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OCCUPATIONAL EXPOSURE TO BERYLLIUM

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Health Services and Mental Health Administration
National Institute for Occupational Safety and Health

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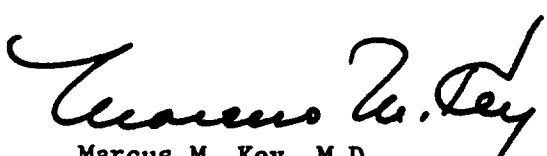
PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health of workers exposed to an ever increasing number of potential hazards at their workplace. To provide relevant data from which valid criteria and effective standards can be deduced, the National Institute for Occupational Safety and Health has projected a formal system of research, with priorities determined on the basis of specified indices.

It is intended to present successive reports as research and epidemiologic studies are completed and sampling and analytic methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on beryllium by members of my staff and the valuable constructive comments by the Review Consultants on Beryllium to NIOSH; the ad-hoc committees of the American Industrial Hygiene Association and the American Medical Association Committee on Occupational Toxicology; and Dr. Harriet L. Hardy, Dartmouth Medical School, and Mr. Harry F. Schulte, Atomic Energy Commission, as unusually qualified experts. The NIOSH recommendations for standards are not necessarily a consensus of all the consultants and professional societies that reviewed this criteria document on beryllium. A list of the Review Committee members and Review Consultants appears on pages iii and iv.



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The Office of Research and Standards Development, National Institute for Occupational Safety and Health, had primary responsibility for development of the criteria and the recommended standard for beryllium. Douglas L. Smith, Ph.D., served as criteria manager and had NIOSH program responsibility for development of the document; Mr. Andrew D. Hosey developed the basic information for consideration by NIOSH staff and consultants under contract No. 68-03-0008.

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CRITERIA DOCUMENT: RECOMMENDATIONS FOR AN OCCUPATIONAL EXPOSURE STANDARD FOR BERYLLIUM

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I. RECOMMENDATIONS FOR A BERYLLIUM STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that worker exposure to beryllium and its compounds in the workplace be controlled by requiring compliance with the standard set forth in the following sections. Control of worker exposure by the techniques recommended should prevent the development of acute and chronic beryllium disease in workers exposed to beryllium.

The limits are attainable with existing technology and measurable by techniques that are valid and reproducible. The standard will be reviewed and revised as necessary.

Section 1 - Environmental (workplace air)

(a) Concentration

No worker shall be exposed at his place of employment to a concentration of beryllium more than two micrograms of total airborne particulate beryllium per cubic meter of air (2 μg Be/m^3)(determined by the breathing-zone and general air methods as described in Appendix I), determined as a time-weighted average (TWA) exposure for an 8-hour work day, and no peak concentration of beryllium to which workers are exposed shall exceed 25 μg Be/m^3 as determined by a minimum sampling time of thirty minutes.

(b) Sampling and Analysis

Procedures for sampling, calibration of equipment, and analysis of beryllium samples shall be as provided in Appendices I and II.

Section 2 - Medical

(a) Medical surveillance as specified in this section is required for workers who are exposed to beryllium.

(b) A comprehensive pre-placement history and physical examination for all worker applicants shall be provided to include as a minimum a 14" by 17" chest roentgenogram, baseline pulmonary function [forced vital capacity (FVC) and forced expiratory volume at one second ($FEV_{1.0}$)], and a baseline weight.

(c) Each worker exposed to beryllium shall receive an annual* evaluation that includes:

(1) Spirometry, including FVC and $FEV_{1.0}$.

(2) A medical history questionnaire that includes presence and degree of respiratory symptoms, i.e., breathlessness, cough, sputum production, and wheezing.

(3) A 14" by 17" chest X-ray.

(d) Department of Health, Education, and Welfare (HEW) and Department of Labor (DOL) physicians and medical consultants and those physicians designated and authorized by the employees shall have access to medical records.

(e) Medical records shall be maintained for at least 20 years.

*Except where a variance has been granted, based on minimal exposure.

Section 3 - Labeling

(a) The following precautionary label shall be applied to all shipping and storage containers or packages containing beryllium and beryllium compounds where exposures to dusts, fumes, powders, or liquids are likely to occur.

BERYLLIUM

(Name of Compound)

Dust, Fume, Powder, or Liquid

DANGER

Harmful If Inhaled and May Cause Immediate Or Delayed Injury

Use Only With Adequate Local Exhaust Ventilation and Approved Respiratory and Personal Protective Devices

May Cause Rash or External Ulcers
Wash Thoroughly After Handling

(b) The following warning sign shall be affixed in a readily visible location on processing and other equipment, on storage bins and tanks, and at or near entrances and areas where exposure to dusts or fumes of beryllium and its compounds are likely to occur.

DANGER

Beryllium Dust (or Fume) Areas

UNAUTHORIZED PERSONS

KEEP OUT

Breathing Dust (Or Fumes) May Cause Immediate or Delayed Injury

Section 4 - Personal Protective Equipment and Clothing

(a) Respiratory Devices

(1) Respiratory protective devices shall be used any time the actual or projected level of beryllium will exceed an 8-hour time-weighted average concentration of 2 $\mu g/m^3$. These devices shall not be used as a substitute for proper engineering controls, but are appropriate for necessary periods where excessive atmospheric concentrations result from emergencies or from maintenance or repair.

(2) If a variance order is granted under provisions of the Occupational Safety and Health Act of 1970 from the environmental limits set forth in Section 1, the provisions of this section shall still apply to safeguard workers.

(3) Standard procedures shall be established for respirator use to include the following:

(i) Procedures established for respirator usage shall insure that no worker is exposed to beryllium in excess of the standard because of improper respirator selection or facepiece fit.

(ii) Facepiece fit shall be checked by the wearer each time he puts on the respirator.

(iii) The respirator used shall be of the appropriate class as determined on the basis of the actual or projected atmospheric concentration of airborne beryllium at the worksite where the respirator is to be used as follows:

(A) Reusable half mask air purifying respirators equipped with high efficiency filters shall be used in atmospheres containing

not more than 25 μg Be/m^3 for any period of time.

(B) Reusable full-facepiece air purifying respirators equipped with high efficiency filter shall be used in atmospheres containing not more than 100 μg Be/m^3 for any period of time.

(C) Powered air purifying respirators equipped with high efficiency filters, operating with positive pressure during the inhalation phase of breathing shall be used in atmospheres containing not more than 1000 μg Be/m^3. When equipped with a "fume filter," respirators shall be used in atmospheres containing not more than 40 μg Be/m^3.

(D) Continuous flow air-line respirators or self-contained breathing units operating in the pressure-demand mode and providing positive pressure during the inhalation phase of breathing, shall be used in atmospheres that exceed 1000 μg Be/m^3.

(iv) Only respirators approved by the U.S. Bureau of Mines and/or NIOSH under the provisions of 30 CFR Part 11 (37 F.R. 6244) shall be used.

(4) An effective respirator program to include selection, use, maintenance and care, special problems, and effective respirator program evaluation shall be established. Compliance with the requirements of the latest revision of the American National Standard Practices for Respiratory Protection Z88.2 shall be considered prima facie evidence of compliance with this subsection.

(b) Protective Clothing

(1) Beryllium Exposed Workers

(i) The employer shall provide each employee except those with minimal exposure with protective clothing, headgear, and shoes when the employee must work with and/or be exposed to beryllium, beryllium compounds, or beryllium containing products.

With minimal exposure with

(A) Such clothing may be coveralls or similar full-body protective clothing.

(B) Protective shoe covers or work shoes shall be worn during the working hours in areas where there is exposure to beryllium.

(C) Resin-impregnated paper or similar protective clothing can be substituted for fabric-type clothing.

(ii) Protective clothing shall be changed at least each day at the end of each shift.

(iii) The employer shall provide for maintenance and laundering of soiled protective clothing, which shall be stored, transported, and disposed of in sealed, non-reusable containers and labeled with easy-to-read letters as outlined in Section 3.

(iv) Dust removal, by blowing or shaking of clothing, shall be prohibited; protective clothing shall be cleaned by power suction (vacuum) prior to removal; removal of contaminated clothing shall be allowed only in the change rooms.

(v) The employer shall provide laundering controls and inform the employee and any third party which launders contaminated clothing of the potentially harmful effects of exposure to beryllium dust and of safe practices required in the laundering of beryllium-soiled work clothing.

(2) Workers with Minimum Beryllium Exposure

(i) The employer shall provide laboratory coats or equivalent protective clothing to each such employee who works with or is exposed to beryllium, beryllium compounds, or beryllium containing products.

(ii) Clean protective clothing shall be supplied to each worker at least weekly.

Section 5 - Apprisal of Employees of Hazards from Beryllium

(a) Each employee exposed to beryllium shall be apprised of all hazards, adverse symptoms of overexposure, appropriate emergency procedures, and proper conditions and precautions for safe use or exposure, to include as a minimum, all information as set forth in Appendix III which is applicable to that specific product or material containing beryllium to which he is exposed.

(b) The information shall be maintained on file and readily accessible to the worker at all places of employment where beryllium is involved in unit processes and operations.

(c) Information as specified in Appendix III shall be recorded on U.S. Department of Labor Form OSHA-20, "Material Safety Data Sheet," or a similar form approved by the Occupational Safety and Health Administration, U.S. Department of Labor.

Section 6 - Work Practices

(a) Emergency Procedures

(1) Procedures, including fire fighting procedures, shall be established and implemented to meet forseeable emergency events, including those involving massive release of beryllium contaminants.

(i) Where there is the possiblility of massive beryllium contamination from accidents involving elevated temperature operations or large scale spills, a general alarm, drench-type showers, and cleansing facilities shall be installed in such a manner as to provide prompt, immediate access by any employee; respirators shall be available for wearing during evacuation procedures if long distances need to be traversed; and full-facepiece or supplied-air respirators shall be available for employee use where equipment or operations cannot be abandoned. If large scale spills occur, careful monitoring of beryllium air levels shall be instituted as soon as possible. Determinations shall be made as to when it is safe to reenter a contaminated area with respiratory protection and to resume operations without respiratory protection. Thoroughly supervised cleanup operations shall be instituted as soon as air levels recede to the point where operations may be conducted.

(ii) Full-facepiece or supplied-air respirators shall be kept ready for emergency use.

(A) They shall be inspected after each use and at least monthly to assure satisfactory working condition.

(B) Where used, air and oxygen cylinders shall be fully charged according to the manufacturer's instructions.

(iii) Sand, soda ash, or commercial metal fire extinguishment powder shall be available for use as an extinguishing agent for beryllium; water and carbon dioxide shall not be used.

(b) Exhaust Systems

Procedures shall be established to reduce exposure to airborne beryllium through implementation of adequate ventilation methods. Local exhaust and collection shall be designed and maintained to prevent the accumulation of beryllium dust and fumes.

(c) General Housekeeping

(1) No dry sweeping shall be performed.

(2) Emphasis shall be placed upon cleanup of spills, periodic repair of equipment and leaks, and proper storage of materials to prevent breakage.

(d) Disposal

Beryllium waste and scrap shall be collected and disposed of in sealed bags or other sealed containers. Scrap shall be recycled or shall be disposed of by burial.

(e) Non-Worker Access to Beryllium Areas

Entry to any area where there is the possibility of exposure to beryllium shall be permitted only on the basis of need and all persons so entering shall be provided with the same protective clothing as required for employees regularly assigned to that area.

(f) Educational Program

An educational program shall be instituted for all workers to include proper instruction in maintenance procedures, cleanup methods, and use of respiratory protective devices and protective clothing.

