda, PA | Importer | 10-100 thousand lb |
| Harrison Crosfield<br>Newton Beach, CA | Importer | 20-200 thousand lb |

Table 16. Producers of Aluminum Oxide and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer | Type of Production | 1977 Production Range (CAS No. 1344-28-1) |
|---|---|---|
| General Motors Corp.<br>Detroit, MI | Importer | 2-20 million lb |
| Rhone-Poulenc<br>Freeport, TX | Importer | 1-10 million lb |
| Groveton Papers Co.<br>Groveton, NH | Importer | 0.1-1 million lb |
| Chevron Research Co.<br>Elyria, OH | Importer | confidential |
| Degussa Corp.<br>Teterboro, NJ | Importer | 0.1-1 million lb |
| Celanese Corp.<br>NYC, NY | Importer | 10-100 thousand lb |
| Kawecki Berylco Ind.<br>Reading, PA | Importer | 1-10 thousand lb |
| Alcan Aluminum Corp.<br>Cleveland, OH | Importer | 10-50 million lb |
| A.P. De Sanyo and Son, Inc.<br>Santa Cruz, CA | Importer | 0.1-1 million lb |
| National Bottle Mfg. Co.<br>Rockdale, IL | Importer | 1-10 million lb |

Table 17. World Nonaluminum Calcined Alumina Markets (MacZura *et al.*, 1978)

| Market | 1968<br>(percentage) | 1975 |
|---|---|---|
| Refractories (includes fused-cast and refractories made with sintered tabular grains) | 38 | 62 |
| Abrasive (fused and polishing aluminas) | 21 | 16 |
| Ceramics, electronic and technical (80+% $Al_2O_3$, includes spark plug insulators) | 29 | 11 |
| Whitewares (includes electrical insulators below 80% $Al_2O_3$) | 6 | 9 |
| Glass enamels | 4 | 1 |
| Miscellaneous | 2 | 1 |

Table 18. Manufacturers of Aluminum Oxide (Activted, Calcined, and Tabular) (SRI International, 1980)

| Producer | Location | Annual Capacity (thousands of tons) |
|---|---|---|
| Akzona Inc. | | |
| Armak Co., subsid. | | |
| Armak Catalysts Div. | Pasadena, TX | n.a. |
| Aluminum Co. of America | Bauxite, AR | 375 |
| | Mobile, AL | 990 |
| | Point Comfort, TX | 1335 |
| Combustion Engineering, Inc. | | |
| C-E Minerals Div. | Greeneville, TN | n.a. |
| Conoco Inc. | | |
| Conoco Chems. Co. Div. | Lake Charles, LA | 20 |
| Ferro Corp. | | |
| Transelco Div. | Penn Yan, NY | n.a. |
| Kaiser Aluminum and Chem. Corp. | | |
| Kaiser Aluminum Div. | Baton Rouge, LA | 1025 |
| | Gramercy, LA | 800 |
| Kaiser Chems. Div. | Baton Rouge, LA | n.a. |
| H. Kohnstamm and Co., Inc. | Camden, NJ | n.a. |
| Martin Marietta Corp. | | |
| Martin Marietta Aluminum Inc., subsid. | St. Croix, VI | 560 |
| Norton Co. | Worcester, MA | n.a. |
| Ormet Corp. | Burnside, LA | 600 |
| Reynolds Metals Co. | | |
| Chems. Div. | Bauxite, AR | 840 |
| | Corpus Christi, TX | 1385 |
| | ADD TOTAL | 7930 |

Source: SRI International estimates.
n.a. = not available

Data available from the U.S. EPA (1980) regarding producers of aluminum oxide and production volumes are presented in Table 16.

The many distributors of alumina, in addition to the manufacturers, include (1980-81 OPD Chemical Buyers Directory, 1980; Chemical Week: 1981 Buyers' Guide Issue, 1980; Chem Sources--USA, 1980):

Accurate Chem.
Air Products and Chemicals
Aldrich Chem.
Alfa Products
Allpax
Aluchem
Anachemia Chem.
Apache Chem.
Aremco Prod.
Atomergic Chemetals
J.T. Baker
Biochemical Labs
Bodman Chem.
Campbell Chem.
Carborundum Co.
Cerac Inc.
Chem. Services
Degussa Corp.
Denimex Development Corp.
Dynamit Nobel
E.M. Chem.
E.M. Labs
Erlanger and Co.
Fisher Sci.
Gallard-Schlesinger Chem.
Great Western Inorganics
Hammill and Gillespie Inc.
Harbison-Walker
Harrison and Crosfield Inc.
Intsel Corp.
Kay-Fries
LaPine Sci.
Metalsmart
National Casein
Noah Chem.
Norton Co.
Orion Chem.
Peltz/Rowley Chem.
Pesses Co.
Pfaltz and Bauer
Rhone-Poulenc Chem. Co.
Reliable Chem.
H.M. Royal Inc.
Signo Trading International
Spex Ind.
Tridom Chem.
Ultra Pure Chem.
United Mineral and Chem.
Var-Lac-Oid Chem.
Kum Yang Co. Ltd.
Whittaker, Clark and Daniels Inc.

## 10. Manufacturing Processes

Aluminum oxide (alumina) occurs abundantly in nature, most often as impure hydroxides, which are the essential constituents of bauxites and laterites. Most of the world's alumina is produced by refining bauxite via the Bayer process (MacZura et al., 1978). A diagram of the Bayer process is shown in the Aluminum Hydroxide profile (III.H). The Bayer process consists of leaching bauxite with caustic soda followed by precipitation of a hydrated aluminum oxide by hydrolysis and seeding of the solution. The alumina hydrate is then washed, filtered, and calcined to remove water and obtain the anhydrous oxide.

The various types of commercial aluminas are made by processing the Bayer-output with heat, pressure, and/or reshaping techniques.

### 11. Impurities or Additives

The compositions of some typical grades of alumina are presented in Table 19 (Treskon, 1976a).

### 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 1,958,561 workers are potentially exposed to aluminum oxide.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum oxide were not found in the literature searched.

### 14. Biological Effects

#### a. Animal Studies

##### (1) Acute Exposures

Single intratracheal instillations of 35-100 mg of alumina (0.005-2 μm) have produced areas of dense collagenous fibrosis in the lungs of rats after 6-12 months (King *et al.*, 1955; Stacy *et al.*, 1959; Klosterkotter, 1960). The degree of fibrosis reached depended upon the dosage, type of alumina, and particle size. Fibrosis due to anhydrous (gamma) alumina was generally more severe than that resulting from powdered hydrated alumina, and condensed fume from a corundum furnace (consisting of approximately one-half alumina and one-half silica) produced less severe pulmonary fibrosis than hydrated alumina.

Table 19. The Compositions of Some Typical Grades of Alumina (Treskon, 1976a)

| | Calcined | Low Soda | Activated | Tabular | White Fused | Brown Fused |
|---|---|---|---|---|---|---|
| $Al_2O_3$ | 99.2% | 99.6-99.8% | 93.0% | 99.54% | 99.6% | 95% |
| $SiO_2$ | 0.02% | 0.02-0.1% | 0.02% | 0.04% | 0.1% | 1.0% |
| $Fe_2O_3$ | 0.04% | 0.01-0.05% | 0.02% | 0.06% | 0.06% | 0.2% |
| $Na_2O$ | 0.5% | 0.05-0.1% | 0.4% | 0.02% | 0.2% | -- |
| $TiO_2$ | 0.002% | 0.002% | 0.002% | 0.002% | -- | 3.0% |
| Other | 0.3% | 0.1-0.3% | 6.0% | 0 | 0 | 0 |
| Specific Gravity | 3.7-3.9 | 3.9 | 3.1 | 3.65-3.8 | 3.95 | 3.95 |

### (2) Subchronic Exposures

Stenback and coworkers (1976) reported that the intratracheal instillation of aluminum oxide dust into Syrian hamsters, as a 3 mg saline solution once per week for 15 weeks, produced interstitial lung fibrosis with occasional alveolar accumulations of macrophages and multinucleated giant cells.

### (3) Chronic Exposures

Inhalation of high levels of gamma-alumina (approximately 33 $g/m^3$, 0.005-0.04 μm average size), 5 hours daily for up to 285 days, caused heavy desquamation of alveolar cells and secondary inflammation, but only slight evidence of fibrosis in rats (Klosterkotter, 1960).

### (4) Carcinogenicity

Stenback _et al_. (1976) were unable to demonstrate an increase in tracheal or laryngeal tumors when aluminum oxide dust was instilled intratracheally into Syrian hamsters as a 3 mg saline solution once per week for 15 weeks.

Intrapleural inoculation of a single dose of aluminum oxide suspension (20 mg/animal) did not produce significant increases in mesothelioma in rats or compared to asbestos-treated animals (Wagner _et al_., 1973).

### (5) Mutagenicity

Testing of aluminum oxide in two strains of recombination-deficient _Bacillus subtilis_ (H17 and M45) did not indicate any mutagenic effects in the rec assay (Kanematsu _et al_., 1980).

### (6) Teratogenicity

Colloidal alumina (Baymal) produced encephalocele and eyelid defects in chick embryos when inoculated into the amniotic cavity (0.01-0.1 mg/egg) on day 5 of incubation (Williamson _et al_., 1963). Severe twisting and distortion of the body axis and appendages were also noted, particularly at the higher doses, although the appendages appeared normal in general development. The embryonic defects were attributed to the presence of the extraneous alumina particulate mater in contact with the developing embryo.

### (7) Reproductive Effects

No information was found in the literature searched.

### (8) Other Relevant Information

No information was found in the literature searched.

## b. Human Studies

### (1) Pharmacokinetics

Inhalation exposure of alumina workers to $Al_2O_3$ dust has been reported to increase blood levels of aluminum two to three times those in controls (Waldron-Edward et al., 1971); it is not clear, however, to what extent inhaled particles were swallowed and subsequently absorbed from the gastrointestinal tract.

### (2) Health Effects

Workers engaged in the manufacture of aluminum oxide have experienced lung disease with symptoms of varied intensity that included cough accompanied by sputum, dyspnea, and substernal discomfort (Shaver and Riddell, 1947).

### (3) Target Organ Toxicity

Shaver and Riddell (1947) described a characteristic non-nodular lung fibrosis that developed in workers who were engaged in the manufacture of aluminum oxide abrasive (corundum) in four different plants. The disease was, on occasion, rapidly progressive, and the fibrosis was accompanied by profound emphysema. Exposure levels, however, were not reported, and the workers were also exposed to silica dust during this manufacturing process. It has been noted that the recent literature does not reveal examples of distinctive pulmonary fibrosis and emphysema in aluminum oxide workers (Sorenson et al., 1974; ACGIH, 1979).

An increased prothrombin time has been noted in workers exposed to aluminum oxide dust during its manufacture by the Bayer process (Waldron-Edward *et al.*, 1971).

(4) Epidemiology

Pulmonary effects were not observed in workers exposed to aluminum dust during the grinding of duralumin propellers (95% aluminum, 4.5% copper, and traces of other metals) with alundum (calcined aluminum oxide) abrasive (Hunter *et al.*, 1944). Atmospheric levels of aluminum particles in the workplace ranged from 0.1-2.7 mg/m$^3$.

## 15. Ongoing Studies

No current toxicological or environmental studies of aluminum oxide were found.

## 16. Exposure Standards

The ACGIH has recommended a Time-Weighted Average (TWA) occupational exposure limit for aluminum oxide of 10 mg/m$^3$, based on consideration of the compound as an inert dust (ACGIH, 1979).

## 17. Sources of Additional Relevant Information

A NIOSH Health Hazard Evaluation (HHE) relating to aluminum oxide has been conducted at the Reynolds Aluminum Company, Bauxite, AR (HHE No. 71-13-47).

## 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum oxide as an occupational hazard was found in the literature searched.

## M. ALUMINUM ORTHO-PHOSPHATE

1. Chemical Name: Aluminum ortho-Phosphate

2. Chemical Structure: $AlPO_4$

3. Synonyms: Aluminum phosphate
Phosphoric acid, aluminum salt (1:1)
Aluminum monophosphate

4. Chemical Abstracts Service (CAS) Number: 7784-30-7

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white infusible crystals or powder |
| Molecular Weight: | 121.95 |
| Boiling Point: | --- |
| Melting Point: | >1500°C |
| Vapor Pressure: | --- |
| Solubility: | practically insoluble in water and alcohols<br>soluble in acids and alkalis |
| Specific Gravity: | 2.566 |
| Stability: | stable at ambient conditions |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum ortho-phosphate and production volumes are presented in Table 20.

8. Use

The most important use for the aluminum phosphates is as high-temperature bonding agents. The aluminum poly-ortho-phosphates, made from the ortho-phosphate, are used as adhesive binders for refractories subjected to furnace temperatures; they are also employed in glasses and ceramics as well as in catalysts. Aluminum phosphate has also found considerable use as a modifying agent in silicate glasses (Van Wazer, 1968).

Table 20. Producers of Aluminum ortho-Phosphate and Production Ranges (U.S. EPA, 1980)

| Producer | Type of Production | 1977 Production Range (CAS No. 7784-30-7) |
|---|---|---|
| Joseph Turner and Co.<br>Ridgefield, NJ | Manufacturer | confidential |
| The Shepherd Chem. Co.<br>Cincinnati, OH | Manufacturer | confidential |
| Hercules Inc.<br>Glen Falls, NY | Manufacturer | confidential |
| Max Marx Color and Chem.<br>Irvington, NJ | Manufacturer | confidential |
| Olin Corp.<br>Joliet, IL | Manufacturer | 1-10 million lb |
| Chemical Products Plant<br>Cleveland, OH | Manufacturer | 0-1000 lb |
| Imperial Wallpaper Mills<br>Plattsburg, NY | Importer | 1-10 thousand lb |
| American Hoechst Corp.<br>Bridgewater, NJ | Importer | zero |
| Superior Materials Inc.<br>NYC, NY | Importer | 1-10 thousand lb |
| Lukens Chem. Co.<br>Cambridge, MA | Importer | 2-20 thousand lb |

Other uses include applications in dental cements, in paints and varnishes, in pulp and paper, in pharmaceutical gels such as Aluphas, Ulcocid, or Phosphaljel, as a cement in admixture with calcium sulfate and sodium silicate, and as an antacid (Hawley, 1977; The Merck Index, 1976).

## 9. Manufacturers and Distributors

SRI International (1980) lists the Mobil Oil Corp. (Fernald, OH) as a manufacturer.

Data available from the U.S. EPA (1980) regarding producers of aluminum ortho-phosphate and production volumes are presented in Table 20.

In addition to the manufacturers, the following are distributors (1980-81 OPD Chemical Buyers Directory, 1980; Chem Sources--USA, 1980):

American Hoechst Corp.
Gallard-Schlesinger Chem.
Nitron Chemical Corp.
S.S.T. Corp.
Stauffer Chemical Corp.

## 10. Manufacturing Processes

Aluminum orthophosphate occurs in nature as the minerals angelite, coeruleolactite, evansite, luncinite, metavariscite, sterretite, variscite, vashegyite, wavellite, and zepharovicht (The Merck Index, 1976).

The synthetic material of commerce is prepared by the interaction of solutions of aluminum sulfate and sodium phosphate (Hawley, 1977). It can also be prepared from $NaAlO_2$ and $H_3PO_4$ (The Merck Index, 1976).

## 11. Impurities or Additives

No information was found in the literature searched.

## 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 10,671 workers are potentially exposed to aluminum ortho-phosphate.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum *ortho*-phosphate were not found in the literature searched.

## 14. Biological Effects

### a. Animal Studies

#### (1) Acute Exposures

Intratracheal injection of 50 mg aluminum *ortho*-phosphate resulted in the development of reticulin nodules in the lungs of rats after 309 days (King *et al*., 1955; Stacy *et al*., 1959). During the following 6-12 months, the lesions became larger and more fibrous, and collagen formation was prominent.

#### (2) Subchronic Exposures

No information was found in the literature searched.

#### (3) Chronic Exposures

No information was found in the literature searched.

#### (4) Carcinogenicity

No information was found in the literature searched.

#### (5) Mutagenicity

Testing of aluminum phosphate in two strains of recombination-deficient *Bacillus subtilis* (H17 and M45) did not indicate any mutagenic effects in the rec assay (Kanematsu *et al*., 1980).

#### (6) Teratogenicity

No information was found in the literature searched.

#### (7) Reproductive Effects

No information was found in the literature searched.

#### (8) Other Relevant Information

No information was found in the literature searched.

b. Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

No information was found in the literature searched.

(3) Target Organ Toxicity

No information was found in the literature searched.

(4) Epidemiology

No information was found in the literature searched.

15. <u>Ongoing Studies</u>

No current toxicological or environmental studies of aluminum <u>ortho</u>-phosphate were found.

16. <u>Exposure Standards</u>

The ACGIH (1979) currently recommends a Threshold Limit Value (TLV) of 2 mg/m$^3$ as Al for the soluble salts of aluminum. The TLV for these soluble salts, such as the chloride and sulfate, is based on the amount of hydrolyzed acid and the corresponding TLV. On the basis that 3 mol of HCl, with a TLV of 5 ppm, hydrolyze from 1 mol of $AlCl_3$, a TLV of 2 mg/m$^3$ as Al is recommended to provide the same degree of freedom from irritation that is provided by the TLV for HCl. As the acute toxicity from $Al_2(SO_4)_3$ is only slightly greater than that of $AlCl_3$, and the toxicity of the alums is considerably less, the 2 mg/m$^3$ is considered to be suitable for the soluble salts of aluminum (ACGIH, 1979).