Section 7 - Sanitation Practices

(a) Food Facilities

Food preparation and eating should be prohibited in beryllium work areas.

(b) Locker and Toilet Facilities*

(1) Separate locker facilities shall be provided for work clothes and street clothes.

(2) Showers for exposed workers shall be required following a work shift and prior to putting on street clothes.

(3) Locker-shower facilities shall be so arranged that the showers can serve to demarcate between potentially "clean" and "contaminated" areas.

(4) Suitable provisions shall be made for the control of contaminated dust in workshoe storage and clothing hamper locations.

(5) Handwashing and toilet facilities shall be arranged so that following use, workers need not re-enter a potentially contaminated area.

*Except where a variance has been granted, based on minimal exposure.

Section 8 - Monitoring and Recordkeeping Requirements

(a) Employers shall maintain records of environmental exposures to beryllium based upon the following sampling and recording schedule:

(1) Quarterly Requirements*

(i) Breathing-zone samples shall be collected from employees at least quarterly for specific work operations. The first sampling period shall be completed within 180 days of the effective date of this standard.

(ii) Samples shall be collected and evaluated as both time-weighted and peak concentration values.

(2) Thirty-Day Requirements

The sampling regime shall be every 30 days for work areas under the following conditions:

(i) The environmental time-weighted average or peak concentrations are in excess of the standard.

(ii) Sampling, monitoring, and recordkeeping requirements of a 30-day schedule shall be required only until two consecutive 30-day sampling periods have resulted in environmental levels which meet the standard.

(b) Records shall be maintained for all sampling schedules to include the type of personal protective devices, if any, in use.

(c) Workers shall be informed of the periodic results of samplings.

*Except where a variance has been granted, based on minimal exposure, as determined by selected sampling of representative or minimal exposed workers. It is recognized that sampling frequency is dependent upon the process and emissions; the quarterly sampling frequency is primarily for production operations.

II. INTRODUCTION

This report presents the criteria and the standard based thereon which were prepared to meet the need for preventing occupational diseases arising from exposure to beryllium and its compounds. The necessary relevant data are made available for use by the Secretary, Department of Health, Education, and Welfare in accordance with the provision of the Occupational Safety and Health Act of 1970 requiring the development of criteria by "The Secretary, Department of Health, Education, and Welfare... on the basis of such research, demonstrations, and experiments and any other information available to him...to effectuate the purposes of this Act."..."...by providing medical criteria which will assure insofar as practicable that no employee will suffer diminished health, functional capacity, or life expectancy as a result of his work experience...".

The National Institute for Occupational Safety and Health (NIOSH), after a review of data and consultation with others, formalized a system for the development of criteria upon which standards can be established to protect the health of workers from exposure to hazardous chemical and physical agents. It should be pointed out that any recommended criteria for a standard should result in development of better engineering controls, resulting in more healthful work practices, and should not be used as a final goal.

These criteria for a standard for beryllium and its compounds are in a continuing series of criteria developed by NIOSH. The criteria and standard apply only to the processing, manufacture, and use of beryllium products as applicable under the Occupational Safety and Health Act of 1970.

These criteria were not designed for the population-at-large, and any extrapolation beyond general occupational exposures is not warranted. They are intended to assure that the standard based theron will (1) protect against development of acute and chronic beryllium disease, (2) be measurable by techniques that are valid; reproducible, and available to industry and official agencies, and (3) be attainable with existing technology.

III. PROPERTIES AND SOURCES

Beryllium is one of the lightest of metals, is widely distributed geographically, and has found wide application in industry. It has many unique properties: it is the only stable, lightweight metal with a high melting point; it has an especially high strength-to-weight ratio; its alloying property confers to metals specific properties of resistance to corrosion, vibration, and shock; and it possesses extreme hardness yet excellent ductility. A condensed list of its physical properties is presented in Table I.[1]

Beryl ($3BeO.Al_2O_3.6SiO_2$) is presently the chief source of beryllium, although bertrandite [$Be_4Si_2O_7(OH)_2$], chrysoberyl ($BeAl_2O_4$), and phenacite ($BeSiO_4$) are also important beryllium-containing minerals.

Domestic production of beryl, the principal beryllium-containing ore of commercial importance, was approximately 500 tons in 1950. Domestic production has remained relatively constant as contrasted with domestic consumption which, in 1969, reached 8500 tons and is forecast to reach 20,000 tons by the year 2000.[2,3] The bulk of our beryllium ore supply is imported[3,4] and is processed primarily in Ohio and Pennsylvania. Products from the initial processing either are utilized locally or shipped to a variety of sources for incorporation into finished products. Beryllium-copper alloys have high tensile strength, excellent casting and machining characteristics, high electrical and thermal conductivity, and resistance to corrosion and fatigue. Heat-treated beryllium-nickel alloys have many properties comparable or superior to heat-treated stainless steel. Beryllium oxide is unusual in that it is both a good conductor of heat and an electrical insulator. It is used in the manufacture of ceramic parts, crucibles,

thermal coatings, and also has application in nuclear reactors. Aerospace applications include structural materials, inertial guidance systems, rocket motor parts, heat shields, rotor blades, and airplane brakes.

Further products which may contain beryllium include jewelry, fishing rods, bicycle spokes, dental plates, furnace bricks, and spark plugs.

The major industrial uses and industies which process and manufacture beryllium products are listed in Tables II and III.[3,5,6]

IV. BIOLOGIC EFFECTS OF EXPOSURE

Extent of Exposure

Potential exposures to beryllium-containing fumes and dusts occur both in large scale processing plants and in small plant operations which perform melting, casting, grinding, drilling, machining, etc.[7] In 1971, approximately 8,000 such plants were estimated to be in current operation in the United States. A survey conducted by the U. S. Public Health Service, Bureau of Occupational Safety and Health, in 1970, estimated that 30,000 persons in the work force could have potential exposure to dust or fumes of beryllium. This would include approximately 2,500 persons in the production industry. The total estimate is regarded as being very conservative if the many small plants are included which do not perform dust-generating operations.

Early Historical Reports

European reports describing a disease in beryllium workers appeared in the 1930's and early 1940's.[8-15] A partial list of early literature on beryllium poisoning is listed in Table IV as presented by Hardy[16] and compiled by Williams.[17] Weber and Engelhardt[8] reported in 1933 that in guinea pigs the effect of inhaling water soluble beryllium dust resulted in lung damage. Marradi-Fabroni[9] also described forms of pneumonia in guinea pigs due to beryllium carbonate exposure and suggested the name of "berylliosis" for this pathogenic condition.*

In 1936 Gelman[10] described illnesses among workers in beryllium plants in Moscow. He described two phases of the clinical symptoms caused

*Much confusion has resulted from use of this term[16] because of its similarity in spelling relating to beryl ore (beryllosis) and to use of the term in describing both acute and chronic manifestations of beryllium related disorders. Accordingly, the terms "beryllium disease" and "beryllium poisoning" will be used in this report.

similarity in spelling relating to beryl ore (beryllosis) and to use

by exposure to vapors of beryllium oxyfluoride: the first phase, beryllium fever, was not unlike that caused by exposure to zinc oxide fumes; the second phase was described as an extensive alveobronchiolitis. Two years later he described effects on the skin and X-ray changes in the lungs.[11] In 1940, Berkovitz and Israel[12] noted changes in the lungs from exposures to beryllium fluoride.

These early foreign reports and the beginning American studies which recognized a beryllium hazard found the problems to be basically acute in nature with effects resembling metal fume fever, chemical pneumonia, and related pulmonary irritations associated with well-known gases such as phosgene or chlorine and corrosive acids and alkalies. Some investigators[18] attributed toxicity to the irritant effects of the anions and, the United States Public Health Service Bulletin,[19] in reviewing the effects of beryllium as related to human illness and animal studies in 1943 concluded, "beryllium of itself is not toxic." Subsequent findings of beryllium poisoning in diverse applications[20,21,22] established that beryllium itself was toxic.

The first report of a delayed beryllium poisoning referred to as "delayed chemical pneumonitis" was made by Hardy and Tabershaw in 1946.[22] These investigators reported 17 cases occurring over a three year period in a fluorescent-lamp manufacturing plant. Of particular interest was the fact that a number of the patients did not manifest illness until sometime after leaving their jobs. Beryllium was one of the materials in fluorescent-lamp phosphors. This, along with evidence of exposures reported in the beryllium processing industry[21] and coupled with the report by Gardner in 1946[23] of five foundry worker fatalities where workers had

been exposed in an operation using a 4 percent beryllium master alloy, substantiated the belief that beryllium was the causative agent in the respiratory diseases observed.

Because of increased interest in beryllium in atomic energy development, and based upon studies performed by Eisenbud and co-workers,[24,25] the Atomic Energy Commission in 1949 issued requirements for environmental control for all contractors involved in the handling of beryllium. These requirements were ultimately adopted by professional groups.[26,27]

Effects of Humans

(1) Acute Effects

The classic symptoms of acute beryllium poisoning have been presented by Tepper, Hardy, and Chamberlin;[28] DeNardi, Van Ordstrand, Curtis, and Zielinski;[29] and Hardy and Stoeckle.[30] Condensed descriptions have also been given by the American College of Chest Physicians[31] and the U.S. Public Health Service.[32]

Tepper, Hardy, and Chamberlin[28] stated that: "Acute beryllium disease may be defined arbitrarily to include those beryllium-induced disease patterns with less than one year's natural duration and to exclude those syndromes lasting more than one year."

(a) Acute Effect--Skin and Conjunctiva: Beryllium diseases of the skin and conjunctiva occur as contact dermatitis, beryllium ulcers, and ocular effects.

(i) Contact dermatitis is characterized by itching and reddened, elevated, or fluid-accumulated lesions which appear particularly on the exposed surfaces of the body, especially the face, neck, arms, and hands.[21] Contact dermatitis has not been seen in workers handling beryllium hydroxide, pure beryllium, and present-day vacuum-cast beryllium

metal,[31] but it may occur either on an allergic basis or from primary irritation, following contact with soluble beryllium salts.[33] A latent period is occasionally noted, indicating the development of delayed hypersensitivity.

Secondary exposures in sensitized individuals result in more rapid development of the dermatitis, often after exposure to lesser amounts of material. Van Ordstrand and his co-workers[21] found that persons with contact dermatitis, if allowed to continue work, might develop bronchitis and pneumonitis from additional exposure. Moisture conditions also influence the severity of beryllium-induced dermatitis. Following cessation of exposure and with simple local treatment, the skin eruptions usually disappear within one to two weeks.

(ii) Beryllium ulcers result from crystal implantation of soluble or insoluble beryllium materials in cutaneous areas previously injured as a result of abrasions, cuts, etc. Abscess and ulceration frequently result. Lesions often last for several months and physical removal of the crystals is necessary before healing can take place. After removal of the foreign material, recovery is rapid and complete, usually within two weeks.

(iii) Ocular effects may occur as inflammation of the conjunctiva in "splash burn" or in association with contact dermatitis.[21] Splashes may also cause corneal burns closely resembling those produced by acids and alkalies. Fluid accumulation and reddening around the eye socket are frequently noted.

(b) Acute Effects--Respiratory: Beryllium-induced acute respiratory effects range from a mild inflammation of the nasal mucous membranes and pharynx, to tracheobronchial involvement, and finally to a severe chemical pneumonitis. Recovery generally ranges from one to six weeks in mild cases; however, recovery from acute pneumonitis may be prolonged to six months following exposure. Severe cases may become fatal. Eighteen acute pneumonitis fatalities were reported[28] following development of pulmonary edema.

(i) Beryllium rhinitis and pharyngitis involve inflammation of the nasal mucosa and pharynx, frequently accompanied by mild nosebleeds. Fluid and blood accumulate in the mucous membranes, and ulcerations may occur. Gelman[11] in reports of cases in Russia described perforation of the nasal septum, but this has not been reported in the United States. Fever and positive chest manifestations are absent. Patients occasionally describe sensations of a peculiar metallic taste. This condition is difficult to diagnose since it closely resembles that seen with the common cold.

(ii) Acute tracheobronchitis is non-specific and not beryllium-related as far as its clinical picture is concerned. The diagnosis can only be made on the basis of beryllium exposure. The effects are characterized by non-productive spasmodic cough, substernal discomfort and burning, tightness of the chest, and moderate difficulty with breathing upon exertion. Other findings include normal body temperature, decreased vital capacity with varying degrees of breathing difficulty, limitations of chest expansion, and sibilant rales in the hilar and basal lung areas. Clinical laboratory findings are within normal limits provided secondary infections are not present. Chest X-ray examinations may show an increase in bronchio-vascular

markings[29] and recovery is usually complete within one to four weeks.

(iii) Acute pneumonitis, while potentially the most serious of the acute syndromes, is encountered only rarely due to improved control methods and prompt medical treatment of beryllium exposures. Both rapid and delayed onsets of this disease have been reported[21,29,34,35] depending upon the magnitude and duration of the exposure. Symptoms of rapidly developing pneumonitis usually occur within 3 days, and possibly up to 8 days, after brief but massive exposures; whereas, the delayed form causes symptoms some weeks after prolonged exposure to lesser concentrations of beryllium compounds. Workers should be observed by a physician to decide whether or not symptoms are due to beryllium overexposure. The following symptoms, although varying in sequence of onset, are representative of acute pneumonitis. Workers complain of progressive cough (generally nonproductive), difficult breathing with tightness of the chest, substernal discomfort or pain, appetite and weight loss, and general weakness and tiredness.[35] The pain usually subsides during the early stages, but the cough may increase in severity so as to become extremely exhausting. Other observations show varying degrees of decreased vital capacity with breathing difficulties, rapid pulse, and cyanosis. Signs of diffuse lung involvement may be noted with fine-to-medium sibilant rales noticeable in the lower thorax. Temperature generally remains normal with the exceptions of secondary infections or during the terminal stages of pneumonitis. Clinical laboratory tests are generally within normal limits. Reported X-ray changes[21] consist of (1) diffused haziness of both lungs, (2) development of soft irregular infiltration areas with prominent peribronchial markings, and (3) appearance of discrete large or small nodules similar to those frequently observed in chronic beryllium disease or sarcoidosis. Importance was placed on the fact that clearing of the lungs preceded

peribronchial markings, and (3) appearance of

complete remission of other symptoms or absence of physical signs.[21] Aub and Grier[35] and Hardy and Stoeckle,[30] however, observed greater persistence of the X-ray findings. Hardy and Stoeckle[30] emphasized the similarity of the observed nodular densities with those frequently seem with bacterial and viral bronchopneumonias or with pulmonary edema. Pathological tissue studies from six patients revealed a nongranulomatous acute or subacute pulmonary edema.[36] Treatment for acute beryllium pneumonitis should include the use of oxygen, steroids, and antibiotics.

(2) Chronic Effects

Tepper, Hardy, and Chamberlin[28] stated that ". . . the term chronic is arbitrarily applied to beryllium disease of more than one year's duration. The clinical character of the chronic illness differs from the acute in that the former is: (1) frequently separated by a period of years from the time of the etiologic beryllium exposure; (2) prolonged in duration with at present (1960) little, if any, evidence for a lasting total 'cure'; (3) commonly progressive in severity in spite of the cessation of exposure; and (4) a systemic disease." These authors also believe that the term "berylliosis" was a poor choice to describe the disease caused by exposure to beryllium and its compounds because considerable confusion was created by its use.

Pneumonitis with accompanying cough, chest pain, and general weakness is the most familiar and striking characteristic of chronic beryllium disease.[30] In addition, pulmonary dysfunction and systemic manifestations may be present. The systemic effects include right heart enlargement with accompanying cardiac (congestive) failure, enlargement of the liver and spleen, cyanosis, digital "clubbing", and the appearance of kidney stones.[37] A number of biochemical abnormalities also may be manifested through changes in serum proteins, liver function, and uric acid and urinary calcium levels.

The delayed onset of pneumonitis is often precipitated by some acute stress; for example, pregnancy, viral respiratory infections, surgery, etc.[30] Hardy and Stoeckle[30] noted that 40% of the women with chronic disease who had become pregnant after beryllium exposure experienced pneumonitic symptoms in conjunction with their pregnancy. The factors responsible for the delay in onset are not known. Sterner and Eisenbud[38] postulated a time lag for development of immunologic processes in susceptible exposed persons.

(a) Chronic Effects - Complications: The development of congestive heart disease (cor pulmonale) has frequently been of greater clinical significance than primary beryllium disease itself.[28] Tepper, Hardy, and Chamberlin[28] pointed out that the incidence of tuberculosis has been conspicuously rare considering the fact that a number of patients have been placed in tuberculosis sanatoriums for treatment due to misdiagnosis of beryllium disease. Further complications due to drug treatment, particularly steroid therapy, and problems of anxiety associated with the disease-producing effects attributed to beryllium have persisted in spite of improved control measures and the decreasing incidence of reported disease cases.

Tepper, Hardy, and Chamberlin[28] pointed out also that the pulmonary neoplasia observed in beryllium-treated animals (see section on animal toxicity) has not been observed in humans. Hardy[39] stated in 1965 that from the 734 entries in the Beryllium Case Registry, although 20 malignant tumors had been recorded, it was "impossible to incriminate beryllium as a carcinogen in human beings on this evidence."

The Committee on Toxicology of the National Academy of Sciences - National Research Council reported,[40] "While certain beryllium salts and

oxides have been productive of osteogenic sarcomas in rabbits following intravenous administration and primary lung tumors in rats and monkeys following inhalation, there is no evidence that community or industrial exposure to beryllium compounds is associated with an increase in the incidence of cancer in humans."

In 1970 Mancuso,[41] in an epidemiological study based upon mortality of beryllium workers, found an equal or higher rate of cancer of the lung in employees employed for a short duration (3 to 15 months) as contrasted to those employed for a longer period (18 months or longer). A higher mortality rate was also suggested among the short duration employees of one plant, but this was not supported by results from a second plant. There was an indication that prior chemical respiratory illness influenced the subsequent development of lung cancer. It was stated that beryllium was acting with other factors, rather than as a single etiology related to the duration of employment (see Correlation of Exposure and Effects).

(b) Chronic Effects - Pathological Changes: Studies of pathological changes due to chronic beryllium disease in over 100 cases have been reported by Williams[42] and Dudley.[43] More recently, Freiman and Hardy[44] discussed pulmonary pathology in 130 cases from the U.S. Beryllium Case Registry. Based on the degree of interstitial cellular infiltration they found that 80 percent of the cases studied showed moderate to marked infiltration whereas in the remainder, cellular infiltration was only slight or absent. Clearly defined granulomatous lesions were not always present. The group with prominent interstitial cellular infiltration could be subgrouped into two groups in which granuloma formation was either

well formed or else poorly-formed-to-absent. Where cellular infiltration was slight or absent, granuloma formation was numerous and well formed. Dudley[43] in 1959 reported that the occurence of granulomatous lesions often tended to draw attention away from the more fundamental diffuse interstitial infiltration of which the granulomas were only a part. This same reaction was also seen in skin, liver, kidney, lymph nodes, and skeletal muscle. Cardiac muscle, spleen, and pleura also could be involved. Freiman and Hardy[44] suggest a distinct relation between the intensity of interstitial cellular infiltration and the forecast of disease severity, with the possibility that the degree of granuloma formation may play a significant secondary role. Calcific inclusions were also commonly present, being observed in about two-thirds of the lungs from patients with chronic disease. In addition, increased tissue levels of beryllium were noted in most cases.

Although most cases of beryllium disease can be recognized by pathologic changes,[44,45,46,47] the observations are not specific for the disease. Pulmonary sarcoidosis, "farmers lung",[48] fungus diseases, and various pneumoconioses are but a few disorders which also produce a similar pathologic picture. Differentiation between sarcoidosis and chronic beryllium disease is the most difficult. Similarities and differences between the two disorders have been presented for diagnostic purposes.[44,49]

(c) Chronic Effects - Treatment: Early treatment of chronic beryllium disease was purely symptomatic with oxygen providing great relief in cases where impaired ventilation was noted. Antibiotics were only of value to treat secondary infections. Long periods of bedrest were employed.

Patients were occasionally transferred to warm or dry climates to provide temporary relief, but no detectable change in the course of the disease was noted.[30] Steroid therapy, initiated in the early 1950's[50,51,52] has proven to be extremely beneficial. Continued therapy with steroid congeners has markedly improved the clinical course of the disease, but because of the prolonged course of the disease, investigators are hesitant to claim "total cures." The incidence of relapse and disability has been reduced. With an adequate steroid regimen,[53] the clinical status of many patients has improved, allowing them to return to useful jobs.[54]

(d) Chronic Effects - Diagnosis: As stated by Van Ordstrand[55] in 1959, "twelve to fifteen years ago it appeared that the diagnosis of beryllium poisoning was not a difficult problem. Today it is not so certain." The diagnosis of chronic beryllium disease requires supportive evidence of X-ray findings, immunological tests, pulmonary function tests, and the establishment of beryllium exposure by finding beryllium in urine or tissue or by strong epidemiological evidence of exposure. The final diagnosis rests upon an evaluation of the entire clinical picture.[56] Sarcoidosis presents the most troublesome problem in differential diagnosis of chronic beryllium disease. Hardy and Freiman,[44,45] in presenting beryllium disease as a continuing diagnostic problem, listed specific differences between beryllium disease and sarcoidosis. These differences include weight loss and severe loss of appetite, rarely seen in sarcoidosis, the presence in histopathologic sections of intense cellular infiltration with nodular lesions and abundant calcific inclusions, the absence of many characteristic localization patterns frequently seen in sarcoidosis,

and the occurrence of significant amounts of beryllium in the tissues of many patients.

(i) X-ray changes were reviewed by Gary and Schatzki[57] in a study of all available X-rays in the Beryllium Registry, and they concluded that there was not an orderly sequence of lung involvement as had been previously postulated,[22,58] but rather, definite reaction types which persisted unchanged for many years. Disease which began with nodular manifestations stayed nodular. Further, they stressed that because of the several types of response seen on films, it appeared impossible to make a differential diagnosis by radiological means alone.

In 1970, Weber, Stoeckle, and Hardy,[59] in a study of 8 cases observed for up to 18 years, reported that X-ray changes, most frequently involving the upper lobes, consisted of granular, nodular, and linear densities occurring singly and in combined forms. Mixed patterns of granular and nodular densities were most commonly seen. Persistence of granular densities alone was rarely observed. Small and scattered linear densities often developed, and in advanced cases, were very marked and associated with emphysema. Fibrotic changes confined to the lower lobes were rarely seen. With fibrotic and emphysematous changes, granular and nodular densities diminished to a point where X-ray diagnosis was not indicated.

Chamberlin[60] stated that clinical and X-ray findings alone established only presumptive diagnosis of beryllium disease. Although X-ray findings are not specific, the appearance of a known pattern of beryllium disease on a chest film should immediately alert the physician to the possibility of this diagnosis.