17. <u>Sources of Additional Relevant Information</u>

No sources of additional relevant information were identified.

18. <u>Other Pertinent Data</u>

No other information that would aid in the assessment of aluminum <u>ortho</u>-phosphate as an occupational hazard was found in the literature searched.

## N. ALUMINUM POTASSIUM SULFATE

1. Chemical Name: Aluminum Potassium Sulfate

2. Chemical Structure: $KAl(SO_4)_2 \cdot 12H_2O$

3. Synonyms: Potassium aluminum sulfate
   Potassium alum
   Potash alum
   Kalinite
   Cube alum
   Alum flour
   Alum meal
   Sulfuric acid, aluminum potassium salt

4. Chemical Abstracts Service (CAS) Numbers: 7784-24-9 (dodecahydrate)
   10043-67-1 (anhydrous)

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   Not listed

6. Chemical and Physical Properties (dodecahydrate):

| | |
|---|---|
| Description: | white crystal |
| Molecular Weight: | 474.39 |
| Boiling Point: | loses $H_2O$ at 200°C |
| Melting Point: | 92.5°C |
| Vapor Pressure: | --- |
| Solubility: | 11.4 g/100 c water (20°C)<br>insoluble in alcohol |
| Specific Gravity: | 1.757 |
| Stability: | attracts moisture from air;<br>noncombustible |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum potassium sulfate and production volumes are presented in Table 21.

Darragh (1978) estimates the annual production to be several thousand metric tons.

Table 21. Producers of Aluminum Potassium Sulfate and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 10043-67-1) |
|---|---|---|
| Allied Chemical Co. | | |
| Claymont, DE | Manufacturer | 1-10 million lb |
| Marcus Hook, PA | Manufacturer | confidential |
| J.T. Baker Chemical Co. | | |
| Phillipsburg, NJ | Manufacturer | 10-100 thousand lb |
| Mead Paper | | |
| Kingsport, TN | Manufacturer/ Produced Site Limited | 10-50 million lb |
| American Hoechst Corp. | | |
| Bridgewater, NJ | Importer | zero |
| ICI Americas Inc. | | |
| Wilmington, DE | Importer | zero |

### 8. Use

Potassium alum is used in water purification, in paper sizing, in medicine, as a mordant in dyeing, in the dressing of skins, and in food applications (Darragh, 1978). Only a small amount is used in food applications; in 1973, only 5 tons was consumed for this purpose. According to Table 21, the largest producer of potassium alum (Mead Paper) is a captive user; captive use is likely for a combination of water purification and paper sizing.

Other uses include matches, paints, waterproofing agents, aluminum salts, manufacture of dyes, lakes, vegetable glue, marble cement, and porcelain cement, in hardening gelatin, sugar clarifying, hardening plastic casts, electrolytic copper plating, catalyst for ammonia synthesis, and hardening agent in microscopy (Hawley, 1977; *The Merck Index*, 1976).

### 9. Manufacturers and Distributors

SRI International (1980) lists Allied Chemical Corp. (Claymont, DE) as the only manufacturer.

Data available from the U.S. EPA (1980) regarding producers of aluminum potassium sulfate and production volumes are presented in Table 21.

In addition to the manufacturers, distributors include (*1980-81 OPD Chemical Buyers Directory*, 1980; *Chemical Week: 1981 Buyers' Guide Issue*, 1980):

Alfa Prod.
American Cyanamid
American Hoechst Corp.
American Sci. and Chem.
Anachemia Chem.
Atomergic Chemetals
Chem. Service
Continental Oil Co.
Delmar
E.M. Labs
Ethyl Corp.
Fisher Sci.
Gallard-Schlesinger
Independent Chem. Corp.
LaPine Sci.
Laporte Ltd.
Mallinckrodt
MCB Reagents
Pfaltz and Bauer
Pioneer Salt and Chem. Co.
Stauffer
Suburban Chem.
Joseph Turner and Co.
Van Waters and Rogers
Worth Chem.

## 10. Manufacturing Processes

Commercially, potassium alum is produced by treating bauxite with sulfuric acid and then potassium sulfate (Darragh, 1978); see the profile on Aluminum Sulfate (III.O) for a similar process description and diagram. Other methods of preparation include: (1) calcination of alunite, leaching with sulfuric acid, and crystallizing the potassium alum with recovery aluminum sulfate from the mother liquors and (2) conversion of aluminum sulfate by addition of potassium sulfate (Darragh, 1978).

Potassium alum is available in several forms including lump, ground, and powder.

## 11. Impurities or Additives

Potassium alum is sold in N.F. and technical grades.

## 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to aluminum potassium sulfate.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum potassium sulfate were not found in the literature searched.

## 14. Biological Effects

### a. Animal Studies

#### (1) Acute Exposures

No information was found in the literature searched.

#### (2) Subchronic Exposures

No information was found in the literature searched.

### (3) Chronic Exposures

Lifetime feeding studies of aluminum potassium sulfate administered in drinking water at 5-ppm levels showed no major toxic symptoms or significant growth retardation produced by this level of compound in either rats or mice (Schroeder and Mitchener, 1975a, 1975b).

### (4) Carcinogenicity

Lifetime feeding of aluminum potassium sulfate at a level of 5 ppm in drinking water produced a slight increase of lymphoma leukemia in female (but not male) mice that the authors did not attribute to a tumorigenic action of the compound (Schroeder and Mitchener, 1975a). A similar study conducted by these investigators in rats failed to show significant tumorigenic effects (Schroeder and Mitchener, 1975b).

### (5) Mutagenicity

Mutagenicity testing of aluminum potassium sulfate, at levels up to 5%, showed no effects in *Salmonella typhimurium* or *Saccharomyces cerevisiae* (Litton, 1977).

### (6) Teratogenicity

No information was found in the literature searched.

### (7) Reproductive Effects

No information was found in the literature searched.

### (8) Other Relevant Information

No information was found in the literature searched.

## b. Human Studies

### (1) Pharmacokinetics

No information was found in the literature searched.

### (2) Health Effects

No information was found in the literature searched.

(3) Target Organ Toxicity

No information was found in the literature searched.

(4) Epidemiology

No information was found in the literature searched.

15. Ongoing Studies

No current toxicological or environmental studies of aluminum potassium sulfate were found.

16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum potassium sulfate were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of aluminum potassium sulfate as an occupational hazard was found in the literature searched.

## O. ALUMINUM SILICATES

1. Chemical Name: Aluminum Silicates

2. Chemical Structure:

   (1) $Al_6O_{13}Si_2$ —— $3Al_2O_3 \cdot 2SiO_2$

   (2) $Al_2SiO_5$ —— $Al_2O_3 \cdot SiO_2$

   (3) $Al_2Si_3O_9$ —— $Al_2(SiO_3)_3$

   (4) $xAl_2O_3 \cdot SiO_2$ (variable)

3. Synonyms:
   (1) Aluminum oxide silicate; mullite
   (2) Aluminum silicate oxide; andalusite; sillimanite; kyanite; cyanite
   (4) Aluminosilicate

4. Chemical Abstracts Service (CAS) Number:
   (1) 1206856-3
   (2) 12141-46-7; 1302-76-7
   (3) 14504-95-1
   (4) 1327-36-2

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   (2) BD1450000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | solids |
| Molecular Weight: | (1) 426.05<br>(2) 162.04 |
| Boiling Point: | (2) >1545°C |
| Melting Point: | (1) 1920°C<br>(2) decomposes at 1545°C to $Al_2O_3 \cdot 2SiO_2$ |
| Vapor Pressure: | --- |
| Solubility: | insoluble in water |
| Specific Gravity: | (1) 3.156<br>(2) 3.247 |
| Stability: | noncombustible |

7. Production

Data available from the U.S. EPA (1980) regarding producers of aluminum silicates and production volumes are presented in Table 22. Data are

Table 22. Producers of Aluminum Silicates and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range |
|---|---|---|
| Aluminum Silicate (1): CAS No. 12068-56-3 | | |
| United Catalysts Inc.<br>Louisville, KY | Manufacturer | 1-10 thousand lb |
| E.I. duPont de Nemours and Co.<br>Cleveland, OH | Manufacturer | confidential |
| CE Minerals<br>Greenville, TN | Manufacturer | 10-100 thousand lb |
| Taylor Refinery, Div. NL Indus.<br>South Shore, KY | Manufacturer | 10-50 million lb |
| Aluminum Silicate (2): CAS No. 12141-46-7 | | |
| Chevron USA<br>Richmond, CA | Manufacturer | 1-10 million lb |
| United Catalysts<br>Louisville, KY | Manufacturer<br>Manufacturer | 0-1 thousand lb<br>1-10 thousand lb |
| Aluminum Silicate (4): CAS No. 1327-36-2 | | |
| Mobil Chemical Co. | | |
| Beaumont, TX | Manufacturer | 0.1-1.0 million lb |
| NYC, NY | Importer | 0.1-1.0 million lb |
| Kaiser Refractories<br>Mexico, MO | Manufacturer | 50-100 million lb |
| W.R. Grace and Co. | | |
| South Gate, CA | Manufacturer | 10-50 million lb |
| Cincinnati, OH | Manufacturer | 10-50 million lb |
| Lake Charles, LA | Manufacturer | 100-500 million lb |
| Henkel Inc.<br>Teaneck, NJ | Importer | 0-1 thousand lb |
| Mobay Chemical Corp.<br>Pittsburgh, PA | Importer | confidential |
| Rhone-Poulenc<br>Freeport, TX | Importer | zero |
| Hamill and Gillespie Inc.<br>Livingston, NJ | Importer | 0.1-1.0 million lb |

available for aluminum silicates (1), (2), and (4) as numbered in the chemical structures above; no data are available for (3).

Aluminum silicate (1), mullite, occurs naturally but is industrially produced by synthetic means. In 1974, synthetic mullite production amounted to approximately 25 thousand tons (Hamme, 1979).

Aluminum silicate (2) occurs naturally and is primarily obtained from mining the ore.

### 8. Use

Aluminum silicate (1), mullite, is used in refractories with about 90% being consumed in the metallurgical and glass industries (Hamme, 1979).

Aluminum silicate (2) has uses similar to those of clay, namely ceramic products, refractories, collodial suspensions, oil-well drilling fluids, fillers for rubber and plastic products, paper coating, decolorizing oils, temporary molds, filtration, carrier in insecticidal sprays, and catalyst supports (Hawley, 1977). The kinds of manufacturers of the synthetic aluminum silicate (2), as listed in Table 22, would indicate uses in the petroleum industry and in catalysts.

Aluminum silicate (3) has uses as a pigment and colorant in plastics (Webber, 1979).

Aluminum silicate (4) is used in petroleum refining and petroleum-cracking catalysts (Wills, 1969).

### 9. Manufacturers and Distributors

SRI International (1980) lists the following manufacturers of aluminum silicate:

| | |
|---|---|
| Combustion Engineering | |
| C-E Minerals | Narvon, PA |
| | Washington, GA |
| Smith Color and Chemical Co. | Jamaica, NY |

A more complete listing is given in Table 22.

In addition to the manufacturers, the distributors include (Chemical Week: 1981 Buyers' Guide Issue, 1979; Chem Sources--USA, 1980):

- Alfa Prod.
- Apache Chem.
- Atomergic Chemetals
- J.T. Baker Chem.
- Burgess Pigment Co.
- Chemical Procurement Labs
- Chem Services
- Commercial Minerals
- Degussa
- Engelhard Minerals
- Fisher Sci.
- Freeport Kaolin
- Gallard-Schlesinger Chem.
- Georgia Kaolin
- Johns-Manville
- Lowe's Inc.
- Metron, Inc.
- Noah Chem.
- Orion Chem.
- Petrarch Systems
- Pfaltz and Bauer
- Smith Chem
- Southeastern Clay Co.
- Thiele Kaolin
- Thompson-Hayward
- R.T. Vanderbilt Co.
- Charles Wagner Co.

### 10. Manufacturing Processes

Synthetic aluminum silicate (1) is produced by heating naturally-occurring aluminum silicate (2) to the decomposition ranges of 1100-1650°C (Hamme, 1979). The decomposition product is synthetic mullite.

Aluminum silicate (2) is a naturally-occurring mineral that is commercially mined. Synthetic aluminum silicates (2) and (3) are produced by the precipitation reaction of aluminum sulfate and a soluble silicate solution (Wills, 1969). The precipitate must be filtered, washed, dried, sized, and packaged. A special grade of aluminum silicate (2) is synthetically made by heating aluminum fluoride at 1000-1200°C with silica and water vapor; the crystals or whiskers obtained are up to 1 cm long, have high strength, and are used in reinforced plastics (Hawley, 1977).

Aluminum silicate (4) is formed by heating compositions of carefully controlled proportions of silica, alumina, and alkalis under conditions found to promote the required crystal structure (Wills, 1969).

### 11. Impurities or Additives

No information was found in the literature searched.

## 12. Occupational Exposure

The National Occupational Hazard Survey (NOHS) indicates that 331,723 workers are potentially exposed to aluminosilicate. NOHS estimates of the number of workers exposed to the other aluminum silicate compounds addressed in this profile are not available.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to the aluminum silicates were not found in the literature searched.

## 14. Biological Effects

### a. Animal Studies

#### (1) Acute Exposures

No information was found in the literature searched.

#### (2) Subchronic Exposures

Dietary exposure to 1.3 g/kg/day of aluminum silicate for 4 weeks did not result in renal lesions in dogs or rats (Newberne and Wilson, 1970).

#### (3) Chronic Exposures

No information was found in the literature searched.

#### (4) Carcinogenicity

Intrapleural inoculation of a single dose (20 mg) of synthetic aluminum silicate fibers did not produce significant increases in mesothelioma in rats as compared to asbestos-treated animals (Wagner *et al*., 1973).

#### (5) Mutagenicity

No information was found in the literature searched.

#### (6) Teratogenicity

No information was found in the literature searched.

(7) Reproductive Effects

No information was found in the literature searched.

(8) Other Relevant Information

No information was found in the literature searched.

b. Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

No information was found in the literature searched.

(3) Target Organ Toxicity

No information was found in the literature searched.

(4) Epidemiology

No information was found in the literature searched.

15. Ongoing Studies

The NCI is currently conducting a carcinogenesis bioassay of sodium aluminosilicate administered in lifetime feeding studies (NTP, 1980).

The co-carcinogenic activity of aluminum silicates administered intratracheally along with benzo[a]pyrene is under investigation in the golden hamster (Neimeier, 1980).

16. Exposure Standards

No recommended or promulgated occupational exposure standards for the aluminium silicates were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of the aluminum silicates as an occupational hazard was found in the literature searched.

## P. ALUMINUM SODIUM SULFATE

1. Chemical Name: Aluminum Sodium Sulfate

2. Chemical Structure: $NaAl(SO_4)_2 \cdot 12H_2O$

3. Synonyms: Sodium alum
   Soda alum
   Sodium aluminum sulfate
   SAS
   Alum, porous
   Sulfuric acid, aluminum sodium salt

4. Chemical Abstracts Service (CAS) Numbers: 7784-28-3 (dodecahydrate)
   10102-71-3 (anhydrous)

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | colorless crystal with astringent taste |
| Molecular Weight: | 458.23 |
| Boiling Point: | --- |
| Melting Point: | 61°C |
| Vapor Pressure: | --- |
| Solubility: | 110 g anhydrous salt/100 cc water (15°C)<br>practically insoluble in alcohol |
| Specific Gravity: | 1.675 |
| Stability: | noncombustible |

7. Production

In 1973, 5.9 million pounds of sodium alum were used for its major use in baking powder (Darragh, 1978).

Data available from the U.S. EPA (1980) regarding producers of aluminum sodium sulfate and production volumes are presented in Table 23.

8. Use

The largest use of sodium alum in as a leavening acid in baking applications (Darragh, 1978). The aluminum sodium sulfate reacts with sodium bicarbonate to liberate carbon dioxide, which raises the dough.

Table 23. Producers of Aluminum Sodium Sulfate and Production Ranges (U.S. EPA. 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 10102-71-3) |
|---|---|---|
| Allied Chem. Corp.<br>East St. Louis, IL | Manufacturer | 1-10 million lb |
| MCB Reagents<br>Inorwood, OH | Manufacturer | under 1000 lb |

Other uses include textiles (mordant and waterproofing), dry colors, ceramics, tanning, paper size precipitant, matches, inks, engraving, sugar refining, water purification, medicine, confectionary, and food additives (Hawley, 1977).

### 9. Manufacturers and Distributors

SRI International (1980) lists Allied Chemical (East St. Louis, IL) as the only manufacturer.

Data available from the U.S. EPA (1980) regarding producers of aluminum sodium sulfate and production volumes are presented in Table 23.