(ii) Tissue sensitization has been reported. Sterner and Eisenbud in 1951[38] proposed that beryllium acts to produce allergic sensitization in tissues. In 1959, the patch test developed by Curtis was claimed to give favorable differentiation between chronic beryllium disease and other pulmonary diseases.[61] The positive patch test did not serve as an absolute diagnostic sign for chronic beryllium disease; in fact, in cases where differential diagnosis has been difficult, the patch test has not been very helpful.[28] Jett[61] has shown an immunologic basis to chronic beryllium disease, and a hypersensitivity phenomenon has been demonstrated.[63] Since the skin patch test can develop a hypersensitive state in persons who have never been exposed to beryllium, its use in differential diagnosis is generally discouraged and the test is best avoided in screening persons who are to be exposed to beryllium.[28]

(iii) Tissue and fluid analysis for beryllium is used to establish previous exposure to beryllium. The detection of beryllium in tissue or urine is evidence of exposure to beryllium only, not necessarily to the presence of beryllium disease.[64] Lung biopsy has been recommended as a means for positive beryllium identification.[65] Frequently, negative findings of beryllium in the lungs of persons having known exposure to the material are due to inadequate sample quantities. At least a 5 gm specimen is recommended for lung tissue.[28] The chances of positive analysis are accordingly reduced for other organs since they contain much less material than the lung. Beryllium is not generally considered to be a natural environmental contaminant; however, Cholak[66] tabulated the presence of extremely small quantities in soil, coal, and air.

(iv) A variety of ventilatory function and gas studies have been utilized in the diagnosis of chronic beryllium disease. Wright[67] indicated a difficulty of oxygen transfer across the pulmonary membranes as the basic defect in chronic beryllium disease. An increase in the alveolar-arterial oxygen tension difference is often noted, and studies have confirmed the problem of oxygen diffusion.[68,69,70]

In contrast, Andrews, Kazemi, and Hardy,[71] in 1967 found that in addition to a restrictive pattern of dysfunction, 39 percent of their 41 patients studied showed changes of obstructive lung disease developement. Patients with an obstructive defect fared worse clinically, with cor pulmonale developing in many. The factors which determined whether airway obstruction or restrictive defects occurred in beryllium workers were largely unknown, but pointed up the value of multiple lung function criteria, particularly forced expiratory volume at 1-second ($FEV_{1.0}$), peak flow (PF), and maximal breathing capacity (MBC).

Animal Toxicity

(1) Toxicity and Potential Health Hazards

A sufficient number of animal toxicity studies have been reported[64] to permit the following generalizations. Soluble beryllium salts (as represented by the sulfate and fluoride), low-fired high surface-area oxide, the hydrated oxide, beryllium hydroxide, and the metal powder in adequate concentration are rapidly (acutely) toxic by all routes of administration.[72,73] when the inhaled concentrations are high, acute and chronic pneumonitis are produced, often following a single exposure. In general, the more soluble, the more rapid and severe is the acute response.

The correlation of biologic activity with chemical and physical properties is demonstrated by the lesser toxicity of beryllium oxide

prepared at 1600°C as compared with beryllium oxide calcined at 1100° and 500°C. The high-fired beryllium oxide induced a minimal cellular reaction and fewer adenocarcinomas as compared with that produced when the low-fired (500°C) compound was injected in rats intratracheally.[74]

Although there are varying quantities of beryllium in the different alloys and beryllides, the intermetallic forms of beryllium and certain alloys of low beryllium content produce little or no activity in rats intratracheally injected with these substances. The fact that no frank beryllium lung disease occurred in experimental animals from these alloys is in conflict with the report of beryllium disease in workers exposed to beryllium-copper alloys,[75] possible a reflection of species or habit differences.

Bertrandite and beryl ores containing 4 percent beryllium have been reported to have tumorigenic capability whereas, in comparison, bertrandite ore containing less than 1.5 percent beryllium lacks this capability.[76] The lack of tumor induction by phenacite ore (1.5 percent beryllium content) parallels the finding with bertrandite of similar beryllium content.[76]

In general, soluble beryllium salts and some of the more insoluble beryllium compounds produce acute inflammatory reactions in animals. Major factors which influence toxicity include solubility, particle size, and percentage of beryllium in the compound. The rate of biological response seems to be related to the rate of solubility. About half of the industrially important forms of beryllium readily induce pulmonary tumors, particularly in the rat, a response that has not yet appeared in beryllium workers. The more rarely produced osteogenic sarcoma and rickets are peculiar to experimental animals, although the granuloma of the skin with ulcer occurs in man as well.

experimental animals

(2) Absorption, Fate, and Excretion

Beryllium is demonstrably toxic by most routes of administration; the routes most commonly employed in animal experiments being intravenous, intraperitoneal, inhalation, intratracheal instillation, subcutaneous, and oral.[77] Noticeable, however, is the difference in oral toxicity to that by other routes. The sulfate, highly toxic by all other routes at a single dose level, is practically nontoxic by mouth at a level several thousand-fold greater by multiple dose (3750 mg/kg/day).[78,79] Beryllium does not localize in the lung, but is transported to all tissues of the body.

(3) Beryllium Effects Peculiar to Animals

Beryllium is capable of inducing primary pulmonary cancer in animals. Evidence has accumulated incriminating a number of beryllium compounds; particularly beryllium oxide, hydroxide, sulfate, and fluoride; as carcinogens for experimental animals.[80]

Osteosarcoma, reported by many investigators using beryllium oxide and zinc beryllium silicate by different routes of administration,[81,82,83] appears to be a beryllium disease that has been demonstrated only in animals, possibly the result of massive exposures not encountered by beryllium workers.

Beryllium "rickets" is likewise a condition not seen in man, probably because the rickets were produced in young animals on diets with substantial amounts of $BeCO_3$ (0.5 and 2%),[84] conditions not met in the human situation.

A toxic macrocytic anemia that has been reported to result in animals exposed by inhalation to beryllium compounds and substantiated by demonstrated interference in both heme and globin synthesis[85] seems not to have been noted in individuals with beryllium disease.

Finally, the morphologic changes in the lungs of animals with alveolar metaplasia, do not resemble in all respects those seen in man.

(4) Biochemistry

Although a considerable number of biochemical investigations have been made during the past two decades,[64] both in the living animal and in tissues excised from animals exposed to beryllium, little of practical clinical value has resulted. The one promising early indicator of response, the interference in the activity of a generally distributed metal-activated enzyme of beryllium,[86] was abandoned when later investigations[87] failed to show a consistent depression in enzyme activity in animals exposed to beryllium throughout a 15-month period.

Beryllium has been found to have especial affinity for intracellular inclusion bodies.[88,89] Further, in guinea pig studies, beryllium has also been found to localize in the granular layer of the skin.[90] As alkaline phosphatase comprises about 50 percent of this layer, it has been surmised that beryllium is bound to the phosphatase.

General adrenal imbalance is proposed as a governing mechanism for the sudden onset of "latent" beryllium disease months and years after exposure to beryllium has ceased by causing tissue redistribution of beryllium into sensitive body sites, resulting in a more severe systemic reaction.[91]

Attempts to find, by animal experimentation, effective therapeutic agents that would rid the body of deposited beryllium[92,93] have met with no human success of clinical importance, at least where long-deposited beryllium is concerned.

beryllium is concerned.

(5) Limitations of Experimental Toxicology

An exact parallelism in the response of animals and man does not always exist. Animals respond toxicologically to beryllium with changes that are morphologically different from those observed in man. In the rat, epithelialization has ultimately resulted in development of an adenomatous tumor. The epithelial proliferation and primary pulmonary cancer was induced in rats after long-term, daily repeated exposures to beryllium sulfate at an average concentration of 643 $\mu g/m^3$ (55 $\mu g/m^3$ of beryllium) and has not been reproduced in man even after long periods of time and high exposure levels. In man, the granulomatous disease seems only to be progressive in this respect. Hence, the carcinogenic exposure-effect relationship observed in animals does not correlate to man. The human organism has not been observed to respond in the same manner as rats to beryllium exposure; therefore, animal studies contribute only indirectly and provide no correlation of human exposure-effect relationships as they pertain to development of a recommended environmental standard.

Beryllium Case Registry

The Beryllium Case Registry was instituted in 1951[54] at the Massachusetts General Hospital to provide a central source for cases of diagnosed beryllium poisoning. Prior to beginning the Registry, a report[94] in 1948 had compiled 108 chronic cases and analyzed them by industrial process. By 1958, the Beryllium Case Registry had recorded 393 chronic cases out of a total of 606;[95] twenty-seven originally acute cases had become chronic. As of 1963, 675 cases were on record,[96] 760 as of 1966,[54] and 822 as of this writing (May, 1972). Annually reported Registry cases decreased considerably following institution of industrial control measures in 1949; nevertheless,

approximately 15 cases per year have consistently have been added to the Registry since 1962.

Chronic beryllium disease has occurred subsequent to the institution of control measures in 1949. Peyton and Worcester[95] reported 10 cases in the Registry (4 acute and 6 chronic) whose first exposures occurred after 1949. In addition, follow-up and new cases of chronic beryllium disease reported by Lieben and Williams[97] imply, from the relatively young ages of some patients, that chronic beryllium disease has been contracted from initial exposures subsequent to 1949.

A 1972 inquiry to the Registry[98] for cases of chronic beryllium disease contracted from initial exposure subsequent to 1949 produced at least 20 case histories; ten representative examples are shown in Table V. The majority of these cases have been diagnosed subsequent to 1965 and have involved direct handling and the resulting inhalation of beryllium. Of interest is that recent cases are occurring not only in smelting and extraction operations, but also in alloy and ceramics operations where contaminant control reportedly has been quite successful. Although environmental exposure levels are generally difficult to relate to individual patients, two items are presented in Table V. For the alloy worker, operations were performed without proper ventilation and exhaust installations. This case occurred from machining and polishing an alloy containing approximately 0.6 percent beryllium. The second example involved a machine-shop operator having maximum daily-weighted average exposures of 5.9 μg Be/m^3 according to the employer.[98] However, the worker was involved in maintenance activities and, from his own report, hood doors were frequently

left open during machining operations. It is apparent that exposure levels were probably much higher than reported.

It is interesting to note that the estimated duration of exposure ranged from 6 weeks to 9-1/2 years for the cases listed in Table V. This would seem to indicate that for development of chronic beryllium disease, comparatively short time intervals are all that are necessary at the relatively low levels believed to be found in industry since 1949.

The Director of the Registry also indicates that the incidence of confirmed chronic beryllium disease is continuing and at least three new cases will be admitted to the Beryllium Case Registry in 1972.[98]

Information from the Beryllium Registry has been valuable in (1) criteria selection for diagnosis of beryllium poisoning, (2) judgment of effectiveness of controls, and (3) evaluation of the clinical course of beryllium disease and response to therapy. Hardy[54] points out, however, that there are three important deficiencies in the Registry: (1) lack of knowledge of the size of population at risk; (2) incomplete data describing the amount of beryllium exposure; and (3) failure to learn of all cases of the disease in a beryllium-using industry.

Neighborhood Cases

The term "neighborhood case" has been applied to a patient in which beryllium disease has developed as a result of what is believed to be indirect exposure outside a plant. Neighborhood cases of beryllium exposure were first recognized by Gelman in 1938.[11] Additional reports of non-occupational cases were reported[25,99,100,101] in individuals either living in close proximity to beryllium handling plants (generally within one mile) or having some direct contact, sometimes unknowingly, with beryllium. An example is given[28,99] of a woman whose daughter, a worker

in a fluorescent lamp plant, came home from work daily with a fine powder on her shoes and in her clothes. The daughter herself developed chronic beryllium disease. During the two-year course of the steadily progressive and finally fatal disease, she was cared-for by the mother, who subsequently also developed the disease and died. By 1966 a total of 60 neighborhood cases had been reported.[54]

In 1949, an extensive community program was conducted in the locality of a beryllium processing plant.[25] From a review of the program's approximately 10,000 X-ray films and multiple air analyses, there emerged recommendations for in-plant and community atmospheric limits for beryllium (see section on Development of Standard).

In nearly every instance of a reported neighborhood case, close examination of the circumstances indicates exposure to be caused, or contributed to, by means other than ambient air pollution. Factors involving laundering of work clothes, having relatives who were beryllium refinery employees, having a milk route within a plant neighborhood, house-cleaning requirements, etc., have all been reported.[97] In one instance, individuals affected lived several miles away from the industrial site but were found to have visited a graveyard and to have tended graves regularly across the street from the beryllium refinery.

It has yet to be definitely established whether ambient air contamination alone, at a distance from a plant, can cause chronic beryllium disease.

Correlation of Exposure and Effects

Clinical findings in some current chronic beryllium disease cases indicate recent initial exposures, and there are new cases of the disease still being reported.[98] Nevertheless, extreme difficulties are presented when attempting to correlate workroom exposure levels of beryllium with

cases of either acute or chronic beryllium disease. The absence of quantitative data on exposures to beryllium in reports prior to 1947 is understandable since (1) airborne beryllium had not at that time been conclusively identified as a cause of disease and (2) no reliable analytical methods had been developed.[102] Undoubtedly, extremely high concentrations were encountered (see Environmental Data).

From 1949 to 1961, controls were imposed by the AEC on industrial beryllium producers through specific contract requirements to meet occupational standards. In some cases industry did not meet the AEC standards that were developed. Little is known of the environmental conditions since 1961.

A survey was performed in 1968 by the U.S. Public Health Service in which 1600 employees were studied from four beryllium production plants. Chest X-rays were taken and gaseous diffusion tests with spirometry measurements were performed in conjunction with a selected questionnaire. Results obtained from the study indicated the possibility of beryllium related pulmonary impairment in isolated cases; however, the data were inconclusive.[103]

A retrospective cohort study of cause-specific mortality among 3,921 males employed in two beryllium plants during January, 1942 through December 1967, was conducted.[104] Comparison was made between the risk of death among beryllium workers with that expected on the basis of age-sex-calendar time of specific mortality rates for the general population. of the United States (Tables VI to X).

Mortality patterns, including mortality from respiratory tract cancer, revealed no significant departure from expectation in this population. Even when consideration was given to a lapsed time of ten years and of fifteen

years after onset of employment, no evidence was demonstrated for an association between beryllium exposure and lung cancer induction in man. Likewise, no association was detected for intensity, duration, or calendar period of exposure to beryllium.

Certainly, exposure levels today are well below those encountered in the early 1940's. Whether a large safety factor is present in the current occupational environment exposure standard for beryllium is unknown. There has been no comprehensive, long-term control study relating environmental beryllium concentrations with a cause-and-effect relationship to beryllium disease; therefore, the level to which a revised standard could be recommended is largely one of conjecture.

V. ENVIRONMENTAL DATA

Exposure levels were extremely high in the beryllium industry prior to the institution of control requirements by the AEC. An indication of the relative exposure levels may be gained from the following selected examples.

In 1946, a survey was conducted[105] of a beryllium plant to provide information which would serve as a basis for toxicologic investigations of beryllium. Table XI indicates conditions observed around a beryllium metal furnace, beryllium fluoride furnace, and an ore treatment unit (rotary kiln dryer). Dust concentrations of 110 to 533 $\mu g\ Be/m^3$ were recorded for the coke removal operation and 1,430 to 4,710 $\mu g/m^3$ were recorded during the beryllium pouring phase. Fluoride levels (not shown in the Table) reached levels as high as 58.2 $milligrams/m^3$. The fluoride levels are mentioned only to emphasize the extremely high contaminant levels encountered in the workroom air and should not be compared with beryllium concentrations. It was also reported[105] that the yearly average case frequencies of beryllium poisoning ranged from 63.5 to 238.1 accidents per million manhours. The standard accepted accident level was 4.0; therefore, the extent of the hazard can be appreciated.

Zielinski[106] also reported extremely high levels of exposure to beryllium in an alloy plant in 1947 and 1948 (Table XII). The figures are derived from very minimal data but, again, the extent of the high exposure level may be seen.

According to Breslin,[102] Shilen reported in 1947 that beryllium dust

concentrations were encountered up to 8.84 milligrams/m^3. Greater than 50 percent of the determinations were in excess of 100 μg Be/m^3. There is little doubt that early exposures were very high.[107,108] Williams[107] in reviewing the Beryllium Case Registry data, prepared a comparison of chronic and acute-to-chronic beryllium cases against the proximity of the patient's job (Table XIII). He cautioned that this did not necessarily reflect the severity of exposure and yet, as also noted by Breslin,[102] the relationship was striking. In a report[34] of 178 cases of pneumonitis and bronchitis in two plants observed from 1940 to 1948, 3 deaths occurred in 1943 and 10 deaths over the 8 year period. High concentrations of beryllium were invariably encountered, certainly in excess of 100 μg/m^3 and probably greater than 1 milligram/m^3.

Subsequent to the institution of control methods in 1949 (see Development of the Standard), environmental exposure levels to beryllium were markedly reduced.[109-112] In one Ohio extraction plant operated for the AEC, exposure levels were recorded at 2 μg Be/m^3 or less most of the time over a 7 year period.[110] This was characteristic for this extraction plant and similar results were reported for other sites such as fabrication shops and especially machine shops[110,111] where it was not unusual for concentrations of 0.1 μg Be/m^3 or less to be reported. Five to ten percent of approximately 2600 samples in the Ohio extraction plant showed concentrations greater than 25 μg/m^3.

Although operations which have continuous hygienic management procedures and updated control methods have achieved beryllium control within present

occupational standards[112] (see Table XIV), other facilities have not achieved such success. Zielinski implied[106] that operations not having prime interest to the AEC were monitored to only a small degree. At the time of surveys certain foundry operations were activated specifically for the purpose of obtaining data and operators were unusually careful in attempting to minimize pollution of the air. Table XV, taken from Zielinski's report, shows time-weighted average values in milligrams/m^3 for exposure of personnel directly involved in the production of a copper-beryllium alloy for the period of 1953 to mid-1960.

Tables XVI to XXX, compiled by NIOSH from AEC data, list daily-weighted, breathing-zone, and general air values sampled from 5 major beryllium processing plants for various periods during 1950 to 1961.

Daily-weighted average exposures are listed in Tables XVI to XX. Employees were consistently exposed to daily-weighted average exposures in excess of 2 $\mu g/m^3$ (40 to 75 percent of workers was not uncommon). Only Plant D (Table XIX) showed consistent improvement and satisfactory achievement of the 2 $\mu g/m^3$ goal. Plants A and B achieved daily-weighted average reductions below 5 $\mu g/m^3$ and Plant C had approximately 90 percent of employees within the 5 μg level. Data were insufficient for Plant E; however, the single study showed inadequate achievement of control.

Average breathing-zone concentrations (Tables XXI to XXV) were consistently below 50 $\mu g/m^3$ and less than 25 $\mu g/m^3$ most of the time. Where values exceeded 50 $\mu g/m^3$ they were of such magnitude as to indicate failure of control methods through either inadequate practices or accidental equipment breakdown. The range in effectiveness of control measures (Table XXIV) is illustrated in the chip transfer and blending operations where breathing-zone

concentrations approximated 1,600 $\mu g/m^3$ in 1955, whereas subsequent levels in 1959 were within the 2 $\mu g/m^3$ range. The high concentrations just cited were not unusual when control measures were inoperative.

Results of average general air sampling are listed in Tables XXVI to XXX. Values generally reflect the same picture as shown in the tables of daily-weighted averages. Plant operations in general, though achieving marked control of beryllium dust concentrations from pre-control levels, seldom consistently achieved an overall average of 2 $\mu g/m^3$. Of interest is the fact that lunch and locker-room facilities frequently showed general air concentrations as high as regular production areas. Plant B (Table XXVII) regularly indicated high beryllium concentrations in the shoe-change room.

Shake-down phases for process equipment often produced dust concentrations which were not expected to represent "normal" operating conditions. Frequently, however, elevated levels were a result of ignoring many of the fundamental principles of good industrial hygiene practice. Occasionally, control improvements resulted in a reduction of exposures to production workers, only to be offset by an upward trend in exposures to non-production workers. It was observed that during the period summarized in Tables XVI to XXX (1950's and early 1960's), the downward shift of exposures was largely attributable to the efforts of the AEC. A careful examination of the survey data will show that at one time or another, nearly every job category was within permissible limits. Individually, operations were controllable, but problems arose in attempting to reach satisfactory control uniformly throughout a plant. When concerted efforts were made to reduce concentrations at offending operations, it was found that the established level of 2 $\mu g/m^3$ could be met.

Although the institution of environmental control procedures for beryllium drastically reduced exposure levels for workers, the established industrial limits had not been consistently attained.

VI. DEVELOPMENT OF THE STANDARD

Basis for Standard

Prior to 1947 it was virtually impossible to correlate medical findings with exposure levels of workmen. One reason for the lack of such data was that, at the time, sensitive analytical methods for beryllium had not been developed, nor were air sampling instruments generally available that were suitable. Because of the steadily increasing accounts of respiratory illness and death resulting from beryllium exposure, and because of the similarities apparent in pneumoconiosis, a symposium was held at Saranac Lake, New York, in the Fall of 1947 to review the entire beryllium problem.[113] This was the 6th Saranac Symposium and information gained from the sessions, coupled with the research and recommendations of Eisenbud and co-workers,[24,25] provided the basis for the United States Atomic Energy Commission Control Requirements established in 1949.

Limited investigations by Eisenbud[24] suggested that maximum concentration at which the beryllium workmen investigated had been exposed did not exceed 15 μg Be/m^3 of air. For control of the acute disease, a value of 25 $\mu g/m^3$ was recommended by Eisenbud as the maximum permissible peak exposure. In addition, Eisenbud's studies of non-occupational cases of beryllium disease[25] resulted in the conclusion that, in the human population around a beryllium production plant, the lowest concentration which produced disease was greater than 0.01 $\mu g/m^3$ and probably less than 0.10 $\mu g/m^3$.

There still remained, however, the problem of recommendations for chronic occupational exposure to beryllium. Eisenbud's comments in 1961[108]

are still appropriate in 1972. "There was not then, nor is there today, any substantial body of environmental information that could be correlated with clinical reports of occupational berylliosis, and such data as do exist are puzzling." Having no real empirical basis for the establishment of a limit for chronic occupational exposure, Eisenbud and Machle arrived at a figure of 2 $\mu g/m^3$ on the basis of information on animals and man and by analogy with industrial air limits for toxicity of heavy metals, such as lead, mercury, cadmium, and thallium.

As a result of the Saranac Symposium and Eisenbud's recommendations, the following limits of permissible concentrations of beryllium were adopted by the Atomic Energy Commission on the recommendation of an ad-hoc committee:

(1) The in-plant atmospheric concentration of beryllium should not exceed 2 micrograms per cubic meter as an average for an 8-hour day.

(2) Even though the daily average may be less than 2 micrograms per cubic meter, no person should be exposed to concentrations greater than 25 micrograms per cubic meter at any time, however short.

(3) In the neighborhood of the AEC plant handling beryllium compounds, the average monthly concentrations at the breathing zone levels should not exceed 0.01 micrograms per cubic meter.