In addition to the manufacturers, the distributors include (*1980-81 OPD Chemical Buyers Directory*, 1980; *Chemical Week: 1981 Buyers' Guide Issue*, 1980; *Chem Sources--USA*, 1980):

Fallek Chemical
George Uhe Co.
LaPine Sci
MCB Reagents
Olin Corp.

### 10. Manufacturing Processes

Sodium alum is produced from aluminum sulfate by addition of a clear solution of sodium sulfate. The change is then diluted to 30°Beμ and heated, and a slurry of potassium sulfate, sodium silicate, and alkali (soda ash) is added to improve the characteristics of the product. The charge is next pumped to the digestor, where it is mixed for several hours by circulation. During this period, chemical analysis is made and the ratio of aluminum sulfate to sodium sulfate is adjusted by additions of either salt solutions or aluminum sulfate solutions. The charge is then pumped to the evaporators where it is evaporated to such a consistency that on discharge upon the cooling pans it will yield a hard cake. This sodium aluminum sulfate cake is charged into roasters, and, after heating, is ground to a fineness of 99% through a 100-mesh screen.

The finished product is packed normally in 100-pound paper bags or in 400-pound fiber drums (Saeman, 1963; Darragh, 1978).

### 11. Impurities or Additives

Aluminum sodium sulfate is sold as pure crystals, and technical, C.P., and F.C.C. grades (Hawley, 1977).

### 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to aluminum sodium sulfate.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum sodium sulfate were not found in the literature searched.

### 14. Biological Effects

No information regarding the biological effects of aluminum sodium sulfate was found in the literature searched.

### 15. Ongoing Studies

No current toxicological or environmental studies of aluminum sodium sulfate were found.

### 16. Exposure Standards

No recommended or promulgated occupational exposure standards for aluminum sodium sulfate were found.

### 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

### 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum sodium sulfate as an occupational hazard was found in the literature searched.

## Q. ALUMINUM SULFATE

1. Chemical Name: Aluminum Sulfate

2. Chemical Structure: $Al_2(SO_4)_3 \cdot 18H_2O$

3. Synonyms: Aluminum sulfate hydrate
   Alum, commercial
   Alum, liquid
   Sulfuric acid, aluminum salt (3:2)
   Paper makers alum
   Pearl alum
   Pickle alum
   Cake alum
   Patent alum

4. Chemical Abstracts Service (CAS) Number: 7784-31-8 ($\cdot 18H_2O$)
   10043-01-3 (anhydrous)

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   BD1700000

6. Chemical and Physical Properties

| | |
|---|---|
| Description: | amorphous solid |
| Molecular Weight: | 666.43 |
| Boiling Point: | decomposes |
| Melting Point: | decomposes |
| Vapor Pressure: | --- |
| Solubility: | 27.8 g/100 g water (25°C) (anhydrous salt)<br>practically insoluble in alcohol<br>soluble in dilute acid |
| Specific Gravity: | $1.69^{17}$ |
| Stability: | stable in air;<br>noncombustible |

7. Production

Recent production of aluminum sulfate is as follows (Chemical and Engineering News, 1980; Darragh, 1978):

| Year | Production ($57\%\ Al_2(SO_4)_3$ Basis) (thousands of tons)<br>Commercial and Municipal | Iron-Free Grade |
|---|---|---|
| 1979 | 1223 | --- |
| 1978 | 1309 | --- |
| 1977 | 1255 | --- |
| 1976 | 1202 | --- |
| 1975 | 1146 | --- |
| 1974 | 1257 | 232 |
| 1973 | 1233 | 230 |
| 1972 | 1193 | 207 |

Data available from the U.S. EPA (1980) regarding producers of aluminum sulfate and production volumes are presented in Table 24.

8. Use

The following tabulation presents the percentage of the total amount of aluminum sulfate produced that is used in each of the applications listed:

| | Percentage of Total |
|---|---|
| Pulp and paper | 48 |
| Treatment of water and waste | 44 |
| Miscellaneous (fire-retardants, deodorants, foaming agent in fire foams, grease and oil recovery) | 5 |
| Export | 3 |

The paper industry uses aluminum sulfate for the clarification of process waters, pH control of pulp slurries, settling of certain dyes, and precipitating colloidal clay and dissolved resin into the size on the fibers of the paper. The alum sold for this use is usually in solution form (Darragh, 1978).

In water and waste treatment, it is used as a coagulant for the removal of turbidity-causing materials, for water softening, for pH control, and as a flocculating agent (Treskon, 1976d).

In addition to the miscellaneous uses listed above, other minor uses include mordant for dyeing, fireproofing cloth, tanning of white leather,

Table 24. Producers of Aluminum Sulfate and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 10043-01-3) |
|---|---|---|
| Hollard Co. | | |
| Adams, MA | Manufacturer | 50-100 million lb |
| Delta Chem. | | |
| Searsport, ME | Manufacturer | confidential |
| Imprial West Chem. | | |
| Antioch, CA | Manufacturer | confidential |
| Spokane, WA | Manufacturer | confidential |
| N-Ren Corp. | | |
| South St. Paul, MN | Manufacturer | 10-50 million lb |
| Kodak (Eastman) | | |
| Rochester, NY | Manufacturer | 0.1-1 million lb |
| Stauffer Chem. | | |
| Springhill, LA | Manufacturer | 10-50 million lb |
| Dominguez, CA | Manufacturer | 10-50 million lb |
| Bastrop, LA | Manufacturer | 50-100 million lb |
| Baton Rouge, LA | Manufacturer | 10-100 thousand lb |
| Counce, TN | Manufacturer | 10-50 million lb |
| Pennington, AL | Manufacturer | 10-50 million lb |
| Richmond, CA | Manufacturer | 10-50 million lb |
| Portland, OR | Manufacturer | 10-50 million lb |
| Tacoma, WA | Manufacturer | 1-10 million lb |
| Houston, TX | Manufacturer | 100-500 million lb |
| Olin Corp. | | |
| Baltimore, MD | Manufacturer | 10-50 million lb |
| Allied Chem. | | |
| Detroit, MI | Manufacturer | 10-50 million lb |
| Dorado, PR | Manufacturer | 10-50 million lb |
| Pittsburg, CA | Manufacturer | 10-50 million lb |
| Claymont, DE | Manufacturer | 100-500 million lb |
| Denver, CO | Manufacturer | 10-50 milllion lb |
| El Segundo, CA | Manufacturer | 10-50 million lb |
| Cleveland, OH | Manufacturer | 10-50 million lb |
| Newall, PA | Manufacturer | 10-50 million lb |
| Kennewick, WA | Manufacturer | 1-10 million lb |
| Middletown, OH | Manufacturer | 10-50 million lb |
| Menasha, WI | Manufacturer | 50-100 million lb |
| Monroe, LA | Manufacturer | 10-50 million lb |
| Wisconsin Rapids, WI | Manufacturer | 10-50 million lb |
| Kalamazoo, MI | Manufacturer | 10-50 million lb |
| Tacoma, WA | Manufacturer | 1-10 million lb |
| East Point, GA | Manufacturer | 10-50 million lb |
| Vancouver, WA | Manufacturer | 10-50 million lb |
| Marrero, LA | Manufacturer | 1-10 million lb |
| Chillicothe, OH | Manufacturer | 10-50 million lb |

Table 24. Producers of Aluminum Sulfate and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 10043-01-3) |
|---|---|---|
| Covington, VA | Manufacturer | 10-50 million lb |
| Port St. Joe, FL | Manufacturer | 10-50 million lb |
| Hopewell, VA | Manufacturer | 50-100 million lb |
| Johnsonburg, PA | Manufacturer | 10-50 million lb |
| Pine Bluff, AR | Manufacturer | 10-50 million lb |
| Redwood, MS | Manufacturer | 10-50 million lb |
| Macon, GA | Manufacturer | 10-50 million lb |
| Jacksonville, FL | Manufacturer | 10-50 million lb |
| Savannah, GA | Manufacturer | 10-50 million lb |
| East St. Louis, IL | Manufacturer | 100-500 million lb |
| Morristown, NJ | Importer | 10-50 million lb |
| Engelhard Ind. | | |
| Newark, NJ | Manufactuer | 0.2 million lb |
| Essex Chem. Corp. | | |
| Newark, NH | Manufacturer | 50-100 million lb |
| H. Kohnstamm and Co. | | |
| Camden, NJ | Manufacturer | confidential |
| Cities Service Co. | | |
| Cedar Springs, CA | Manufacturer | confidential |
| Augusta, GA | Manufacturer | confidential |
| Crown Zellerbach | | |
| Bogalusa, LA | Manufacturer | 10-50 million lb |
| Carthage, NY | Importer | 0.1-1 million lb |
| ABC Compounding Co. | | |
| Atlanta, GA | Manufacturer | 10-100 thousand lb |
| Armak Catalysts | | |
| Pasadena, TX | Manufacturer | confidential |
| E.I. duPont de Nemours | | |
| Linden, NJ | Manufacturer | 10-50 million lb |
| U.S. Filter Corp. | | |
| Salt Lake City, UT | Manufacturer | 1-10 million lb |
| Nalco Chem. Co. | | |
| Chicago, IL | Manufacturer | confidential |
| Titanium Pigment Div. | | |
| St. Louis, MO | Manufacturer | 1-10 million lb |
| South Amboy, NJ | Manufacturer | 1-10 million lb |

Table 24. Producers of Aluminum Sulfate and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 10043-01-3) |
|---|---|---|
| W.R. Grace and Co. | | |
| South Gate, CA | Manufacturer | 10-50 million lb |
| Cincinnati, OH | Manufacturer | 10-50 million lb |
| Lake Charles, LA | Manufacturer | 100-500 million lb |
| Dan River Inc. | | |
| Danville, VA | Manufacturer | 1-10 million lb |
| UOP Process Div. | | |
| Shreveport, LA | Manufacturer | confidential |
| Witco Chem. Corp. | | |
| Lynwood, CA | Manufacturer | confidential |
| CP Chemicals | | |
| Sewaren, NJ | Manufacturer | confidential |
| Continental Oil Co. | | |
| Westlake, LA | Manufacturer | 10-50 million lb |
| Russ Chemical Co. | | |
| Odessa, TX | Manufacturer | 1-10 million lb |
| J.M. Huber Corp. | | |
| Etowah, TN | Manufacturer | 10-50 million lb |
| W.H. Shurtleff Co. | | |
| Portland, ME | Importer | 1-10 million lb |
| Browning Chem. | | |
| NYC, NY | Importer | zero |
| Fraser Paper Lmt. | | |
| Madawaska, ME | Importer | 1-10 million lb |
| American Cyanamid Co. | | |
| Kalamazoo, MI | Importer | confidential |
| Escanaba, MI | Importer | confidential |
| Georgetown, SC | Importer | confidential |
| Demopolis, Al | Importer | confidential |
| Coosa Pines, Al | Importer | confidential |
| Mobile, AL | Importer | confidential |
| Joliet, IL | Importer | confidential |
| Michigan City, IN | Importer | confidential |
| De Rideler, LA | Importer | confidential |
| Cloquet, MN | Importer | confidential |
| Ferguson, MS | Importer | confidential |
| Plymouth, NC | Importer | confidential |
| Hamilton, OH | Importer | confidential |
| Chattanooga, TN | Importer | confidential |
| Charlotte, NC | Importer | confidential |
| Linden, NJ | Importer | confidential |
| Fort Worth, TX | Importer | confidential |

Table 24. Producers of Aluminum Sulfate and Production Ranges (U.S. EPA, 1980) (Cont'd)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 10043-01-3) |
|---|---|---|
| Agfa-Gevaett Inc.<br>Teterboro, NJ | Importer | 1-10 thousand lb |
| A and S Corp.<br>Parsippany, NJ | Importer | zero |
| Hamblet and Hayes Co.<br>Salem, MA | Importer | 0.1-1 million lb |
| Polar Chemicals<br>Lewistown, ME | Importer | 0.1-1 million lb |
| Mead Corp.<br>Dayton, OH | Importer | 10-100 thousand lb |
| Diamond Shamrock<br>Plattsburgh, NY | Importer | 0.2-2 million lb |
| Alcan Aluminum Corp.<br>Cleveland, OH | Importer | 1-10 million lb |

manufacturing of synthetic rubber, catalyst, waterproofing agent for concrete, clarifying agent, lubricating compositions, and the production of other aluminum compounds (Treskon, 1976d).

The iron-free grade is used as a reagent for dyes, for the sizing of high-grade satin paper, as a color fixing agent for textile dyes, for the production of white latex, for the treatment of some white leathers, and as a food additive (Treskon, 1976d).

## 9. Manufacturers and Distributors

There are numerous plants in the United States that manufacture aluminum sulfate. SRI International (1980) lists the following (those manufacturers marked with an asterisk are known to make the iron-free grade):

| | |
|---|---|
| Allied Chem Corp.<br>Chems. Co. | Chillicothe, OH |
| | Claymont, DE* |
| | Cleveland, OH* |
| | Covington, VA |
| | Denver, CO |
| | Detroit, MI |
| | Dorado, PR |
| | East Point, GA* |
| | East St. Louis, IL |
| | El Segundo, CA* |
| | Hopewell, VA |
| | Jacksonville, FL |
| | Johnsonburg, PA |
| | Kalamazoo, MI |
| | Kennewick, WA |
| | Macon, GA |
| | Marrero, LA |
| | Menasha, WI |
| | Middletown, OH* |
| | Monroe, LA |
| | Newell, PA |
| | Pine Bluff, AR |
| | Pittsburg, CA |
| | Port St. Joe, FL |
| | Savannah, GA |
| | Tacoma, WA* |
| | Vancouver, WA |
| | Vicksburg, MS |
| | Wisconsin Rapids, WI |

Pages misnumbered - no information is missing between page 161 and 163.

| | |
|---|---|
| American Cyanamid Co. | |
| Indust. Chems. Div. | Chattanooga, TN |
| | Cloquet, MN |
| | Coosa Pines, AL |
| | Demopolis, AL |
| | De Ridder, LA |
| | Escanaba, MI |
| | Georgetown, SC |
| | Hamilton, OH |
| | Joliet, IL |
| | Kalamazoo, MI |
| | Linden, NJ* |
| | Mobile, AL |
| | Monticello, MS |
| | Plymouth, NC |
| Burris Chem. Inc. | Catawba, SC |
| | East Point, GA |
| Midland Chem. Co., subsid. | Springfield, TN |
| Ciba-Geigy Corp. | |
| Dyestuffs and Chems. Div. | |
| Hamblet and Hayes Co., subsid. | Salem, MA |
| Cities Service Co. | |
| Minerals Group | Augusta, GA |
| | Cedar Springs, GA |
| | Fernandina Beach, FL |
| Crown Zellerbach Corp. | |
| Chem. Products Div. | Bogalusa, LA |
| Dan River, Inc. | |
| Chem. Products Div. | Danville, VA |
| Delta Chems., Inc. | Searsport, ME |
| E.I. duPont de Nemours and Co., Inc. | |
| Chems., Dyes and Pigments Dept. | Linden, NJ* |
| Essex Chem. Corp. | |
| Indust. Chems. Div. | Newark, NJ |
| Ethyl Corp. | |
| Chems. Group | Pasadena, TX |
| W.R. Grace and Co. | |
| Indust. Chems. Group | |
| Davison Chem. Div. | Cincinnati, OH* |
| | Curtis Bay, MD* |
| | Lake Charles, LA* |
| Howerton Gowen Chems., Inc. | Chesapeake, VA |
| Imperial West Chem. Co. | Antioch, CA |
| The Mead Corp. | Kingsport, TN |
| NRen Corp. | |
| North Star Div. | Pine Bend, MN |

| | |
|---|---|
| Olin Corp. | |
| Olin Chems. Group | Curtis Bay, MD |
| Sacramento, City of | Sacramento, CA |
| Stauffer Chem. Co. | |
| Indust. Chem. Div. | Bastrop, LA* |
| | Baton Rouge, LA |
| | Counce, TN |
| | Dominguez, CA |
| | Houston, TX* |
| | Naheola, AL |
| | North Portland, OR |
| | Richmond (Stege), CA* |
| | Springhill, LA |
| | Tacoma, WA |
| United States Filter Corp. | |
| Filtrol Corp., subsid. | Salt Lake City, UT |

Several of the above producers are known to use all production captively.

There are many distributors of aluminum sulfate. In addition to the previously listed manufacturers, the distributors include (<u>1980-81 OPD Chemical Buyers Directory</u>, 1980; <u>Chemical Week: 1981 Buyers' Guide Issue</u>, 1980; <u>Chem Sources--USA</u>, 1980):

Alcan Aluminum
Aldrich Chem.
Alfa Prod.
Anachemia Chem.
Apache Chem.
A and S Corp.
Ashland Chem.
Atomergic Chemetals
J.T. Baker Chem.
Barker Ind.
Bio-Clinical Labs
Bodman Chem.
Brown Chem.
Browning Chem.
Burris Chem.
Leonard J. Buck and Co.
Chemical Ind.
Chem. Services
Delamar Inc.
Eagle Chem.
E. M. Labs
Fielding Chem.
Fisher Sci.
Gallard-Schlesinger
Great Lakes Chem.
Jayar-Hoag Chem.
Jones Chem.
E and F King and Co.
LaPine Sci
Mallickrodt
MCB Regents
McKesson Chem.
Mida Chem.
Montedison
Mutchler Chem.
Pioneer Salt and Chem.
Pfaltz and Bauer
Ruger Chem.
Sal Chem.
E.M. Sargeant Pulp and Chem.
Chas Schaeffer Sons Inc.
Signo Trading
G. Fredick Smith Co.
Spex Ind.
Stinnes Oil and Chem.
Suburban Chem.
TAB Chem.
Thompson-Hayward Chem.
T.R. America
Tridon Chem.

C.P. Hall Co.
Hamblet and Hayes
Hawkins Chem.
Helm NY Chem.
Henderson Chem.
Holland Co.
Hukill Chem.
Int'l Commodities Export.
Joseph Turner and Co.
Ulrich Chem.
Universal Preservachem.
Van Waters and Rogers
Westco Chem.
Worth Chem.
Young Chem.

## 10. Manufacturing Processes

The following passages from Faith, Keyes, and Clark's Industrial Processes (Lowenheim and Moran, 1975) describe the manufacturing process:

> Aluminum sulfate is produced by the reaction of sulfuric acid on bauxite, a naturally occurring hydrated alumina ore having the approximate formula $Al_2O_3 \cdot 2H_2O$. The mined material varies in composition and generally contains one to three molecules of water plus impurities such as iron, silica, titanium, and selenium. The soluble aluminum oxide ($Al_2O_3$) content of a typical bauxite varies from 52 to 57% and it may contain 1 to 10% ferric oxide ($Fe_2O_3$).
>
> The crude bauxite ore is ground to a fine powder (80% passes 200 mesh) and charged into open lead-lined steel reaction tanks. Sulfuric acid (sp gr 1.7) is added, and the raw materials are thoroughly agitated using paddle agitators, hot air, or live steam. The reaction mixture is kept at a temperature of 105 to 110°C by the live steam or lead steam coils. An excess of bauxite is fed to the reactor, so that there is an excess of 0.1 to 0.2% of soluble aluminum oxide. From 15 to 20 hours are required to complete the reaction. At the end of this time, a reducing material is added to the reaction mixture to reduce the iron (ferric sulfate) to a colorless ferrous condition. Barium sulfide in the form of black ash is commonly utilized, although sodium sulfide, hydrogen sulfide, sodium bisulfite, or sulfur dioxide may also be used.
>
> If the operation is performed in batches, the charge is allowed to settle in settling tanks. Flaked glue or some similar coagulable substance is generally added to remove the finely divided suspended material remaining in the supernatant liquid. This liquid is drawn off, and the residue is washed several times. The washings are combined with the decanted liquor, which is then sent to concentrators.
>
> The process is generally operated in a continuous manner by using a battery of combined reaction and settling tanks. A common variation of this process is

the Dorr procedure, which utilizes reaction agitators in series. The reactants are thoroughly mixed and heated, using mechanical agitators, air, and live steam. Black ash (barium sulfide) is added to the last reactor to reduce the ferric sulfate. The reaction mixture is sent through a series of thickeners, operating countercurrently, which remove the undissolved material. At the same time the waste is washed thoroughly, so that it contains practically no aluminum sulfate when discarded. Glue is generally added to the first thickener as a coagulant.

The clarified aluminum sulfate solution, from the countercurrent decantation system, is concentrated in open steam-coil-heated, lead-lined evaporators. Here, the specific gravity is increased from about 1.3 to about 1.7. The concentrated solution is run into flat iron pans or onto a cooling table. The liquid quickly and completely solidifies, and when cool, is broken up and ground to a uniform powder for shipment.

Commercial aluminum sulfate generally contains only about 13 or 14 moles of water instead of the theoretical 18 moles. Also, it is usually in the basic form containing excess alumina. Anhydrous aluminum sulfate may be obtained by dehydration. The yield of aluminum sulfate based on the amount of aluminum oxide in both the finished product and raw material is 90 to 95% (Lowenheim and Moran, 1975).

The manufacturing process is shown in Figure 7.

The iron-free grade is produced by using pure alumina trihydrate in place of bauxite or clay (Darragh, 1978).

## 11. Impurities or Additives

Aluminum sulfate is commonly marketed in the technical or commercial grade. The commercial grade is available both as a lump or granular solid containing 17.0-17.5% $Al_2O_3$ (57% $Al(SO_4)_3$ basis; $Fe_2O_3$ <0.5%; water of composition 42-43%; and insolubles <1.0%) and as a solution containing 7.5-8.5% $Al_2O_3$ (Darragh, 1978). The iron-free grade has <0.005% $Fe_2O_3$.

## 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 189,639 workers are potentially exposed to aluminum sulfate.

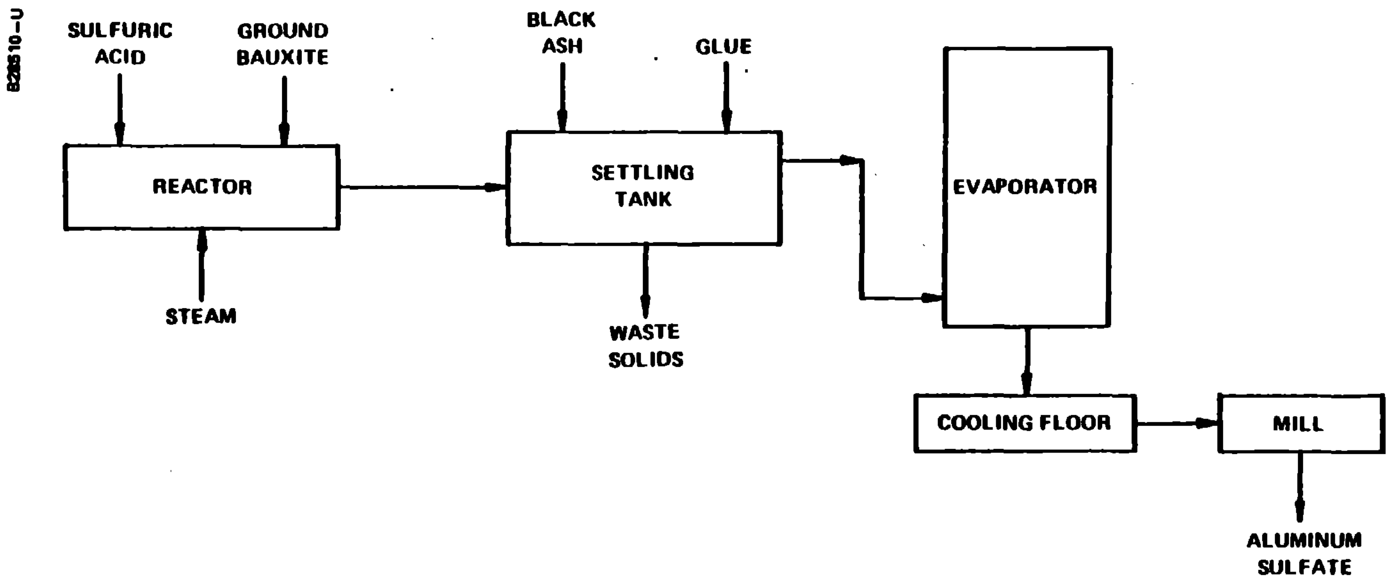


Figure 7. Manufacture of Aluminum Sulfate (Lowenheim and Moran, 1975)

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to aluminum sulfate were not found in the literature searched.

## 14. Biological Effects

### a. Animal Studies

#### (1) Acute Exposures

The acute toxicity of aluminum sulfate is summarized in Table 25. The administration of lethal oral doses of 1 or 2% $Al_2(SO_4)_3$ to rats that were 5/6 nephrectomized resulted in symptoms of lethargy, anorexia, and orbital bleeding (Berlyne et al., 1972). In non-nephrectomized rats, 350 mg Al/kg/day of 2% $Al_2(SO_4)_3$ caused periorbital bleeding in 3 of 5 rats, but no mortality when administered in the drinking water.

Ulcerations that progressively healed and associated inflammatory reactions that persisted for at least 3 weeks were noted in rabbit back skin following single and repeated (after 8 weeks) subcutaneous injections of 85 mg aluminum sulfate (Prior and Cronk, 1959). Similar changes were found in rabbit ears following single or repeated intracutaneous injections of 17 mg aluminum sulfate. Percutaneous application of a 17% solution of aluminum sulfate (applied with saturated cotton pads) produced a transient redness during the first 48 hours that gradually disappeared during the second 48 hours; this did not develop into a granulomatous response.

#### (2) Subchronic Exposures

Pulmonary function alterations (increased pulmonary resistance, respiratory frequencies, functional residual capacity, and static deflation volumes) were reported in rats following 7 weeks of continuous exposure to aluminum sulfate aerosol at a 2 mg/m$^3$ level (Lewkowski et al., 1979). When rats were exposed to smaller particles of aluminum sulfate (1.4 mm) at a slightly

Table 25. Acute Toxicity of Aluminum Sulfate

| Route | Species | Dose | Response | Reference |
|---|---|---|---|---|
| oral | mice | 980 mg/kg | LD50 | Ondreicka *et al*., 1966 |
| oral | rats | 200 mg Al/kg/day | 0/5 deaths | Berylne *et al*., 1972 |
| oral | rats | 350 mg/kg/day | 0/5 deaths | Berylne *et al*., 1972 |
| i.p.[a] | mice | 270 mg/kg | LD50 | Bienvenu *et al*., 1963 |

[a] i.p. = intraperitoneal

higher concentration (2.6 mg/$m^3$) for 8 weeks, an increase in respiratory frequency and a decrease in lung compliance were observed.

Lansdown (1973) found that 10% aluminum sulfate did not produce any visible or microscopic changes to the uncovered back skin of mice, rabbits, or guinea pigs when applied daily for 5 consecutive days.

(3) Chronic Exposures

No information was found in the literature searched.

(4) Carcinogenicity

No information was found in the literature searched.

(5) Mutagenicity

Testing of aluminum sulfate in two strains of recombination-deficient Bacillus subtilis (H17 and M45) did not indicate any mutagenic effects in the rec assay (Kanematsu et al., 1980).

Aluminum sulfate failed to enhance the transformation of Syrian hamster embryo cells by simian adenovirus SA7 (Casto et al., 1979).

Sirover and Loeb (1976) reported that aluminum sulfate at a concentration of 0.99 mM did not affect the accuracy of DNA synthesis in a cell-free DNA transcription assay system.

(6) Teratogenicity

No information was found in the literature searched.

(7) Reproductive Effects

Single intratesticular injections of aluminum sulfate (0.08 mmol/kg) have been reported to reduce the weight of the testis and produce degeneration of the seminiferous tubules in rats after 2 and 7 days (Kamboj and Kar, 1963). When administered subcutaneously in 30 daily doses, 0.08 mmol/kg aluminum sulfate reduced testicular weight in mice but had no necrotic effect.

(8) Other Relevant Information

Aluminum has been shown to accumulate in the skeleton, liver, testes, and adrenals of rats administered high levels of aluminum sulfate (2835 ppm in the feed) for 24 days (Ondreicka et al., 1966).

b. Human Studies

(1) Pharmacokinetics

No information was found in the literature searched.

(2) Health Effects

No information was found in the literature searched.

(3) Target Organ Toxicity

No information was found in the literature searched.

(4) Epidemiology

No information was found in the literature searched.

## 15. Ongoing Studies

The role of brain aluminum levels in producing toxic encephalopathy in rats and mice is currently being studied (Delaney, 1980).

## 16. Exposure Standards

The ACGIH (1979) currently recommends a Threshold Limit Value (TLV) of 2 mg/m$^3$ as Al for the soluble salts of aluminum. The TLV for these soluble salts, such as the chloride and sulfate, is based on the amount of hydrolyzed acid and the corresponding TLV. On the basis that 3 mol of HCl, with a TLV of 5 ppm, hydrolyze from 1 mol of $AlCl_3$, a TLV of 2 mg/m$^3$ as Al is recommended to provide the same degree of freedom from irritation that is provided by the TLV for HCl. As the acute toxicity from $Al_2(SO_4)_3$ is only slightly greater than that of $AlCl_3$, and the toxicity of the alums is considerably less, the 2 mg/m$^3$ is considered to be suitable for the soluble salts of aluminum (ACGIH, 1979).

### 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

### 18. Other Pertinent Data

No other information that would aid in the assessment of aluminum sulfate as an occupational hazard was found in the literature searched.

## R. CALCIUM ALUMINUM SILICATE

1. Chemical Name: Calcium Aluminum Silicate

2. Chemical Structure: $CaO \cdot Al_2O_3 \cdot SiO_2 \cdot H_2O$ (variable)

3. Synonyms: Aluminosilicic acid ($H_2Al_2SiO_6$), calcium salt (1:1)
   Aluminum calcium silicate

4. Chemical Abstract Service (CAS) Number: 12252-33-4

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number: Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | solid |
| Molecular Weight: | variable |
| Boiling Point: | --- |
| Melting Point: | --- |
| Vapor Pressure: | --- |
| Solubility: | practically insoluble in water |
| Specific Gravity: | --- |
| Stability: | noncombustible |

7. Production

Data available from the U.S. EPA (1980) regarding producers of calcium aluminum silicate and production volumes are presented below:

Hooker Chemical and Plastics (Columbia, TN)
Manufacturer
1977 Production: 500 million to 1 billion lb

United Mineral and Chem. Corp. (NYC, NY)
Importer
1977 Production: under 1000 lb

8. Use

A variety of patent literature indicates that calcium aluminum silicate is useful as a filler in plastics, rubbers, glasses, and gypsum. It can also be used as an anticaking agent in food products (Chapman and Kertesz, 1966), as a bore hole plugging component, and as a glass formatant.

## 9. Manufacturers and Distributors

See Section 7.

## 10. Manufacturing Processes

The commercial process is not available; however, calcium aluminum silicate can be prepared by reacting an aqueous aluminum salt (such as $AlCl_3$) with calcium silicate, which is prepared from sodium silicate (Allen, 1957).

## 11. Impurities or Additives

No information was found in the literature searched.

## 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to calcium aluminum silicate.

## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to calcium aluminum silicate were not found in the literature searched.

## 14. Biological Effects

No information regarding the biological effects of calcium aluminum silicate was found in the literature searched.

## 15. Ongoing Studies

No current toxicological or environmental studies of calcium aluminum silicate were found.

## 16. Exposure Standards

No recomended or promulgated occupational exposure standards for calcium aluminum silicate were found.

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of calcium aluminum silicate as an occupational hazard was found in the literature searched.

## S. DIETHYLALUMINUM CHLORIDE

1. Chemical Name: Diethylaluminum Chloride

2. Chemical Structure: $(C_2H_5)_2AlCl$

3. Synonyms: Aluminum diethylmonochloride
   Aluminum, chlorodiethyl
   Chlorodiethyl aluminum
   DEAC

4. Chemical Abstracts Service (CAS) Number: 96-10-6

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | colorless pyrophoric liquid |
| Molecular Weight: | 120.56 |
| Boiling Point: | 208-214°C |
| Melting Point: | -50 to -74°C |
| Vapor Pressure: | --- |
| Solubility: | decomposes with water |
| Specific Gravity: | $0.971^{25}_{25}$ |
| Stability: | highly flammable on air contact |

7. Production

Data available from the U.S. EPA (1980) regarding producers of diethylaluminum chloride and production volumes are presented in Table 26.

8. Use

Diethylaluminum chloride is used as a polymerization catalyst in the production of polyolefins, polybutadienes, and ethylene-propylene elastomers. It is also used as an intermediate in the synthesis of organometallics (Kuzma and Kelly, 1979; Borg, 1979; Hawley, 1977).

9. Manufacturers and Distributors

SRI International (1980) lists Texas Alkyls (Deer Park, TX) and Ethyl Corp. (Pasadena, TX, and Orangeburg, SC) as manufacturers; in addition, see Table 26.

Table 26. Producers of Diethylaluminum Chloride and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 96-10-6) |
|---|---|---|
| Texas Alkyls, Inc.<br>Deer Park, TX | Manufacturer | confidential |
| Ethyl Corp.<br>Pasadena, TX | Manufacturer | confidential |
| Shell Oil Co.<br>Woodburg, NJ | Manufacturer/<br>Produced Site Limited | 0.1-1 million lb |
| Houston, TX | Importer | 1-10 thousand lb |
| Plant Site Not on File | Importer | 0-1000 lb |

In addition to being distributed by the manufacturers, DEAC is distributed by Stauffer Chem. (1980-81 OPD Chemical Buyers Directory, 1980), a joint ownder of Texas Aklyls. Other distributors include (Chem Sources--USA, 1980):

Aldrich Chem.
Alfa Prod.
Apache Chem.
Atomergic Chemetals
Chemical Procurement Labs
Columbia Organic Chem.
EM Labs
ICN/K and K
Orion Chem.
Pfaltz and Bauer
Reliable Chem.
Tridom Chem.

### 10. Manufacturing Processes

Diethylaluminum chloride is manufacturerd industrially by producing ethylaluminum sesquichloride from aluminum powder and ethyl chloride and then reacting the sesquichloride with triethylaluminum to obtain the diethylaluminum chloride (Anderson, 1963; Hawley, 1977).

It can also be prepared by reacting triethylaluminum with aluminum chloride (Anderson, 1973).