The AEC Division of Biology and Medicine established the control of beryllium hazards, and it was binding on all AEC installations handling beryllium. In addition, all AEC contracts involving the handling of beryllium carried a health and safety clause which required adherance to these requirements. The first two requirements involved in-plant controls whereas the latter represented the community air limit.

In 1955[26] the American Conference of Governmental Industrial Hygienists (ACGIH) adopted, on a tentative basis, an 8-hour, daily-weighted average exposure level of 2 μg Be/m^3. The American Industrial Hygiene Association, in 1956, also published a Hygienic Guide[27] which recommended the AEC values.

In 1958 the AEC ad-hoc review committee was dissolved in accordance with its own recommendation that henceforth proper governmental and industrial agencies be encouraged to adopt maximum allowable concentrations for general publication. The nationally recognized health and safety guides and standards for beryllium were then prescribed by the AEC as applicable to their activities. The contract clause was still maintained, however, to afford a means of standard enforcement to AEC contractors. These same standards are used today (1972) for AEC industrial hygiene control.

In 1961, based on the Federal Walsh-Healey Act, the AEC was relied upon for surveillance of occupational exposures to beryllium for as long as the AEC contractual provisions remained in effect. By late 1962, the AEC had terminated all beryllium contracts and relied upon acquisition of their beryllium needs through direct purchase from the various commercial beryllium producers.

Other Beryllium Standards

(1) Foreign Standards

(a) Exposure limits to beryllium, as specified by the AEC, have been adopted by the West German Government and serve as the basis for their industrial health practices for beryllium.[114]

(b) The World Health Organization, in 1969, issued a joint statement with the International Labor Organization on permissible levels of occupational exposure to airborne toxic substances. The recommended safe

concentration zone[115] for beryllium and its compounds is 0.001 to 0.002 mg/m^3.

(2) Standards for Beryllium Rocket-Motor Firing

The National Academy of Sciences - National Research Council in 1966[40] developed criteria and standards for protection of off-site personnel from intermittent exposures to beryllium compounds arising from the firing of rocket motors. These limits are as follows:

(a) For soluble beryllium compounds and beryllium oxide comparable to a product calcined at temperatures around 400°C, a standard of 75 μg-minutes/m^3 within the limits of 10 to 60 minutes, accumulated during any two consecutive weeks.

(b) For beryllium oxide comparable to a product calcined at temperatures in excess of 1,600°C, a standard of 1,500 μg-minutes/m^3 within the limits of 10 to 60 minutes, accumulated during any two consecutive weeks.

The above standards need adjustment for the overall concentration of soluble beryllium compounds in the effluent. The present occupational standards were established in 1949 out of a caution based upon a lack of definite data upon which to establish a standard and were considered at that time to be markedly low. There appears to be no more scientific basis for establishing these short-term exposure limits on a microgram-minute basis than there was available to develop the occupational standard. The standard was based upon national interest as well as protection of the worker and the general public. Present research indicates a lesser degree of toxicity to high-fired beryllium oxide[116] than to the low-fired oxides.

The standard recommended in this document is similar to that adopted by the AEC in 1949 and the present OSHA environmental standard. It is felt to be feasible technologically for the control of worker exposure to beryllium and effective biologically for protection of the worker from acute and chronic beryllium disease.

The "State of the Art" of data related to development of beryllium disease has made some progress since 1949, but little can be added to effectively refine the standard developed at that time. Consideration was given to the lower environmental levels since 1949 in AEC controlled plants and the chronic beryllium disease in workers exposed since that time; however, data that would give a direct dose-response relationship are not available in that group of workers.

The finding in animals that some beryllium compounds are carcinogenic was also considered; however, the cautions approach that must be taken in data interpretation between humans and experimental animals is supported by the evidence as reported by Bayliss.[104] His finding of no significant departure from expected causes of death from respiratory tract cancers in almost 4000 workers shows no evidence of an association between beryllium exposure and lung cancer induction in man.

Until more complete knowledge can be obtained through comprehensive long-term controlled studies relating contact with beryllium to the incidence of disease in man, experience with present exposure limits for beryllium must provide the basis for establishment of the standard recommended in this report.

VII. COMPATIBILITY WITH EMISSION STANDARDS

The proposed national emission standard for beryllium was published in the Federal Register on December 7, 1971, Vol. 36, No. 234, pages 23243-23245 (40 CFR 61.30-61.46) by the Environmental Protection Agency. The emission standard will be applicable to machine shops, ceramic plants, propellant plants, foundries, extraction plants, and incinerators designed or modified for disposal of toxic substances.

The standards are based upon information derived from many sources, including health effect levels, meteorology, technical analysis of control capability, and consideration of economic impact. The overriding considerations are health effects. These beryllium standards are limited, in general, to emissions to the ambient atmosphere.

The guideline used in the development of the standards is based on a maximum allowable concentration of beryllium for ambient air that has been in use by the Department of Defense and the Atomic Energy Commission for many years. The proposed standards offer the owner or operator the option of determining compliance either by emission testing or by measurement of ambient concentration levels in the vicinity of the plant. In addition, separate emission standards for beryllium-rocket motor firing are proposed.

(a) National Emission Standards for Beryllium

(1) Total emissions to the atmosphere shall not exceed 10 grams of beryllium in a 24-nour day.

(2) Total emissions to the atmosphere shall not exceed amounts which result in an out-plant concentration of 0.01 micrograms of beryllium per cubic meter of air averaged over a 30-day period.

(b) National Emission Standards for Beryllium-Rocket Motor Firing

(1) Emissions to the atmosphere shall not cause atmospheric concentrations of beryllium to exceed 75 microgram-minutes per cubic meter of air within 10 to 60 minutes, accumulated during any two consecutive weeks measured anywhere beyond the property line of such source or at the nearest place of human habitation.

(2) If combustion products of motors containing beryllium propellant are fired into a closed tank, emissions from such tanks shall not exceed 2 grams per hour at a maximum of 10 grams per day.

These environmental standards are based either directly or indirectly upon the original AEC occupational and non-occupational exposure limits, which also provide the foundation for the standards proposed in this document. The occupational and non-occupational levels differ in that exposure to the general public is on a 24-hour day, 7-days-a-week basis whereas the occupational standards are based on an 8-hour day, 40-hour work week.

(c) Compatibility with Emission Standards

The assumptions made in 1966 by the Committee on Toxicology and the Advisory Center on Toxicology[40] in relating occupational to community exposure to beryllium materials support the compatibility of the proposed occupational standard with the National air pollution emission standard. The comparisons are based upon an empirical approach and no data are available to support the assumptions.

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IX. APPENDIX I

SAMPLING PRACTICES FOR BERYLLIUM

Air Sampling

The measurement of general air concentrations shall be included with worker breathing zone samplings and shall meet the following criteria in order to evaluate conformance with the standard:

(a) Samples collected shall measure accurately the individual worker's exposure.

(b) Samples shall include all beryllium particles, both respirable and non-respirable, in the volume of air sampled. The standard is based upon total beryllium content, and it is inappropriate to sample only respirable dust. The attempt to apply the results of respirable sampling to the present recommended standard of 2 ug Be/m^3 potentially eases the standard as much as five to ten times depending on the percentage of respirable dust present in any given air sample determination.

(c) Sampling procedures shall include a log of:

(1) The time of sample collection, (2) sampling duration, (3) volume rate of the sampler, and (4) a description of the sampling location and pertinent circumstances.

(d) General air and breathing-zone samples shall be collected with samplers having an air capacity not less than 0.05 m^3 per minute and equipped with Whatman No. 41 filters or equivalent.

General Room-Air Sampling

(a) A minimum of 3 general air measurements shall be made in each location during a work period and averaged.

(b) General air sampling periods shall be from a minimum of 30 minutes

to no more than two hours.

(c) Non-working areas (eating, smoking, locker, etc.) shall be sampled during periods of representative activity.

Breathing Zone Sampling

(a) Breathing-zone samples shall be collected as near as practicable to the worker's face without interfering with his freedom of movement and shall characterize the exposure from each job or specific operation in each production area.

(b) A minimum of three breathing-zone samples shall be taken for each operation (four or five samples are recommended) and averaged on a time-weighted basis.

(c) Breathing-zone sampling periods shall be for a minimum of 3 minutes.

Evaluation of Exposure

(a) On the basis of results from the environmental samples a time-weighted average concentration shall be completed for each work area and properly logged and maintained on file for review. A job analysis format as presented by Breslin[7] is shown in Figure 1.

(b) Exposure evaluations shall be performed at least quarterly for each work area where potential exposure to beryllium could occur.

Calibration of Sampling Equipment

Air samplers shall be calibrated prior to each use by a typical system as shown in Figure 2. A calibration curve is established by obtaining at least ten evenly spaced flow rates over the entire operating range of the air sampler. The motor speeds of the air blower and air sampler should be varied concurrently to set the rotameter at a given air-flow rate while maintaining atmospheric conditions at the upstream face of the filter. For

each rotameter air flow rate, either the corresponding air-flow rate on the sampler or the static pressure-drop across the filter is used. The measurements are repeated for each filter at the same air-flow rates and at least ten filters shall be tested to establish each initial calibration curve. For future calibration checks, fewer filters may be tested as long as they are within the limits of the ten initial filters.

X. APPENDIX II

ANALYTICAL METHOD FOR BERYLLIUM

ATOMIC ABSORPTION METHOD

Use of an atomic absorption spectrophotometer provides perhaps the most economical method for the analysis of beryllium. This method is recommended by NIOSH for purposes of determining compliance with the recommended beryllium standard. Other methods of analysis for beryllium may be used provided their accuracy and sensitivity are determined to be equivalent to the method presented herein.

Principle of the Method

The liquid sample containing the beryllium is aspirated into the flame of the burner-assembly and the vaporized sample is irradiated by a lamp containing a cathode made of beryllium metal. The ground-state atoms of beryllium in the sample absorb the 2348.6A resonance line of beryllium emitted by this lamp, thereby effecting a decrease in the intensity of light reaching a photodetector. The percent of the absorption so indicated is a measure of the concentration of beryllium in the sample.

Range and Sensitivity

For aqueous solutions, the working range for beryllium is linear from concentrations of 0.03 µg/ml to approximately 4 µg/ml.[117] The sensitivity under the standard operating conditions is about 0.03 µg/ml beryllium for 1 percent absorption.[117] This sensitivity can be increased with chemical concentration by solvent extraction.

Interferences

High concentrations of aluminum (500 µg/ml) depress the sensitivity of the beryllium determination. High concentrations of silicon and magnesium also decrease the sensitivity. The interference can be controlled by adding oxine (8-hydroxy-quinoline) to the sample and standards.[117]

Precision and Accuracy

The standard procedure for beryllium will provide a coefficient of variation of about 0.5 to 2 percent depending upon the instrument used and the absorbance of the samples.[117]

Apparatus

(a) Atomic absorption spectrophotometer, having a monochrometer with a reciprocal linear dispersion in the ultraviolet region of about 6.5 A/mm. The instrument should have a sensitivity sufficient to provide a calibration curve usable from 0.2 to 8 ppm with the 2348.6A beryllium line.

(b) Beryllium hollow cathode lamp of high spectral purity and adequate sensitivity.

(c) Acetylene gas in a cylinder equipped with a two-gauge, two-stage pressure-reducing regulator and hose connections.

(d) Nitrous oxide in a cylinder equipped with a two-gauge, two-stage pressure-reducing regulator and hose connections. Heat-tape, with the temperature controlled by a rheostat, is wound around the second stage regulator and connecting hose to prevent freeze-up of the line.

Reagents

All reagents are analytical reagent-grade. Nitric and hydrochloric acids are redistilled. All solutions are prepared from deionized water.