### 11. Impurities or Additives

No information was found in the literature searched.

### 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to diethylaluminum chloride.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to diethylaluminum chloride were not found in the literature searched.

### 14. Biological Effects

No information regarding the biological effects of diethylaluminum chloride was found in the literature searched.

15. Ongoing Studies

No current toxicological or environmental studies of diethyl aluminum chloride were found.

16. Exposure Standards

No recommended or promulgated occupational exposure standards for diethylaluminum chloride were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of diethylaluminum chloride as an occupational hazard was found in the literature searched.

## T. SODIUM ALUMINATE

1. Chemical Name: Sodium Aluminate

2. Chemical Structure: $NaAlO_2$; $Na_2O \cdot Al_2O_3$; or $Na_2Al_2O_4$
The commercial product, however, has the amount of excess caustic as indicated by typical values of $Na_2O/Al_2O_3$ between 1.05 and 1.50.

3. Synonyms: Aluminum sodium oxide
Sodium *meta*-aluminate

4. Chemical Abstracts Service (CAS) Number: 1302-42-7

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:
BD1600000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | white crystalline solid in pure form |
| Molecular Weight: | variable |
| Boiling Point: | --- |
| Melting Point: | 1650-1800°C |
| Vapor Pressure: | --- |
| Solubility: | soluble in water<br>insoluble in alcohol |
| Specific Gravity: | --- |
| Stability: | noncombustible |

7. Production

Sodium aluminate has been known for many years as an intermediate product in the extraction of aluminum hydroxide from bauxite by the Bayer process. As a final product for commercial use, total production of sodium aluminate in 1976 was estimated to be 50,000 metric tons (approximately 110 million pounds) (Busler, 1978).

Data available from the U.S. EPA (1980) regarding producers of sodium aluminate and production volumes are presented in Table 27.

Table 27. Producers of Sodium Aluminate and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1302-42-7) |
|---|---|---|
| Los Angeles Chemical Co.<br>South Gate, CA | Manufacturer | 30-300 thousand lb |
| Olin Corp.<br>Kansas City, KS | Manufacturer | 10-100 thousand lb |
| Katalco Corp.<br>Chicago, IL | Manufacturer - Not distributed | confidential |
| Ethyl Corp.<br>_______, TX | Manufacturer | 1-10 million lb |
| H. Kohnstamm and Co.<br>Camden, NJ | Manufacturer | confidential |
| Vinings Chemical Co.<br>Marietta, GA | Manufacturer | confidential |
| Consolidated Foods Corp.<br>Atlanta, GA | Manufacturer | 1-10 thousand lb |
| Ormet Corp.<br>Burnside, LA | Manufacturer - Not distributed | over 1 billion lb |
| Union Carbide Corp.<br>South Charleston, WV | Manufacturer - Not distributed | 1-10 thousand lb |
| Aluminum Co. of Amer.<br>Mobile, AL | Manufacturer | confidential |
| Armak Catalysts<br>Pasadena, TX | Manufacturer | confidential |
| Adrian Joyce Works<br>Baltimore, MD | Manufacturer - Not distributed | confidential |
| PPC Corpus Christi Refinery<br>Corpus Christi, TX | Manufacturer | none |
| SCM Corp.<br>Astabula, OH | Manufacturer | confidential |
| The Mogul Corp.<br>Chagrin Falls, OH | Manufacturer | 10-100 thousand lb |
| Minneapolis, MN | Manufacturer | under 1000 lb |
| Charlotte, NC | Manufacturer | 1-10 thousand lb |
| Matthey Bishop Inc.<br>Winslow, NJ | Manufacturer | 1-10 million lb |

Table 27. Producers of Sodium Aluminate and Production Ranges (U.S. EPA, 1980) (Continued)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1302-42-7) |
|---|---|---|
| Nalco Chemical Co. | | |
| Chicago, IL | Manufacturer | confidential |
| Grayville, LA | Manufacturer | confidential |
| Titanium Pigment Division | | |
| St. Louis, MO | Manufacturer - Not distributed | 1-10 million lb |
| South Amboy, NJ | Manufacturer - Not distributed | 0.1-1 million lb |
| W.R. Grace and Co. | | |
| South Gate, LA | Manufacturer - Not distributed | 1-10 million lb |
| Cincinnati, OH | Manufacturer - Not distributed | 1-10 million lb |
| Lake Charles, LA | Manufacturer - Not distributed | 10-50 million lb |
| South Pittsburg, TN | Manufacturer | 1-10 million lb |
| Curtis Bay, MD | Manufacturer - Not distributed | 10-50 million lb |
| Dan River Inc. | | |
| Danville, VA | Manufacturer | 10-100 thousand lb |
| Groveton Papers | | |
| Groveton, NH | Manufacturer - Not distributed | under 1000 lb |
| The Chemithon Corp. | | |
| Seattle, WA | Manufacturer | confidential |
| Culligan USA | | |
| San Bernardino, CA | Manufacturer | confidential |
| Reynolds Metal Co. | | |
| Bauxite, AR | Manufacturer | over 1 billion lb |
| Sheffield, AL | Manufacturer - Not distributed | 0.1-1 million lb |
| Massena, NY | Manufacturer - Not distributed | 1-10 million lb |
| Troutdale, OR | Manufacturer - Not distributed | 0.1-1 million lb |
| Gregory, TX | Manufacturer - Not distributed | 100-500 million lb |
| Longview, WA | Manufacturer - Not distributed | 1-10 million lb |

Table 27. Producers of Sodium Aluminate and Production Ranges (U.S. EPA, 1980) (Continued)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1302-42-7) |
|---|---|---|
| J.M. Huber Corp. | | |
| Havre De Grace, MD | Manufactuer - Not distributed | 10-50 million lb |
| United Mineral and Chem. | | |
| NYC, NY | Importer | under 1000 lb |
| Henkel Inc. | | |
| Teaneck, NJ | Importer | under 1000 lb |
| American Cyanamid | | |
| Michigan City, IN | Importer - Not distributed | confidential |
| Savannah, GA | Importer - Not distributed | confidential |
| Fort Worth, TX | Importer - Not distributed | confidential |
| Para-Chem. Southern Inc. | | |
| Philadelphia, PA | Importer | 10-100 thousand lb |
| The Harshaw Chemical Co. | | |
| Elyria, OH | --- | 1-10 million lb |

### 8. Use

Sodium aluminate is used in treatments of industrial and municipal water supplies as a clarifying agent, precipitant, and coagulant aid. It is an effective precipitant for soluble phosphates in sewage and wastewaters of low alkalinity (Busler, 1978).

Large quantities of sodium aluminate are used in the papermaking industry to improve sizing and filler retention. The addition of sodium aluminum to titanium dioxide paint pigment improves the nonchalking performance of outdoor paints. The etching of glass and ceramics by alkaline washing solutions is inhibited by the inclusion of sodium aluminate in the formulations. The use of sodium aluminate solutions in the processing of acrylic and polyester synthetic fibers improves drying, antipiling, and antistatic properties of the fiber. Sodium aluminate is also used as a binder in foundry molds, in the preparation of zeolite catalysts, and in rigid insulating foams (Busler, 1978).

Other uses include the manufacture of milk-glass, soap and cleaning compounds, and lakes; the hardening of building stones (Hawley, 1977; The Merck Index, 1976); the coating of steel surfaces for protection from galvanizing; and in oil well drilling muds (Ryznar and Thompson, 1963).

### 9. Manufacturers and Distributors

SRI International (1980) lists the following manufacturers:

| | |
|---|---|
| Chemed Corp. (Dearborn Chem.) | Lake Zurich, IL |
| Ciba-Geigy Corp. (Hamblet and Hayes) | Salem, MA |
| Culligan International | San Bernardino, CA |
| W.R. Grace and Co. | Cincinnati, OH |
| | Curtis Bay, MD |
| | Lake Charles, LA |
| Howerton Gowen Chems. | Roanoke Rapids, NC |
| Nalco Chem. Co. | Chicago, IL |
| Vinings Chem. Co. | Vinings, GA |

Data available from the U.S. EPA (1980) regarding producers of sodium aluminate and production volumes are presented in Table 27.

In addition to the manufacturers, the distributors include (1980-81 OPD Chemical Buyers Directory, 1980; Chemical Week; 1980 Buyers' Guide Issue, 1980; Chem Sources--USA, 1980):

Anachemia Chem.
Ashland Chem.
Carus Chem.
Chem. Services
Coastal Aluminate
Dan River Inc.
Delmar Inc.
Delta Chemical
Fisher Sci.
ICN/K and K
Kay-Fries Inc.
LaPine Sci.
MCB Reagents
Metalene Chem. Co.
Orion Chem.
Pfaltz and Bauer
Thompson-Hayward Chem.
T.R. America
United Mineral and Chem.
Vining Chem.
A.B. Wood Chemical

### 10. Manufacturing Processes

Commercial quantities of sodium aluminate are made from alumina (Busler, 1978). The alumina used may be naturally occurring bauxites or the product of the Bayer process. The alumina is reacted with sodium hydroxide to form the aluminate; the process can be either an aqueous or dry operation depending upon the form of the aluminate to be produced.

In practice, about half of the digestion liquor produced in the aqueous process is sold as liquid sodium aluminate after filtration and dilution or concentration to conform with product specifications. Liquid sodium aluminate is available in steel drums, tank trucks, or railway tank cars with a density usually in the range of 1400-1600 kg/m$^3$. Solid products are available in bags, drums, or hopper cars.

### 11. Impurities or Additives

Some liquid sodium aluminate products contain small amounts of powdered insoluble solids that act as precipitation or congulation aids in water treatment processes. Concentrated solutions of sodium aluminate tend to decompose by alumina precipitation; decomposition is controlled by addition of excess caustic and small quantities of certain organic compounds (Busler, 1978).

12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to sodium aluminate.

13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to sodium aluminate were not found in the literature searched.

14. Biological Effects

No information regarding the biological effects of sodium aluminate was found in the literature searched.

15. Ongoing Studies

No current toxicological or environmental studies of sodium aluminate were found.

16. Exposure Standards

No recommended or promulgated occupational exposure standards for sodium aluminate were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of sodium aluminate as an occupational hazard was found in the literature searched.

## U. TRI-*n*-BUTYLALUMINUM

1. Chemical Name: Tri-*n*-butylaluminum

2. Chemical Structure: $(CH_3CH_2CH_2CH_2)_3Al$

3. Synonyms: Tributylaluminum
   Aluminum, tributyl-
   TNBA

4. Chemical Abstracts Service (CAS) Number: 1116-70-7

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | colorless pyrophoric liquid |
| Molecular Weight: | 198.33 |
| Boiling Point: | 120°C (2 mm Hg) |
| Melting Point: | -26.7°C |
| Vapor Pressure: | --- |
| Solubility: | decomposes in water |
| Specific Gravity: | 0.823 |
| Stability: | ignites spontaneously in air |

7. Production

Data available from the U.S. EPA (1980) regarding producers of tri-*n*-butylaluminum and production volumes are presented in Table 28.

8. Use

The tri-*n*-butylaluminum used captively by Conoco is likely used as an intermediate in the manufacture of linear primary alcohols and alpha-olefins.

Tri-*n*-butylaluminum is also used in the synthesis of organo-tin compounds (Hawley, 1977).

Table 28. Producers of Tri-n-butylaluminum and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1116-70-7) |
|---|---|---|
| Texas Alkyls, Inc.<br>Deer Park, TX | Manufacturer | confidential |
| Continental Oil Co.<br>Westlake, LA | Manufacturer/<br>Produced Site Limited | 1-10 million lb |

### 9. Manufacturers and Distributors

SRI International (1980) lists Texas Alkyls as a manufacturer of tri-n-butylaluminum; Table 28 also cites Continental Oil Co. (Conoco) as a manufacturer. Ethyl Corp. produces tri-n-butylaluminum in developmental quantities (Chemical Week: 1981 Buyers' Guide Issue, 1980).

In addition to the manufacturers, tri-n-butylaluminum is distributed by Stauffer Chem. (1980-81 OPD Chemical Buyers Directory, 1980), a joint owner of Texas Alkyls. Other distributors include (Chem Sources--USA, 1980):

Apache Chem.
ICN/K and K
Noah Chem.
Pfaltz and Bauer
Reliable Chem.
Tridom Chem.

### 10. Manufacturing Processes

Tri-n-butylaluminum is manufacturerd by the exchange reaction of 1-butene and isobutylaluminum (Hawley, 1977). This type of transalkylation process is shown in Figure 10 in the Tri-n-octylaluminum profile (III.V).

### 11. Impurities or Additives

No information was found in the literature searched.

### 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to tri-n-butylaluminum.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to tri-n-butylaluminum were not found in the literature searched.

### 14. Biological Effects

No information regarding the biological effects of tri-n-butylaluminum was found in the literature searched.

### 15. Ongoing Studies

No current toxicological or environmental studies of tri-*n*-butylaluminum were found.

### 16. Exposure Standards

No recommended or promulgated occupational exposure standards for tri-*n*-butylaluminum were found.

### 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

### 18. Other Pertinent Data

No other information that would aid in the assessment of tri-*n*-butylaluminum as an occupational hazard was found in the literature searched.

## V. TRIETHYLALUMINUM

1. Chemical Name: Triethylaluminum

2. Chemical Structure: $(C_2H_5)_3Al$

3. Synonyms: Aluminum, triethyl
   ATE
   TEA

4. Chemical Abstracts Service (CAS) Number: 97-93-8

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:

   BD2050000

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | colorless, pyrophoric liquid |
| Molecular Weight: | 114.17 |
| Boiling Point: | 194°C |
| Melting Point: | -52.5°C |
| Vapor Pressure: | --- |
| Solubility: | decomposes in water<br>miscible with saturated hydrocarbons |
| Specific Gravity: | 0.837 |
| Stability: | highly flammable, ignites spontaneously in air; reacts violently with water, acids, alcohols, halogens, and amines; Flash point: -63°F |

7. Production

Data available from the U.S. EPA (1980) regarding producers of triethylaluminum and production volumes are presented in Table 29.

8. Use

The most important commercial uses of triethylaluminum are in the production of primary linear alcohols and alpha-olefins. Continental Oil Co. (Conoco) and Ethyl Corp. produce linear alcohols from triethylaluminum that is captively consumed. Conoco's capacity to produce linear alcohols is 214 million pounds per year, whereas the capacity of Ethyl Corp. is 220 million pounds per

Table 29. Producers of Triethylaluminum and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 97-93-8) |
|---|---|---|
| Texas Alkyls, Inc. | | |
| Deer Park, TX | Manufacturer | confidential |
| Ethyl Corp. | | |
| Orangeburg, SC | Manufacturer | confidential |
| Pasadena, TX | Manufacturer | confidential |
| Continental Oil Co. | | |
| Westlake, LA | Manufacturer/ Produced Site Limited | 50-100 million lb |
| Plant Site Not on File | Importer/ Produced Site Limited | 0-1000 lb |

year (Gautreaux et al., 1978). As seen in Table 29, Conoco captively consumed between 50 and 100 million pounds of triethylaluminum in 1977.

Ethyl Corp. and Gulf Oil Corp. produce alpha-olefins using ethylene and a triethylaluminum catalytic initiator. Bradley (1976) has estimated that the amount of ethylene consumed in the production of aluminum alkyls for initiators and catalysts was 5-10 million in 1973; this could correlate to a triethylaluminum usage of 15-30 million pounds.

Triethylaluminum is also used as a catalyst in the synthesis of olefin polymers, as an intermediate in production of other organometallics and other organic chemicals, in the gas plating of aluminum onto other materials by thermal decomposition, and in pyrophoric fuels for turbojet engines (Anderson, 1963; Hawley, 1977).

### 9. Manufacturers and Distributors

Data available from the U.S. EPA (1980) regarding producers of triethylaluminum and production volumes are presented in Table 29. SRI International (1980) lists the same manufacturers as shown in Table 29.

In addition to the manufacturers, triethylaluminum is distributed by (Chemical Week: 1981 Buyers Guide Issue, 1980; Chem Sources--USA, 1980):

Aldrich Chem.
Alfa Products
(Thiokol/Ventron)
Apache Chem.
Atomergic Chemetals
EM Labs
Orion Chem.
Pfaltz and Bauer
Reliable Chem.
Stauffer Chemicals
Synthetic Prod.
Tridon Chem.

### 10. Manufacturing Processes

Triethylaluminum is manufactured by either a one- or two-stage process. In the two-stage process, aluminum powder is added to recycle triethylaluminum, and the slurry reacts with hydrogen to produce diethylaluminum hydride, which reacts with ethylene to produce triethylaluminum. In the one-stage process, hydrogen and ethylene are simultaneously fed into a reactor containing triethylaluminum and aluminum powder (Gautreaux et al., 1978).

A sample flow diagram illustrating triethylaluminum manufacture is shown in Figure 8.

### 11. Impurities or Additives

The specifications for triethylaluminum are as follows (Anderson, 1963):

| Chemical Composition | Percent By Weight | Typical Analysis (Percent) |
|---|---|---|
| Triethylaluminum | 88-94 | 91.25 |
| Soluble aluminum | 23.0, min. | 23.3 |
| Tri-*n*-butylaluminum | 5-7 | 5.5 |
| Triisobutylaluminum | 2, max. | 0.94 |
| Hydride as $AlH_3$ | 2, max. | 0.92 |

### 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 5961 workers are potentially exposed to triethylaluminum.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to triethylaluminum were not found in the literature searched.

### 14. Biological Effects

No information regarding the biological effects of triethylaluminum was found in the literature searched.

### 15. Ongoing Studies

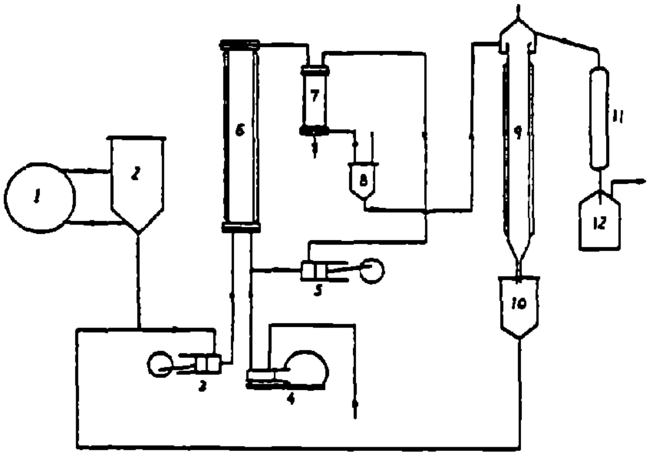
No current toxicological or environmental studies of triethylaluminum were found.

### 16. Exposure Standards

No recommended or promulgated occupational exposure standards for triethylaluminum were found.

**Reaction:**

$$Al + 3C_2H_4 + 3/2\,H_2 \longrightarrow Al(C_2H_5)_3$$



1. Wet micropulverizer for Al / Al $(C_2H_5)_3$ mixture
2. Slurry storage tank
3. Plunger pump
4. Mixed ( 2 : 1 ) ethylene-hydrogen feed compressor
5. Recycle gas pump
6. Reactor
7. Gas-liquid separator
8. Crude product receiver
9. Falling film evaporator
10. Still residue receiver
11. Cooler
12. Refined product receiver

**Feed Materials:**

Aluminum
Ethylene
Hydrogen

| | |
|---|---|
| **Catalyst:** | Iodine (Optional) |
| **Phase:** | Liquid |
| **Reactor type:** | Tubular Autoclave |
| **Solvent used:** | None |
| **Temperature, °C:** | 110-150 |
| **Pressure psi:** | 1500-2250 |
| **Reaction time:** | 2 hours |

Figure 8. Manufacture of Triethylaluminum (from Sittig, 1967: based on U.S. Patent 3,016,369 by T. Irie et al. to Sumitoma Chemical Co., Jan. 9, 1962)

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of triethylaluminum as an occupational hazard was found in the literature searched.

## W. TRI-*n*-HEXYLALUMINUM

1. Chemical Name: Tri-*n*-hexylaluminum

2. Chemical Structure: $(C_6H_{13})_3Al$

3. Synonyms: Aluminum, trihexyl-
   Trihexylaluminum

4. Chemical Abstracts Service (CAS) Number: 1116-73-0

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:
   Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | colorless pyrophoric liquid |
| Molecular Weight: | 282.49 |
| Boiling Point: | 210°C (0.05-0.06 mm Hg) |
| Melting Point: | --- |
| Vapor Pressure: | --- |
| Solubility: | decomposes in water |
| Specific Gravity: | --- |
| Stability: | ignites at room temperature |

7. Production

Data available from the U.S. EPA (1980) regarding producers of tri-*n*-hexylaluminum and production volumes are presented in Table 30.

8. Use

The tri-*n*-hexylaluminum captively used by Conoco is probably used as an intermediate in the manufacture of primary linear alcohols and alpha-olefins.

Tri-*n*-hexylaluminum is also used as a polyolefin catalyst (Hawley, 1977).

9. Manufacturers and Distributors

SRI International (1980) lists Texas Alkyls (Deer Park, TX) as a manufacturer of tri-*n*-hexylaluminum; Table 30 also lists Continental Oil Co. (Conoco).

Table 30. Products of Tri-n-hexylaluminum and Production Ranges (U.S. EPA, 1980)

| Producer and Location | Type of Production | 1977 Production Range (CAS No. 1116-73-0) |
|---|---|---|
| Texas Alkyls, Inc.<br>Deer Park, TX | Manufacturer | confidential |
| Continental Oil Co.<br>Westlake, LA | Manufacturer/ Produced Site Limited | 10-50 million lb |

In addition to the manufacturers, tri-n-hexylaluminum is distributed by Stauffer Chem. (1980-81 OPD Chemical Buyers Directory, 1980), a joint owner of Texas Alkyls. It is also distributed by Pfaltz and Bauer and Reliable Chem. (Chem Sources--USA, 1980).

### 10. Manufacturing Processes

Tri-n-hexylaluminum is derived by an exchange reaction between hexene and isobutylaluminum (Hawley, 1977). This type of transalkylation process is shown in Figure 10 in the Tri-n-octylaluminum profile (III.V).

### 11. Impurities or Additives

No information was found in the literature searched.

### 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to tri-n-hexylaluminum.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to tri-n-hexylaluminum were not found in the literature searched.

### 14. Biological Effects

No information regarding the biological effects of tri-n-hexylaluminum was found in the literature searched.

### 15. Ongoing Studies

No current toxicological or environmental studies of tri-n-hexylaluminum were found.

### 16. Exposure Standards

No recommended or promulgated occupational exposure standards for tri-n-hexylaluminum were found.

### 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of tri-*n*-hexylaluminum as an occupational hazard was found in the literature searched.

## X. TRIISOBUTYLALUMINUM

1. Chemical Name: Triisobutylaluminum

2. Chemical Structure: $[(CH_3)_2CHCH_2]_3Al$

3. Synonyms: Aluminum, triisobutyl-
   TIBAL
   TIBA
   Aluminum, tris (2-methylpropyl)-

4. Chemical Abstracts Service (CAS) Number: 100-99-2

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number:
   Not listed

6. Chemical and Physical Properties:

|  |  |
|---|---|
| Description: | colorless, pyrophoric liquid |
| Molecular Weight: | 198.33 |
| Boiling Point: | 212°C; 114°C (30 mm Hg) |
| Melting Point: | +1 to -5.6°C |
| Vapor Pressure: | 1 mm Hg (47°C) |
| Solubility: | decomposes with water |
| Specific Gravity: | 0.7876 |
| Stability: | ignites spontaneously in air;<br>Flash point: below 32°F |

7. Production

Cosslett and Gerry (1976) estimated that 3.5 million pounds of isobutylaluminum were produced in 1974; this included triisobutylaluminum and diisobutylaluminum chloride and hydride. The diisobutylaluminum compounds are prepared from triisobutylaluminum (Hoff et al., 1978; Anderson, 1963). In 1977, about 2 million pounds of isobutylene were used in the production of di- and triisobutylaluminums (Hoff et al., 1978); this corresponds to a triisobutylaluminum production of roughly 2 million pounds.

Production of triisobutylaluminum may be somewhat higher than the above figures would indicate. In 1977, Conoco produced from 1-10 million pounds of tributylaluminum and 10-50 million pounds of trihexylaluminum (U.S. EPA, 1980). Both compounds are apparently produced by exchange reactions with triisobutyl aluminum (Hawley, 1977). Therefore, a sizable amount of triisobutylaluminum may have been generated as an intermediate to produce these compounds.

Production ranges from the U.S. EPA (1980) are not available for triisobutylaluminum .

## 8. Use

As stated above, triisobutylaluminum is used as an intermediate in the production of other aluminum alkyl compounds. It is also used as a polymerization co-catalyst in the manufacture of polybutadiene, polyisoprene, and polypropylene (Cosslett and Gerry, 1976).

Other uses include manufacture of primary alcohol and alpha-olefins and use as a pyrophoric fuel (Hawley, 1977).

## 9. Manufacturers and Distributors

SRI International (1980) and U.S. EPA (1980) list the following manufacturers:

| | |
|---|---|
| Ethyl Corp. | Orangeburg, SC<br>Pasadena, TX |
| Texas Alkyls, Inc. | Deer Park, TX |

In addition to the manufacturers, triisobutyl aluminum is distributed by Stauffer Chem. (1980-81 OPD Chemical Buyers Directory, 1980), a joint owner of Texas Alkyls. Other distributors include (Chem Sources--USA, 1980):

- Aldrich Chem.
- Apache Chem.
- Atomergic Chemetals
- Chemical Procurement Labs
- EM Labs
- ICN/K and K
- Orion Chem.
- Pfaltz and Bauer
- Reliable Chem.
- Tridom Chem.

### 10. Manufacturing Processes

Triisobutylaluminum is manufactured by reaction of isobutylene with aluminum at 80°C and 200 atmospheres pressure of hydrogen (Hoff et al., 1978). A sample flow diagram depicting this type of process is shown in Figure 9.

### 11. Impurities or Additives

Triisobutylaluminum has the following specifications (Anderson, 1963):

| Chemical Composition | Percent By Weight | Typical Analysis (Percent) |
|---|---|---|
| Triisobutylaluminum | 95.6, min. | 95.7 |
| Soluble aluminum | 13.4, min. | 13.66 |
| Tri-n-butylaluminum | 0.4, max. | 0.33 |
| Hydride as $AlH_3$ | 0.8, max. | 0.56 |
| Dissolved isobutylene | 4.0, max. | 2.98 |

### 12. Occupational Exposure

The National Occupational Hazard Survey indicates that 6377 workers are potentially exposed to triisobutylaluminum.

### 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to triisobutylaluminum were not found in the literature searched.

### 14. Biological Effects

No information regarding the biological effects of triisobutylaluminum was found in the literature searched.

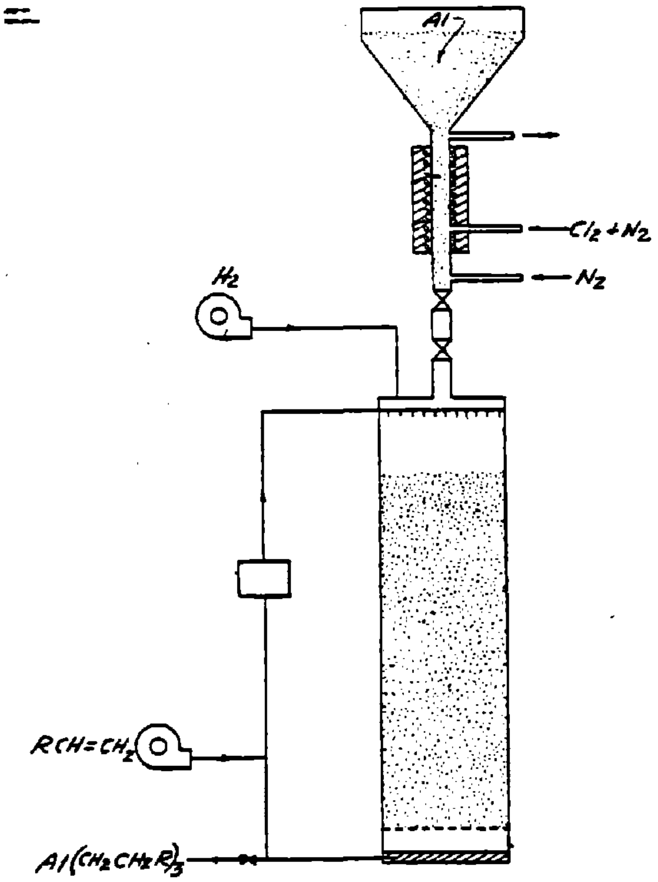
### 15. Ongoing Studies

No current toxicological or environmental studies of triisobutylaluminum were found.

### 16. Exposure Standards

No recommended or promulgated occupational exposure standards for triisobutylaluminum were found.

**Reaction:** $Al + 3RCH{=}CH_2 + 3/2\,H_2 \longrightarrow Al(CH_2CH_2R)_3$



**Feed Materials:**
- Aluminum
- Isobutylene
- Hydrogen

| | |
|---|---|
| **Catalyst:** | Chlorine as Activator |
| **Phase:** | Mixed Liquid-Gas |
| **Reactor type:** | Tower |
| **Solvent used:** | None |
| **Temperature, °C:** | 110-150 |
| **Pressure psi:** | 1500-2250 |
| **Reaction time:** | 3 hrs. |
| **Heat Required:** | Yes |

Figure 9. Manufacture of Triisobutylaluminum (from Sittig, 1967: based on U.S. Patent 3,000,919 by G. Wetroff <u>et</u> <u>al</u>. to Pechiney, Sept. 19, 1961)

## 17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

## 18. Other Pertinent Data

No other information that would aid in the assessment of triisobutylaluminum as an occupational hazard was found in the literature searched.

## Y. TRI-n-OCTYLALUMINUM

1. Chemical Name: Tri-n-octylaluminum

2. Chemical Structure: $(C_8H_{17})_3Al$

3. Synonyms: Aluminum, triocytl-

4. Chemical Abstracts Service (CAS) Number: 1070-00-4

5. Registry of Toxic Effects of Chemical Substances (RTECS) Number: Not listed

6. Chemical and Physical Properties:

| | |
|---|---|
| Description: | colorless pyrophoric liquid |
| Molecular Weight: | 366.65 |
| Boiling Point: | --- |
| Melting Point: | --- |
| Vapor Pressure: | --- |
| Solubility: | --- |
| Specific Gravity: | --- |
| Stability: | flammable; ignites in air |

7. Production

Data available from the U.S. EPA (1980) indicate that the Continental Oil Co. produced between 10 and 50 million pounds of tri-n-octylaluminum in 1977 for captive use only.

8. Use

Tri-n-octylaluminum is used as a polyolefin catalyst (Hawley, 1977). The captive use by Conoco may also include use in the manufacture of primary linear alcohols and alpha-olefins.

9. Manufacturers and Distributors

SRI International (1980) lists Texas Alkyls (Deer Park, TX) as a manufacturer. The U.S. EPA (1980) lists the Continental Oil Co. (Westlake, LA) as a captive manufacturer.

In addition to the manufacturers, tri-n-octylaluminum is distributed by Stauffer Chem. (1980-81 OPD Chemical Buyers Directory, 1980), a joint owner of Texas Alkyls. Other distributors include (Chem Sources--USA, 1980):

- Atomergic Chemetals
- Chemical Procurement Labs
- EM Labs
- ICN/K and K
- Orion Chem.
- Pfaltz and Bauer
- Reliable Chem.

## 10. Manufacturing Processes

Tri-n-octylaluminum is made by the reaction of octene and isobutylaluminum (Hawley, 1977). This type of transalkylation process is shown in Figure 10.

## 11. Impurities or Additives

No information was found in the literature searched.

## 12. Occupational Exposure

The National Occupational Hazard Survey does not provide an estimate of the number of workers who are potentially exposed to tri-n-octylaluminum.

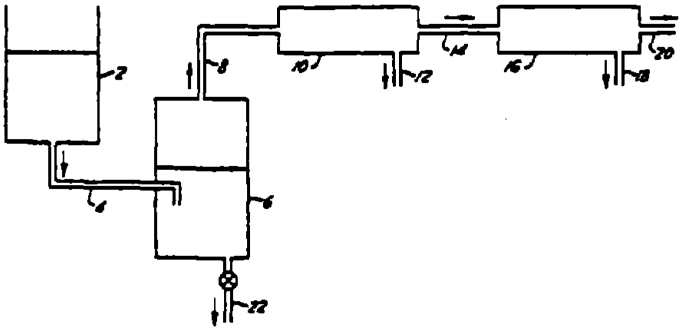
## 13. Control Technology and Work Practices

Specific factors that may contribute to or prevent employee exposure to tri-n-octylaluminum were not found in the literature searched.

## 14. Biological Effects

No information regarding the biological effects of tri-n-octylaluminum was found in the literature searched.

**Reaction:** $Al(C_4H_9)_3 + 3C_8H_{16} \longrightarrow Al(C_8H_{17})_3 + 3C_4H_8$



2-Octene storage
4-Octene feed line
6-Reactor
8-Gaseous products line
10-Condenser
12-Unreacted octene out
14-Gaseous products line
16-Condenser
18-Isobutylene out
20-Hydrogen vent
22-Product outlet

**Feed Materials:**
Aluminum Triisobutyl
1-Octene

**Coproducts:**
Isobutylene
Octene Dimers

| | |
|---|---|
| **Catalyst:** | None |
| **Phase:** | Mixed Liquid-Gas |
| **Reactor type:** | Tower |
| **Solvent used:** | None |
| **Temperature, °C:** | 70-250 |
| **Pressure psi:** | 1.0 psi absolute |
| **Reaction time:** | 1-10 hrs. |
| **Heat Required:** | - |
| **Heat evolved:** | - |
| **Product yield:** | 95% |

Figure 10. Aluminum Alkyls by Transalkylation (from Sittig, 1967: based on U.S. Patent 3,014,941 by W.L. Walsh to Goodrich-Gulf Chemicals Inc., Dec. 26, 1961)

15. Ongoing Studies

No current toxicological or environmental studies of tri-n-octylaluminum were found.