(a) Stock beryllium solution. A solution containing 1000 μg of beryllium per milliliter is prepared by dissolving 1.000 gm of beryllium metal in a minimum volume of 1:1 HCl. Dilute to 1 liter with 1% (V/V) HCl.

(b) Beryllium standard solution. Prepared by making appropriate dilutions from the stock beryllium solution and acidifying with 1 ml of redistilled HCl for each 10 ml of solution. Thus prepared, a standard solution is stable for at least several months.

Procedure

Borosilicate glassware is recommended for this method. Glassware is soaked in a mild detergent solution immediately after use to remove any residual grease or chemicals and thus to prevent the formation of an adsorptive surface. Before use, each piece is cleaned with a saturated solution of sodium dichromate in concentrated sulfuric acid and then rinsed thoroughly in succession with warm tap water, concentrated nitric acid, tap water, and finally deionized water.

(a) Sample Preparation

Air Samples--The entire filter or impinger sample is transferred to a 125 ml Phillips beaker and ashed with nitric acid. If a fiberglass filter was used for sampling, it is necessary to first destroy the filter with hydrofluoric acid in a platinum or teflon dish prior to ashing with nitric acid in the Phillips beaker. When ashing is complete, convert

the residue to the chloride form. The residue is then dissolved in a minimal amount of hydrochloric acid and water and evaporated in an oven to a volume of 2.0 ml or more depending on the amount of beryllium expected in the sample.

(b) Determination of Beryllium

The HCl solution of the ashed or fused sample is aspirated directly into the nitrous oxide-acetylene flame. A special nitrous oxide-acetylene burner head must be used. The 2348.6A resonance line of beryllium is used. The operating parameters vary according to the make of instrument being employed. Consult the instrument manufacturer's instructions for the particular instrument settings and procedure for lighting the nitrous oxide-acetylene flame. A reducing, fuel-rich flame, is needed for the desired sensitivity in the beryllium analysis.

If the beryllium concentration falls between 0.2 and 8.0 μg/ml, the percent of absorption values of the samples are recorded on the 1X scale or the absorbance or concentration values are read directly if these features are available on the instrument being employed. If the beryllium concentration is between 0 and 0.2 μg/ml, scale expansion can be used, if available; however, longer aspiration time is needed when using scale expansion since higher noise suppression is required. The percent of absorption of each sample run on the 1X scale is determined from the recorder chart and this value is converted to absorbance. The concentration of beryllium in each sample is determined by referring to the standard curve where beryllium concentration is plotted versus absorbance. If the samples were recorded on an expanded scale, the percent of absorption

value is related directly to concentration since the standard curve is plotted similarly. If absorbance values are read directly from the instrument, a standard curve is prepared plotting the absorbance versus concentration.

Standardization

Beryllium standards are prepared by appropriate dilutions of the stock solution. Each standard solution contains 1 ml of 1:1 redistilled HCl per 10 ml of solution. The standards are aspirated into the flame and the percent of absorption is recorded or the absorbance is read for each concentration. A standard curve is prepared for the two concentrations; ranges of 0 to 8 µg/ml and 0 to 0.5 µg/ml. If high concentrations of aluminum, silicon, or magnesium are present in the samples, the standards should be prepared in a similar base.

Calculations

The percent of absorption is converted to absorbance. The standard curve is used to get a beryllium concentration value in terms of µg/ml for the absorbance value. This µg Be/ml value is multiplied by the sample aliquot to determine the total beryllium in the sample.

Calculation of Beryllium Concentration

$$\frac{\text{Total µg Be}}{\text{m}^3 \text{ of air sample}} = \text{µg Be/m}^3 \text{ of ambient air}$$

Effect of Storage

Samples and standards can be stored indefinitely without loss of beryllium as long as the pH of solutions is maintained at less than 2.

XI. APPENDIX III

MATERIAL SAFETY DATA SHEET

The following items of information which are applicable to a specific product or material containing beryllium shall be provided in the appropriate section of the Material Safety Data Sheet or approved form. If a specific item of information is inapplicable (i.e., flash point) initials "n.a." for not applicable shall be inserted.

(a) The product designation in the upper left hand corner of both front and back to facilitate filing and retrieval. Print in upper case letters in as large print as possible.

(b) Section I. Source and Nomenclature.

(i) The name, address, and telephone number of the manufacturer or supplier of the product.

(ii) The trade name and synonyms for a mixture of chemicals, a basic structural material, or for a process material; and the trade name and synonyms, chemical name and synonyms, chemical family, and formula for a single chemical.

(c) Section II. Hazardous Ingredients

(i) Chemical or widely recognized common name of all hazardous ingredients.

(ii) The approximate percentage by weight or volume (indicate basis) which each hazardous ingredient of the mixture bears to the whole mixture. This may be indicated as a range of maximum amount; i.e., 10-20% V; 10% max. W.

(iii) Basis for toxicity for each hazardous material such as established OSHA standard (TLV), in appropriate units and/or LD_{50}, showing

amount and mode of exposure and species, or LC_{50} showing concentration and species.

(d) Section III. Physical Data.

Physical properties of the total product including boiling point and melting point in degrees Fahrenheit; vapor pressure, in millimeters of mercury, vapor density of gas or vapor (air=1), solubility in water, in parts per hundred parts of water by weight; specific gravity (water=1); percent volatile, indicate if by weight or volume, at 70 degrees Fahrenheit; evaporation rate for liquids (indicate whether butyl acetate or ether=1); and appearance and odor.

(e) Section IV. Fire and Explosion Hazard Data.

Fire and explosion hazard data about a single chemical or a mixture of chemicals, including flash point, in degrees Fahrenheit; flammable limits, in percent by volume in air; suitable extinguishing media or agents; special fire fighting procedures; and unusual fire and explosion hazard information.

(f) Section V. Health Hazard Data.

Toxic level for total compound or mixture, relevant symptoms of exposure, skin and eye irritation properties, principal routes of absorption, effects of chronic (long-term) exposure, and emergency and first aid procedures.

(g) Section VI. Reactivity Data.

Chemical stability, incompatibility, hazardous decomposition products, and hazardous polymerization.

(h) Section VII. Spill or Lead Procedures.

Detailed procedures to be followed with emphasis on precautions

to be taken in cleaning up and safe disposal of materials leaked or spilled. This includes proper labeling and disposal of containers containing residues, contaminated absorbants, etc.

(i) Section VIII. Special Protection Information.

Requirements for personal protective equipment, such as respirators, eye protection and protective clothing, and ventilation such as local exhaust (at site of product use or application), general, or other special types.

(j) Section IX. Special Precautions.

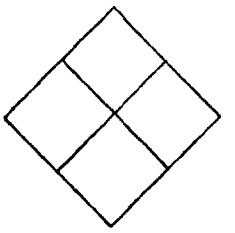
Any other general precautionary information such as personal protective equipment for exposure to the thermal decomposition products listed in Section VI, and to particulates formed by abrading a dry coating, such as by a power sanding disc.

(k) The signature of the responsible person filling out the data sheet, his address, and the date on which it is filled out.

PRODUCT DESIGNATION

MATERIAL SAFETY DATA SHEET

Form Approved
Budget Bureau No.
Approval Expires
Form No. OSHA



SECTION I SOURCE AND NOMENCLATURE

MANUFACTURER'S NAME	EMERGENCY TELEPHONE NO.
ADDRESS (Number, Street, City, State, ZIP Code)	
TRADE NAME AND SYNONYMS	CHEMICAL FAMILY
CHEMICAL NAME AND SYNONYMS	FORMULA

SECTION II HAZARDOUS INGREDIENTS

BASIC MATERIAL	APPROXIMATE OR MAXIMUM % WT. OR VOL.	ESTABLISHED OSHA STANDARD	LD_{50}		LC_{50}	
			ORAL	PERCUT.	SPECIES	CONC.

SECTION III PHYSICAL DATA

BOILING POINT °F.	VAPOR PRESSURE mm Hg.
MELTING POINT °F.	VAPOR DENSITY (Air=1)
SPECIFIC GRAVITY (H_2O=1)	EVAPORATION RATE (_____=1)
SOLUBILITY IN WATER Pts/100 pts H_2O	VOLATILE % Vol. % Wt.
APPEARANCE AND ODOR	

SECTION IV FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	FLAMMABLE (EXPLOSIVE) LIMITS	UPPER
METHOD USED		LOWER
EXTINGUISHING MEDIA		
SPECIAL FIRE FIGHTING PROCEDURES		
UNUSUAL FIRE AND EXPLOSION HAZARDS		

PRODUCT DESIGNATION

SECTION V HEALTH HAZARD DATA	
TOXIC LEVEL	CARCINOGENIC
PRINCIPLE ROUTES OF ABSORBTION	SKIN AND EYE IRRITATION
RELEVANT SYMPTOMS OF EXPOSURE	
EFFECTS OF CHRONIC EXPOSURE	
EMERGENCY AND FIRST AID PROCEDURES	

SECTION VI REACTIVITY DATA
CONDITIONS CONTRIBUTING TO INSTABILITY
CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION
INCOMPATABILITY (Materials to Avoid)
HAZARDOUS DECOMPOSITION PRODUCTS

SECTION VII SPILL OR LEAK PROCEDURES
STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
WASTE DISPOSAL METHOD

SECTION VIII SPECIAL PROTECTION INFORMATION	
VENTILATION REQUIREMENTS LOCAL EXHAUST	PROTECTIVE EQUIPMENT (Specify Types) EYE
MECHANICAL (General)	GLOVES
SPECIAL	RESPIRATOR
OTHER PROTECTIVE EQUIPMENT	

SECTION IX SPECIAL PRECAUTIONS
PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE
OTHER PRECAUTIONS

Signature _____ Address

Date _____

TABLE I*
PHYSICAL PROPERTIES OF BERYLLIUM

Property		Value
Atomic number		4
Atomic weight, chemical		9.013
Electron configuration		$1s^2\ 2s^2$
Thermal conductivity, cal/(sec)(cm^2)(°C/cm)	0-100°C	0.349
Density, gm/cm^3	25°C	1.8477 ± 0.0007
Melting point		1283°C, 2341°F
Boiling point		2970°C
Electrical Resistivity, μohm-cm		4.31
Optical properties		Steel-gray color, reflectivity 50-55%
Sound conductance, m/sec		12,600
ft/sec		41,300