16. Exposure Standards

No recommended or promulgated occupational exposure standards for tri-n-octylaluminum were found.

17. Sources of Additional Relevant Information

No sources of additional relevant information were identified.

18. Other Pertinent Data

No other information that would aid in the assessment of tri-n-octylaluminum as an occupational hazard was found in the literature searched.

# APPENDIX

## ALUMINUM COMPOUNDS

The following alphabetical list of chemicals comprises all aluminum compounds considered for inclusion in this information profile, regardless of their commercial importance or biological activity.

Aluminum
Aluminum acetate, mono-
Aluminum acetate, di-
Aluminum acetate, tri-
Aluminum acetate, sub-
Aluminum acetotartrate
Aluminum acetylacetonate
Aluminum acetylsalicylate
Aluminum acrylate
Aluminum p-aminobenzoate
Aluminum ammonium chloride
Aluminum ammonium fluoride
Aluminum ammonium sulfate
Aluminum amphomycin
Aluminum anilide
Aluminum antimonide
Aluminum arsenate
Aluminum arsenide
Aluminum barium oxide
Aluminum benzoate
Aluminum bismuth hydroxide carbonate
Aluminum bismuth oxide
Aluminum borate
Aluminum boride
Aluminum boroformate
Aluminum borohydride
Aluminum borotannate
Aluminum bromide
Aluminum n-butoxide
Aluminum sec-butoxide
Aluminum tert-butoxide
Aluminum sec-butoxide diisopropoxide
Aluminum sec-butoxide stearate
Aluminum calcium hydride
Aluminum calcium iron oxide
Aluminum calcium oxide
Aluminum calcium silicate
Aluminum caprate
Aluminum caproate
Aluminum caprylate
Aluminum carbide
Aluminum carbonate
Aluminum cesium sulfate

Aluminum chlorate
Aluminum chlorhydrate
Aluminum chlorhydrol
Aluminum chlorhydroxy allantoinate
Aluminum chloride, anhydrous
Aluminum chloride, hydrous
Aluminum chloride hydroxide
Aluminum chlorite
Aluminum chlorohydroxide
Aluminum chromate
Aluminum citrate
Aluminum cobalt oxide
Aluminum copper phosphate
Aluminum cyclohexane butyrate
Aluminum dihydroxy allantoinate
Aluminum dihydroxy aminoacetate
Aluminum diisopropoxide acetoacetic ester chelate
Aluminum dimagnesium silicate
Aluminum diphenylamide
Aluminum diphenylchloride
Aluminum dodecarboride
Aluminum dodecylbenzenesulfonate
Aluminum dodecylsulfate
Aluminum ethoxide
Aluminum 2-ethylhexanoate
Aluminum ferrocyanide
Aluminum fluoborate
Aluminum fluoride
Aluminum fluorosulfate, hydrate
Aluminum fluosilicate
Aluminum formate, di-
Aluminum formate, tri-
Aluminum formate, basic
Aluminum formoacetate
Aluminum glycinate
Aluminum heptylate
Aluminum hexacyanoferrate
Aluminum hexadecycloxide isopropoxide stearate
Aluminum hexafluoroacetylacetonate
Aluminum hexafluorosilicate
Aluminum hexaurea dinitrate triiodide
Aluminum hexaurea sulfate triiodide
Aluminum hydride
Aluminum hydroxide acetate
Aluminum hydroxychloride
Aluminum 8-hyroxyquinolate
Aluminum hydroxystearate
Aluminum hypophosphite
Aluminum iodide
Aluminum iron silicide
Aluminum isopropoxide
Aluminum isopropoxide chelates
Aluminum lactate
Aluminum laurate

Aluminum lauryl sulfate
Aluminum lignosulfonate
Aluminum lithium hydride
Aluminum lithium silicate
Aluminum magnesium acetate hydroxide
Aluminum magnesium carbonate hydroxide
Aluminum magnesium hydroxide
Aluminum magnesium phosphide
Aluminum magnesium silicate
Aluminum magnesium sulfate
Aluminum metaphosphate
Aluminum methacrylate
Aluminum methoxide
Aluminum o-molybdate
Aluminum myristate
Aluminum naphthenate
Aluminum 2-naphthol-3,6-disulfonate
Aluminum nicotinate
Aluminum nitrate
Aluminum nitride
Aluminum octanoate
Aluminum oleate
Aluminum orthohydroxyquinoline sulfate
Aluminum orthophosphate
Aluminum oxide
Aluminum oxychloride
Aluminum palmitate
Aluminum perchlorate
Aluminum permanganate
Aluminum phenolsulfonate
Aluminum phenoxide
Aluminum phosphate
Aluminum phosphide
Aluminum phthalocyanine chloride
Aluminum picrate
Aluminum polygalacturonate
Aluminum potassium chloride
Aluminum potassium oxide
Aluminum potassium sulfate
Aluminum propoxide
Aluminum resinate
Aluminum beta-resorcylate
Aluminum ricinoleate
Aluminum rubidium sulfate
Aluminum salicylate
Aluminum selenate
Aluminum selenide
Aluminum selenite
Aluminum silicates
Aluminum silicide
Aluminum silicofluoride
Aluminum sodium chlorhydroxy lactate
Aluminum sodium chloride
Aluminum sodium fluoride

Aluminum sodium lactate
Aluminum sodium oxide
Aluminum sodium sulfate
Aluminum stearate, mono-
Aluminum stearate, di-
Aluminum stearate, tri-
Aluminum suboxide
Aluminum sulfamate
Aluminum sulfate
Aluminum sulfide
Aluminum tantalide
Aluminum tartrate
Aluminum tellurate
Aluminum telluride
Aluminum tellurite
Aluminum tetraisoproxide
Aluminum thiocyanate
Aluminum thiophenoxide
Aluminum _m_-titanate
Aluminum triacetylide
Aluminum tri-_sec_-butoxide
Aluminum trihydrate
Aluminum tungstate
Aluminum zinc sulfate
Aluminum _m_-zirconate
Calcium aluminate
Dibutylaluminum chloride
Diethylaluminum amide
Diethylaluminum chloride
Diethylaluminum cyanide
Diethylaluminum ethoxide
Diethylaluminum fluoride
Diethylaluminum hydride
Diethylaluminum iodide
Diisobutylaluminum chloride
Diisobutylaluminum ethoxide
Diisobutylaluminum hydride
Dimethylaluminum chloride
Dipropylaluminum chloride
Dipropylaluminum hydride
Ethylaluminum dibromide
Ethylaluminum dichloride
Ethylaluminum diethoxide
Ethylaluminum sesquibromide
Ethylaluminum sesquichloride
Isobutylaluminum dichloride
Isobutylaluminum sesquichloride
Isoprenylaluminum
Lithium aluminate
Lithium aluminum hydride
Magnesium aluminum silicate
Methylaluminum dichloride
Methylaluminum sesquibromide
Methylaluminum sesquichloride

Potassium aluminate
Sodium aluminate
Sodium aluminum bis(2-methoxyethoxy)dihydride
Sodium aluminum diethyl dihydride
Sodium aluminum hydride
Sodium aluminum phosphate
Sodium aluminum silicate
Tributylaluminum
Tri-_n_-decylaluminum
Triethylaluminum
Tri-_n_-hexylaluminum
Triisobutylaluminum
Trimethylaluminum
Tri-2-methylpentylaluminum
Tri-_n_-octylaluminum
Tri-_n_-propylaluminum

## REFERENCES

ACGIH (American Conference of Governmental Industrial Hygienists) (1979). Documentation of the Threshold Limit Values for Substances in Workroom Air, 3rd ed., 1971, with supplements through 1979. Cincinnati, OH: ACGIH.

Allen, E.M. (1957). Alumina-silica compositions. U.S. Patent 2,786,776 (to Columbia-Southern Chem. Corp.). March 26, 1957. Taken from: Chem. Abst. 51:10019d, 1957.

Allfrey, A.; LeGendre, G.; and Kaehny, W. (1976). Dialysis dementia. New Engl. J. Med. 294:184.

Aluminum Association, Inc. (1977). Mortality of Aluminum Workers. Final Report. Unpublished report submitted to NIOSH by the Aluminum Association, Inc., NY, May 1977, 74 pp. (Cited in: NIOSH (National Institute of Occupational Safety and Health (1977). Criteria for a Recommended Standard: Occupational Exposure to Coal Tar Products, DHEW (NIOSH) Publication No. 78-107. Cincinnati, OH: U.S. Dept. of Health, Education, and Welfare, Public Health Service, Center for Disease Control, NIOSH.)

Anderson, A.R. (1963). Aluminum compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 2, pp. 25-40.

Anderson, W.A., and Haupin, W.E. (1978). Aluminum and alloys. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 1, pp. 140-144, 155.

Anderson, A.F., and Thomas, I.M. (1963). Alkoxides, metal. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 1, p. 845.

Badenoch-Jones, P.; Turk, J.L.; and Parker, D. (1978). The effects of some aluminum compounds and zirconium compounds on guinea pig peritoneal macrophages and skin fibroblasts in culture. J. Pathol. 124:51-62.

Bellan, A., and Deneke, K. (1972). Basic aluminum chloride. German Patent 2,048,273 (assigned to Dynamit Nobe AG). April 6, 1972. Taken from: Chem. Abst. 77:7928g, 1972.

Benett, R.; Persaud, T.; and Moore, K. (1975). Experimental studies on the effects of aluminum on pregnancy and fetal development. Anat. Anz. Bd. 138:365-378.

Berlyne, G.; Ben-Ari, J.; Knopf, E.; Yagil, R.; Weinberger, G.; and Danovitch, G. (1972). Aluminum toxicity in rats. Lancet 1:564-567.

Berlyne, G.M.; Ben-Ari, J.; Pest, D.; Weinberger, J.; Stern, M.; Gilmore, G.R.; and Levine, R. (1970). Hyperaluminaemia from aluminum resins in renal failure. Lancet, September 5, pp. 494-496.

Berlyne, G., and Rubin, J. (1977). Aluminum ion: Metabolism and toxicity. J. Human Nutr. 31:439-442.

Bienvenu, P.; Nofre, C.; and Cier, A. (1963). [General comparative toxicity of metal ions. Relationship with their periodic classification.] C.R.H. Acad. 256:1043-1044. (In Fr.)

Borg, E.L. (1979). Elastomers, synthetic (ethylene-propylene). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 8, p. 495.

Bradley, R.F. (1976). Linear alpha-olefins. In: Chemical Economics Handbook. Menlo Park, CA: Stanford Research Institute, pp. 681.5032 B-D.

Bretzinger, D., and Josten, W. (1978). Alkoxides, metal. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 2, pp. 12-13.

Brown, D.; Brown, J.; and Egan, B. (1980). Epidemiology and Industrial Hygiene Study of Aluminum Reduction Workers. National Institute for Occupational Safety and Health, Division of Surveillance, Hazard Evaluations, and Field Studies, Cincinnati, OH. Grant No. VMHC22563. Taken from: Smithsonian Science Information Exchange (1980). SSIE Current Research. The Lockheed Dialog Retrieval Service, File 65.

Busler, W.R. (1978). Aluminum compounds (aluminates). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 2, pp. 199-200.

Casto, B.C.; Meyers, J.; and DiPaolo, J.A. (1979). Enhancement of viral transformation for evaluation of the carcinogenic or mutagenic potential of inorganic metal salts. Cancer Res. 39:193-198.

Cavender, F.L.; Steinhagen, W.H.; and Cockrell, B.Y. (1978). Chronic toxicity of aluminum chlorhydrate. Clin. Tox. 12:606 (Abstract).

Chapman, D.G., and Kertesz, Z.I. (1966). Food additives. In: Kirk-Othmer Encyclopedia of Chemical Teechnology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 10, p. 4.

Chemical and Engineering News (1980). Untitled. June 9, 1980, p. 39.

Chemical Week: 1981 Buyers' Guide Issue (1980). October, 1980. New York: McGraw Hill, Inc., pp. 196, 349-353, 356-359, 637, 681.

Chem Sources--USA, 1980 ed. (1980). Ormond Beach, FL: Directories Publishing Company, Inc., pp. 24-25, 218, 552, 598, 602, 607, 614.

Clarkson, E.; Luck, V.; and Hynson, W. (1972). The effect of aluminum hydroxide on calcium, phosphorous, and aluminum balances; the serum parathyroid concentration; and the aluminum content of bones in patients with chronic renal failure. Clin. Sci. 43:519-531.

CMR (Chemical Marketing Reporter) (1980a). Chemical profile: $AlCl_3$, anhydrous. June 9, 1980, p. 9.

CMR (Chemical Marketing Reporter) (1980b). Chemical profile: $AlCl_3$, hydrous. June 16, 1980, p. 9.

Corrin, B. (1963). Aluminum pneumoconiosis. II. Effect on the rat lung of intratracheal injections of stamped aluminum powders containing different lubricating agents and of a granular aluminum powder. Brit. J. Ind. Med. 20:268-276.

Cosslett, P.D., and Gerry, R.T. (1976). Butylenes. In: Chemical Economics Handbook. Menlo Park, CA: Stanford Research Institute, p. 620.5043C.

Crapper, D.; Krishnan, S.; and Dalton, A. (1973). Brain aluminum distribution in Alzheimer's disease and experimental neurofibrillary degeneration. Science 180:511-513.

Crombie, D.; Blaisdell, J.; and MacPherson, G. (1944). The treatment of silicosis by aluminum powder. Can. Med. Assoc. J. 50:318-321.

Danner, M., and Krieg, M. (1974). Basic aluminum chloride solution. German Patent 2,309,610 (assigned to Farbwerke Hoeschst AG). September 12, 1974. Taken from: Chem. Abst. 81:61296r, 1975.

Darragh, K.V. (1978). Aluminum compounds ($Al_2(SO_4)_3$), alums). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 2, pp. 244-250.

Delaney, J.F. (1980). Role of Aluminum in a Pathogenesis of Alzheimer's Disease. U.S. Veterans Administration Hospital, Dept. of Medicine and Surgery, Pittsburgh, PA. Grant No. 159321479; 646001P. Taken from: Smithsonian Science Information Exchange (1980). SSIE Current Research. The Lockheed Dialog Retrieval Service, File 65.

Dixon, R.L.; Sherins, R.J.; and Lee, I.P. (1979). Assessment of environmental factors affecting male fertility. Environ. Health Perspect. 30:53-68.

Drew, R.; Bhola, N.; Bend, J.; and Hook, G. (1974). Inhalation studies with a glycol complex of aluminum chloride hydroxide. Arch. Environ. Health 28:321.

Elliott, H.L.; Dryburgh, F.; Fell, G.S.; Sabet, S.; and MacDougall, A.I. (1978). Aluminum toxicity during regular hemodialysis. Brit. Med. J. 1(6120): 1101-1103.

Ellis, H.; McCarthy, J.; and Herrington, J. (1979). Bone aluminum in hemodialysed patients and in rats injected with aluminum chloride: Relationship to impaired mineralization. J. Clin. Pathol. 32:832-844.

Feria-Velasco, A.; Olivares, N.; Rivas, F.; Velasco, M.; and Velasco, F. (1980). Alumina cream-induced focal motor epilepsy in cats. IV. Thickness and cellularity of layers in the perilesional motor cortex. Arch Neurol. 37:287-290.

Frosch, P.J., and Kligman, A.M. (1977). The chamber-scarification test for assessing irritancy of topically applied substances. In: Conference on Cutaneous Toxicity, 3rd, Washington, DC, 1976. Drill, V.A., and Lazard, P., editors. New York: Academic Press, Inc., pp. 127-154.

Gall, J.F. (1980). Fluorine compounds, inorganic. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 10, pp. 661-663.

Gautreaux, M.F.; Davis, W.T.; and Travis, E.D. (1978). Alcohols, higher aliphatic (synthetic). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 1, pp. 740-747.

Gibbs, G.W., and Horowitz, I. (1979). Lung cancer mortality in aluminum reduction plant workers. J. Occup. Med. 21:347-353.

Goralewski, G. (1947). Aluminum lung: A new occupational disease. Z. Gesamte Inn. Med. 2:665. (In Ger.)

Gorsky, J.; Dietz, A.; Spencer, H.; and Osis, D. (1979). Metabolic balance of aluminum studied in six men. Clin. Chem. 25:1739-1743.

Gottlieb, R. (1963). Aluminum compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 2, p. 24.

Greenberg, S.R. (1977). The pulmonary effects of pure aluminum. Bull. Soc. Pharmacol. Environ. Pathol. 5(4):8-11.

Gross, P.; Harley, R.; and deTreville, R. (1973). Pulmonary reaction to metallic aluminum powders. Arch. Environ. Health 26:227.

Haddow, A., and Horning, E. (1960). On the carcinogenicity of an iron-dextran complex. J. Nat. Cancer Inst. 24:109-127.

Hamme, J.V. (1979). Ceramics (raw materials). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 5, p. 247.

Hart, M., and Adamson, R. (1971). Antitumor activity and toxicity of salts of inorganic Group IIIa metals: Aluminum, gallium, indium, and thallium. Proc. Nat. Acad. Sci. 68:1623.

Hartford, W.H. (1979). Chromium compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 6, p. 113.

Hartford, W.H., and Copson, R.L. (1964). Chromium compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 5, p. 499.

Hawley, G.G., editor (1977). The Condensed Chemical Dictionary, 9th ed. New York: Van Nostrand Reinhold Company, p. 31-37, 149, 213, 285-287, 352, 517-518, 559, 875, 881, 884, 890, 892.

Hayes, E.R. (1963). Acetaldehyde. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 1, p. 82.

Hoff, M.C.; Im, U.K.; Hauschildt, W.F.; and Puskas, I. (1978). Butylenes. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 4, pp. 349, 361, 366.

Hunter, D.; Milton, R.; Perry, K.; and Thompson, D. (1944). Title unavailable. Brit. J. Ind. Med. 1:159. (Cited in McLaughlin, 1962.)

Isacoff, H. (1979). Cosmetics. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 7, p. 151.

Kaehny, W.D. (1980). Aluminum Metabolism (Human). University of Colorado, Medical Center School of Medicine, Denver, CO. Sponsored by: U.S. Dept. of Health, Education, and Welfare, Public Health Service, National Institute for Occupational Safety and Health, Bethesda, MD. Grant No. MO1RR000511803̲44. Taken from: Smithsonian Science Information Exchange (1980). SSIE Current Research. The Lockheed Dialog Retrieval Service, File 65.

Kamboj, U., and Kar, A. (1964). Antitesticular effects of metallic and rare earth salts. J. Reprod. Fert. 7:21-28.

Kanematsu, N.; Hara, M.; and Kada, T. (1980). Rec assay and mutagenicity studies on metal compounds. Mutat. Res. 77:109-116.

Kang, K.; Bill, D.; Hoffman, E.; D'Amato, R.; and Salvaggio, J. (1977). Experimental studies of sensitization to beryllium, zirconium, and aluminum compounds in the rabbit. J. Allergy Clin. Immunol. 59:425-436.

King, E.J.; Harrison, C.V.; Mohanty, G.P.; and Nagelschmidt, G. (1955). The effect of various forms of alumina on the lungs of rats. J. Pathol. Bacteriol. 69:81-93.

King, E.J.; Harrison, C.V.; Mohanty, G.P.; and Yoganathan, M. (1958). The effect of aluminum and of aluminum containing 5 per cent quartz in the lungs of rats. J. Pathol. Bacteriol. 75:429-434.

King, G.; DeBoni, U.; and Crapper, D. (1975). Effect of aluminum upon conditioned avoidance response acquisition in the absence of neurofibrillary degeneration. Pharmacol. Biochem. Behav. 3:1003-1009.

Klosterkotter, W. (1960). Effects of ultramicroscopic gamma-aluminum oxide on rats and mice. AMA Arch. Ind. Health 21:458.

Krasovskii, G.; Yasukovich, L.; and Chariev, O. (1979). Experimental study of biological effects of lead and aluminum following oral administration. Environ. Health Perspect. 30:47-51.

Kunesh, C.J. (1978). Barium compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 3, pp. 459-460.

Kuzma, L.J., and Kelly, W.J. (1979). Elastomers, synthetic (polybutadiene). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 8, p. 555.

Lansdown, A.B.G. (1973). Production of epidermal damage in mammalian skins by some simple aluminum compounds. Brit. J. Dermatol. 89:67-76.

Landsdown, A.B.G. (1974). Aluminum compounds in the cosmetics industry. Their action as antiperspirants and safety in use. Soap Perfume Cosmet. 47(5):209-212.

Lawler, G.M., editor. (1977). Chemical Origins and Markets, 5th ed. Menlo Park, CA: Stanford Research Institute, pp. 31, 93.

Lewkowski, J.P.; Malanchuk, M.; Hastings, L.; Vinegar, A.; and Cooper, G.P. (1979). Effects of chronic exposure of rats to automobile exhaust, sulfuric acid, sulfur dioxide, aluminum sulfate, and carbon monoxide. In: Assessing the Toxic Effects of Environmental Pollution. Lee, S.D., and Mudd, J.B., editors. Ann Arbor, MI: Ann Arbor Science, pp. 187-217.

Litton (1977). Mutagenicity Evaluation of FDA7591: Aluminum Potassium Sulfate, Publication No. FDA/BF78/57. Prepared by Litton Bionetics, Kensington, MD, under Contract No. FDA223762104. U.S. Food and Drug Administration, Washington, DC. Available from: National Technical Information Service, Springfield, VA (NTIS-PB-278-461).

Lowenheim, F.A., and Moran, M.K. (1975). Faith, Keyes, and Clark's Industrial Chemicals, 4th ed. New York: John Wiley and Sons, Inc., pp. 72, 76-79.

MacZura, G.; Goodboy, K.P.; and Koenig, J.J. (1978). Aluminum compounds (aluminum oxide). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 2, pp. 218, 225, 227, 230-234, 236-239.

Manna, G.K., and Das, R.K. (1972). Chromosome aberrations in mice induced by aluminum chloride. Nucleus (Calcutta) 15:180-186.

Marstiller, C.M. (1978). Aluminum compounds ($AlX_3$, $Al(NO_3)_3$). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 2, pp. 209-217.

Martin, J.J.; Rubino, A.M.; Jones, J.L.; and Lawrence, J.A. (1966). A new aerosol antiperspirant. Drug Cosmet. Ind. 99:54.

MCA (Manufacturing Chemists Association) (1975). Statistical Summary 1975. Washington, DC: MCA, p. 24.

McCormack, K.; Ottosen, L.; Sanger, V.; Sprague, S.; Mayor, G.; and Hook, J. (1979). Effect of prenatal administration of aluminum and parathyroid hormone on fetal development in the rat. Proc. Soc. Exp. Biol. Med. 161:74-77.

McLaughlin, A.; Kazantis, G.; King, E.; Teare, D.; Porter, R.; and Owen, R. (1962). Pulmonary fibrosis and encephalopathy associated with the inhalation of aluminum dust. Brit. J. Ind. Med. 18:21-23.

Mecca, S.B. (1970). Uric acid. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 21, p. 113.

The Merck Index: An Encyclopedia of Chemicals and Drugs, 8th ed. (1968). Stecher, P.G.; Windholz, M.; and Leahy, D.S., editors. Rahway, NJ: Merck and Co., Inc., p. 43.

The Merck Index: An Encyclopedia of Chemicals and Drugs, 9th ed. (1976). Windholz, M., editor. Rahway, NJ: Merck and Co., pp. 44-50, 345, 366.

Milham, S. (1979). Mortality in aluminum reduction plant workers. J. Occup. Med. 21:475-480.

Milvy, P., and Kay, K. (1978). Mutagenicity of 19 major graphic arts and printing dyes. J. Toxicol. Environ. Health 4:31-36.

Mitchell, J.; Manning, B.; Molyneux, M.; and Lane, R. (1961). Pulmonary fibrosis in workers exposed to finely powdered aluminum. Brit. J. Ind. Med. 18:10-20.

Moser, F.H. (1968). Phthalocyanine compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 15, p. 490.

Nashed, N. (1975). Preparation of peritoneal cell metaphases of rats, mice, and Chinese hamsters after mitogenic stimulation with magnesium sulfate and/or aluminum hydroxide. Mutat. Res. 30:407-416.

Neimeier, R. (1980). Co-Carcinogenicity of Foundry Particulates. National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Science, Cincinnati, OH. Grant No. V00C24289. Taken from: Smithsonian Science Information Exchange (1980). SSIE Current Research. The Lockheed Dialog Retrieval Service, File 65.

Nekipelov, M.I. (1966). Hygienic standard for aluminum nitrate in water basins. Hyg. Sanit. 31:204-208.

Newberne, P.M., and Wilson, R.B. (1970). Renal damage associated with silicon compounds in dogs. Proc. Nat. Acad. Sci. 65:872-875.

1980-81 OPD Chemical Buyers Directory, 68th ed. (1980). New York: Schnell Publishing Co., Inc., pp. 54-65, 334, 901, 1031, 1038, 1041, 1042.

NIOSH (National Institute for Occupational Safety and Health) (1975). Criteria for a Recommended Standard: Occupational Exposure to Inorganic Fluorides, DHEW (NIOSH) Publication No. 76-103. Cincinnati, OH: U.S. Dept. of Health, Education, and Welfare, Public Health Service, Center for Disease Control, NIOSH.

Norseth, T. (1979). Aluminum. In: Handbook on the Toxicology of Metals. Friberg, L. et al., editors. New York: Elsevier/North-Holland Biomedical Press, pp. 275-281.

NTP (National Toxicology Program) (1980). Chemicals on Standard Protocol. Bethesda, MD: NTPμ Carcinogenesis Testing Program. Available from: Technical Information Resources Branch, Carcinogenesis Testing Program, NTP, Landow Bldg., Rm. A306, Bethesda, MD 20014.

Nishioka, H. (1975). Mutagenic activities of metal compounds in bacteria. Mutat. Res. 31:185-189.

Ondreicka, R.; Ginter, E.; and Kortus, J. (1966). Chronic toxicity of aluminum in rats and mice and its effects on phosphorous metabolism. Brit. J. Ind. Med. 23:305.

Papee, D., and Tertian, R. (1963). Aluminum compounds (aluminum oxides). In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 2, p. 50.

Parsons, T. (1977). Industrial Process Profiles for Environmental Use. Chapter 25. Primary Aluminum Industry. Prepared by Radian Corp. Austin, TX, under Contract No. 68021319. U.S. Environmental Protection Agency, Cincinnati, OH, pp. 5, 12, 25.

PEDCo Environmental, Inc. (1978). Environmental Assessment of the Domestic Primary Aluminum Industry (Prepublication copy). Prepared by PEDCo Environmental, Inc., Cincinnati, OH, under Contract No. 68032537, Work Directive No. 1. U.S. Environmental Protection Agency, Cincinnati, OH, pp. 78.

Prior, J.T., and Cronk, G.A. (1959). Pathological changes associated with aluminum and zironium compounds. An experimental study of skin pathology following the application of aluminum chlorohydroxide, aluminum sulfate, sodium aluminum lactate, and zirconium tetraisopropoxide. Amer. Med. Assoc. Arch. Dermatol. 80:105/477-112/454.

Ridgway, L., and Karnofsky, D. (1952). The effects of metals on the chick embryo: Toxicity and production of abnormalities in development. Ann. N.Y. Acad. Sci. 55:203-15.

Ringk, W., and Theimer, E.T. (1978). Benzyl alcohol and beta-phenethyl alcohol. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 3, p. 800.

Ryznar, J.W., and Thompson, A.C. (1963). Aluminum compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 2, pp. 9-10.

Saeman, W.C. (1963). Aluminum compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 2, p. 65.

Schliffer, W.H. (1947). Aluminum nitrate. In: Encyclopedia of Chemical Technology. Kirk, R.E., and Othmer, D.F., editors. New York: Interscience Encyclopedia, Inc., Vol. 1, p. 640.

Schroeder, H., and Mitchener, M. (1975a). Lifetime effects of mercury, methyl mercury, and nine other trace metals on mice. J. Nutr. 105:452-458.

Schroeder, H., and Mitchener, M. (1975b). Lifeterm studies in rats: Effects of aluminum, barium, beryllium, and tungsten. J. Nutr. 105:421-427.

Shaver, C., and Riddell, A. (1947). Lung changes associated with the manufacture of alumina abrasives. J. Ind. Hyg. Toxicol. 29:145-157.

Sirover, M.A., and Loeb, L.A. (1976). Infidelity of DNA synthesis in vitro: Screening for potential metal mutagens or carcinogens. Science 194:1434-1436.

Sittig, M. (1967). Organic Chemical Process Encyclopedia, 1967. Park Ridge, NJ: Noyes Development Corp., pp. 559, 65, 66.

Sorensen, J.; Campbell, I.; Tepper, L.; and Lingg, R. (1974). Aluminum in the environment and human health. Environ. Health Perspect. 8:3-95.

SRI International (1980). 1980 Directory of Chemical Producers: United States of America. Menlo Park, CA: SRI International, pp. 431-435, 674, 866.

Stacy, B.D.; King, E.J.; Harrison, C.V.; Nagelschmidt, G.; and Nelson, S. (1959). Tissue changes in rats' lungs caused by hydroxides, oxides, and phosphates of aluminum and iron. J. Pathol. Bacteriol. 77:417-426.

Stamper, J.W., and Kurtz, H.F. (1976). Aluminum. Mineral Facts and Problems, 1975 ed. Washington, DC: U.S. Dept. of the Interior, Bureau of Mines, pp. 53, 60, 62.

Stankus, R.P.; Schuyler, M.R.; D'Amato, R.A.; and Salvaggio, J.E. (1978). Bronchopulmonary cellular response to aluminum and zirconium salt. Infection and Immunity 20:847-852.

Stenback, F.; Rowland, J.; and Sellakumar, A. (1976). Carcinogenicity of benzo[a]pyrene and dusts in the hamster lung (instilled intratracheally) with titanium oxide, aluminum oxide, carbon, and ferric oxide. Oncology 33:29-34.

Stewart, A.E. (1963). Aluminum compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 2, pp. 11-12.

Sullivan, E.A., and Wade, R.C. (1980). Hydrides. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 12, pp. 777, 788.

Thurston, H.; Gilmore, G.; and Swales, J. (1972). Aluminum retention and toxicity in chronic renal failure. Lancet 1:881-883.

Toubes, B. (1963). Aluminum compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 2, p. 16.

Treskon, D.J. (1976a). Alumina salient statistics. In: Chemical Economics Handbook. Menlo Park, CA: Stanford Research Institute, pp. 702.2000B-C.

Treskon, D.J. (1976b). Aluminum-salient statistics. In: Chemical Economics Handbook. Menlo Park, CA: Stanford Research Institute, p. 702.3000F.

Treskon, D.J. (1976c). Aluminum chloride salient statistics. In: Chemical Economics Handbook. Menlo Park, CA: Stanford Research Institute, pp. 702.4000B, D.

Treskon, D.J. (1976d). Aluminum sulfate (alum) salient statistics. In: Chemical Economics Handbook. Menlo Park, CA: Stanford Research Institute, pp. 702.5000G-H.

Tucker, H., and Horne, S.E., Jr. (1979). Elastomers, synthetic (polyisoprene). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 8, p. 585.

Turk, J.L., and Parker, D. (1977). Granuloma formation in normal guinea pigs injected intradermally with aluminum and zirconium compounds. J. Invst. Dermatol. 68:336-340.

USDC (U.S. Dept. of Commerce) (1979). U.S. Exports Schedule E Commodity Groupings. Schedule E Commodity by Country, FT 410/December 1978. Washington, DC: U.S. Bureau of the Census, p. 113.

U.S. EPA (U.S. Environmental Protection Agency) (1980). Computer print-out of nonconfidential production data from TSCA Inventory. U.S. EPA, Office of Pesticides and Toxic Substances, Chemical Information Division, Washington, DC.

USITC (U.S. International Trade Commission) (1976). Synthetic Organic Chemicals: United States Production and Sales, 1974, USITC Publication 776. USITC, p. 200.

USITC (U.S. International Trade Commission) (1977a). Synthetic Organic Chemicals: United States Production and Sales, 1975, USITC Publication 804. USITC, p. 196.

USITC (U.S. International Trade Commission) (1977b). Synthetic Organic Chemicals: United States Production and Sales, 1976, USITC Publication 833. USITC, p. 300.

USITC (U.S. International Trade Commission) (1978). Synthetic Organic Chemicals: United States Production and Sales, 1977, USITC Publication 920. USITC, p. 358.

USITC (U.S. International Trade Commission) (1979). Synthetic Organic Chemicals: United States Production and Sales, 1978, USITC Publication 1001. USITC, pp. 310, 330.

Van Wazer, J.R. (1968). Phosphoric acid and phosphates. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 15, p. 275.

Wagner, J.; Berry, G.; and Timbrell, V. (1973). Mesothelioma in rats after inoculation with asbestos and other materials. Brit. J. Cancer 28:173-185.

Waldbott, G.L. (1963). Acute fluoride intoxication. Acta Med. Scand. (suppl.) 400:5-42.

Waldron-Edward, D.; Chan, P.; and Skoryna, S. (1971). Increased prothrombin time and metabolic changes with high serum aluminum levels following long term exposure to Bayer-process alumina. Can. Med. Assoc. J. 105:1297.

Warner, G.H. (1978). Aluminum compounds (carboxylates). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 2, pp. 202-207.

Webber, T.G. (1979). Colorants for plastics. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 18, pp. 157-158.

Wentorf, R.H. (1978). Boron compounds (refractory). In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed. Grayson, M., and Eckroth, D., editors. New York: John Wiley and Sons, Inc., Vol. 4, p. 126.

Whitaker, G.C. (1965). Driers and metallic soaps. In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 7, p. 274.

Williamson, A.P.; Blattner, R.J.; and Lutz, H.R. (1963). Abnormalities in chick embryos following thalidomide and other insoluble compounds in the amniotic cavity. Proc. Soc. Exp. Biol. Med. 112:1022-1025.

Wills, J.H. (1969). Silicon compounds (silicates). In: Kirk-Othmer Encyclopedia of Chemical Technology, 2nd ed. Standen, A., editor. New York: John Wiley and Sons, Inc., Vol. 18, pp. 157-158.