*See reference No. 1

TABLE II*

INDUSTRIAL USES OF BERYLLIUM PRODUCTS

1. Nuclear Applications

   Moderator reflectors

   Weapons production

2. Guided Missiles and Space Vehicles

   Inertial guidance

   Radome and microwave windows

   Fuels

3. Electrical Measuring Instruments

   Alloy springs, connectors, contacts

4. Switchgear

   Alloy electrical switches

   Household appliances

5. Welding Apparatus

   Alloy electrodes

   Resistance welding equipment

6. Electronic Computer Equipment

   Circuitry

7. Radio and Television Equipment

   Circuitry

8. Other Uses

   Molds for plastics

   Chemical reagents

   Alloy development

*See reference Nos. 3,5,6

TABLE III*
INDUSTRIES PROCESSING AND MANUFACTURING
BERYLLIUM PRODUCTS

Aerospace equipment specialty products

Alloy manufacturing

Beryllium alloy machining and fabrication

Beryllium ceramic products

Electronic equipment manufacturing

Extraction of beryllium

Metallurgical operation

Mining and beneficiation of beryllium minerals

Non-ferrous foundry products

Phosphor manufacturing

Special chemicals

Tool and die manufacturing

*See reference Nos. 3,5

TABLE IV*
EARLY LITERATURE ON BERYLLIUM POISONING

Author	Date	Be compounds and/or processes mentioned	Diagnoses
Weber and Engelhardt (Germany)	1933	Extraction of Be	Bronchitis; bronchiolitis
Fabroni (Italy)	1935	Be carbonate	Berylliosis; forms of pneumonia (guinea pigs)
Menesini (Italy)	1937	Be carbonate	Poisoning, by inhalation, of lungs and larger glands; acute accident pneumopathy (animals)
Gelman (Russia)	1936 & 1938	Be metal	Metal fume fever; nasopharyngitis; bronchitis and bronchioalveolitis; dermatitis; conjunctivitis ("neighborhood" cases)
Berkowitz and Israel (German--writing from Russia)	1940	Be metal, fluoride	Fluorine beryllium poisoning; acute bronchiolitis
Meyer (Germany)	1942	Be silicate, hydroxide, sulfate, chloride	Berylliosis; chronic large-celled pneumonia; pulmonary sclerosis
Wurm and Ruger (Germany)	1942	Be silicate, hydroxide, sulfate, chloride	Beryllium dust pneumonia (pathology of human cases; animal studies)
Van Ordstrand, Hughes and Carmody (USA)	1943	Extraction of Be; Be oxide, sulfate, chloride	Chemical pneumonia
Shilen, Galloway, and Mellor (USA)	1943	Extraction of Be; Be oxide, fluoride	Respiratory diseases
Kress and Crispell (USA)	1944	Fluorescent powder, Be carbonate; Be,Mn silicate	Atypical pneumonitis
Van Ordstrand, DeNardi, and Carmody (USA)	1945	Be metal, oxide, sulfate, fluoride, oxyfluoride	Beryllium poisoning, contact dermatitis; contact conjunctivitis; chemical nasopharyngitis; chemical pneumonitis
Hardy and Tabershaw (USA)	1946	Fluorescent powder; Zn, Be, Mn silicate	Delayed chemical pneumonitis

TABLE IV

(Continued)

Author	Date	Be compounds and/or processes mentioned	Diagnoses
Koelsch (Germany)	1947	Be silicate, sulfate, chloride, hydroxide	Bronchitis; atypical pneumonitis
Machle, Beyer, Gregorius and Tebrock (USA)	1948	Be oxide; Zn,Be,Mn silicate; Be halides	Berylliosis; acute pneumonitis; pulmonary granulomatosis
Agate (Gt. Britain)	1948	Fluorescent powder	Delayed pneumonitis (systemic disease)
Vigliani (Italy)	1948	Be extraction; fabrication Be alloys; Be fluoride, oxide, metal	Respiratory diseases; acute pneumonitis; chronic bronchitis; dermatitis; conjunctivitis

*See reference No. 17

TABLE V

CONFIRMED CASES* OF CHRONIC BERYLLIUM DISEASE FROM THE

BERYLLIUM CASE REGISTRY OF WORKERS EXPOSED SINCE 1949

Sex	Year of Birth	Source of Exposure	Duration of Exposure	Dates of Diagnosis	Proximity to Source	Delay Between First Exposure & Symptoms	Environmental Levels $\mu g\ Be/m^3$
M	1919	Machining & Polishing -- Fabrication work with Be-Cu	1 year	9/67	Handling or Breathing Zone	2 1/2 years	General Room Air 19.7 Polishing Operations 208.0, 346.0 Machining 0.08 to 1.6
M	1939	Machining-- Be Alloys	2 1/2 months	1/69	Handling or Breathing Zone	10 years	----
M	----	Machining-- Draftsman where Be pressed & fired	1 year	----	Under Same Roof	10 months	----
F	1924	Ceramics-- Be in porcelain	15 years	9/68	Handling or Breathing Zone	13 years	----
M	1932	Be powder	5 years	5/69	Handling or Breathing Zone	Less than 5 years	----
M	1917	Ceramics	6 weeks	1965	Handling or Breathing Zone	----	----
M	1927	Foundry-- Smelting Beryllium	3 years	1969	Handling or Breathing Zone	3 years	----

TABLE V

CONFIRMED CASES* OF CHRONIC BERYLLIUM DISEASE FROM THE

BERYLLIUM CASE REGISTRY OF WORKERS EXPOSED SINCE 1949

(Continued)

Sex	Year of Birth	Source of Exposure	Duration of Exposure	Dates of Diagnosis	Proximity to Source	Delay Between First exposure & Symptoms	Environmental Levels$_3$ µg Be/m
M	1940	Grinding Shop-- Be-Ni Alloy	9 1/2 years	1961	Handling or Breathing Zone	3 years	----
M	1940	Ceramic Machine Shop--Technician & Maintenance	9 1/2 years	1971	Handling or Breathing Zone	8 1/2 years	Per Employer daily weighted averages- Low 0.7, High 5.9, Avg 2.0
–	1922	Smelting & Extraction	Greater than 2 years	1971	Handling or Breathing Zone	Less than 10 years	----

*Ten representative case histories of approximately 20 examined.

TABLE VI

STATUS OF MALE BERYLLIUM STUDY COHORT AS OF JANUARY 1, 1968

STATUS	NUMBER	
Known to be alive	3297	
Known to be deceased	618	
Known causes		595
Unknown causes		7
Overseas		16
Not known to be alive or deceased	6	
TOTAL	3921	

TABLE VII

EXPECTED AND OBSERVED DEATHS BY SELECTED CAUSES
OCCURRING TO BERYLLIUM WORKERS, 1942-1967

CAUSE OF DEATH	LIST NO. (ICD)*	EXPECTED	OBSERVED
MALIGNANT NEOPLASMS	140-205	105.24	91
Digestive	150-159	37.65	30
Lung	160-164	25.41	25
Residual	140-149, 165-205	42.18	36
CEREB-VASC ACCIDENTS	330-334	56.81	40
HEART DISEASE	400-443	271.03	273
RESPIRATORY DISEASES	470-527	31.08	34
EXTERNAL CAUSES	800-999	78.24	65
ALL OTHER CAUSES		125.93	92
UNKNOWN			7
ALL CAUSES		668.33	602

*ICD = International Classification of Diseases and Cause of Death

TABLE VIII

EXPECTED AND OBSERVED DEATHS BY CAUSE AND BY YEARS
AFTER START OF BERYLLIUM WORK AT DIFFERING LEVELS OF EXPOSURE*

	<5 YRS. EXPOSURE				5-14 YRS. EXPOSURE				≥15 YRS. EXPOSURE			
	HIGH		LOW		HIGH		LOW		HIGH		LOW	
CAUSE OF DEATH	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.
MALIGNANT NEOPLASMS	6.02	2	5.72	4	21.58	20	19.00	15	29.89	29	23.00	19
Digestive	2.49	1	2.42	1	7.96	7	7.10	5	9.97	9	7.70	6
Lung	1.10	0	1.03	0	4.80	6	4.13	6	8.16	9	6.17	5
Residual	2.43	1	2.27	3	8.82	8	7.77	4	11.76	11	9.13	8
CEREB-VASC ACCIDENTS	2.80	1	2.77	0	10.83	12	10.05	11	16.80	6	13.53	10
HEART DISEASE	14.71	11	14.09	10	54.24	51	48.47	56	78.07	73	61.28	71
RESPIRATORY DISEASE	2.23	3	1.99	1	5.34	7	4.74	5	9.38	12	7.39	6
EXTERNAL CAUSES	10.96	9	9.11	4	19.15	17	15.62	14	13.17	15	10.14	6
ALL OTHER CAUSES	12.85	3	11.44	5	26.80	15	23.17	15	28.86	27	22.65	26
UNKNOWN	0	1	0	0	0	1	0	1	0	3	0	1
ALL CAUSES	49.57	32	45.12	24	137.94	123	121.05	117	176.17	165	137.99	139

*Based Upon Opinion of a Professional Industrial Hygienist

TABLE IX

EXPECTED AND OBSERVED DEATHS BY CAUSE AND BY YEARS
AFTER START OF BERYLLIUM WORK BY TOTAL TIME IN JOB

	<5 YRS. AFTER START OF WORK						5-14 YRS AFTER START OF WORK						≥15 YRS. AFTER START OF WORK					
	<6 MOS		6 MOS. TO <2-1/2 YRS.		≥2-1/2 YRS.		<6 MOS		6 MOS. TO <2-1/2 YRS.		≥2-1/2 YRS.		<6 MOS		6 MOS. TO <2-1/2 YRS.		≥2-1/2 YRS.	
CAUSE OF DEATH	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.
MALIGNANT NEOPLASMS	5.85	4	4.35	3	1.49	0	18.76	21	10.75	3	11.08	12	25.63	26	14.87	10	12.41	12
Digestive	2.49	2	1.85	0	0.56	0	6.87	6	4.07	2	4.13	5	8.43	9	4.99	3	4.25	3
Lung	1.04	0	0.78	0	0.31	0	4.19	7	2.29	1	2.45	3	7.09	8	4.00	3	3.24	3
Residual	2.32	2	1.72	3	0.62	0	7.70	8	4.39	0	4.50	4	10.11	9	5.88	4	4.92	6
CEREB-VASC ACCIDENTS	2.80	1	2.13	0	0.62	0	9.51	10	5.73	7	5.64	6	14.20	8	8.79	4	7.35	4
HEART DISEASE	14.49	12	10.76	6	3.50	3	47.43	51	27.53	30	27.79	27	66.81	62	39.59	42	33.00	40
RESPIRATORY DISEASE	2.21	2	1.55	1	.45	1	4.67	6	2.65	4	2.76	2	8.12	10	4.80	4	3.85	4
EXTERNAL CAUSES	10.63	6	6.95	5	2.34	2	16.95	12	8.58	13	9.27	6	12.12	11	6.16	3	5.06	7
ALL OTHER CAUSES	12.87	7	8.79	2	2.56	0	23.18	11	13.18	12	13.66	7	25.09	23	14.43	11	12.00	20
UNKNOWN	.00	0	.00	1	.00	0	.00	1	.00	1	.00	0	.00	2	.00	2	.00	0
ALL CAUSES	48.85	32	34.53	18	10.96	6	120.50	112	68.42	70	70.20	60	151.97	142	88.64	75	73.67	87

TABLE X

EXPECTED AND OBSERVED DEATHS BY CAUSE AND BY YEARS
AFTER START OF BERYLLIUM WORK BY PERIOD WHEN STARTED WORK

	<5 YEARS						5-14 YEARS						≥15 YEARS					
	<1943		1943-47		>1947		<1943		1943-47		>1947		<1943		1943-47		>1947	
CAUSE OF DEATH	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.	EXP.	OBS.
MALIGNANT NEOPLASMS	2.71	2	5.39	3	3.65	2	13.01	9	18.48	18	9.11	9	26.02	22	23.55	23	3.34	3
Digestive	1.35	1	2.57	1	1.00	0	5.19	5	7.28	6	2.60	2	8.74	5	7.98	9	0.95	1
Lung	0.45	0	0.86	0	.82	0	2.59	1	3.75	4	2.60	6	7.07	5	6.17	8	1.10	1
Residual	0.91	1	1.96	2	1.83	2	5.23	3	7.45	8	3.91	1	10.21	12	9.40	6	1.29	1
CEREB-VASC ACCIDENTS	1.42	1	2.96	0	1.21	0	6.86	7	11.03	12	2.98	4	14.35	8	14.88	7	1.10	1
HEART DISEASE	7.24	2	13.96	11	7.69	8	33.27	28	49.25	55	20.23	25	67.70	69	64.18	66	7.52	9
RESPIRATORY DISEASE	1.41	1	1.80	2	1.03	1	3.18	3	4.56	8	2.35	1	7.96	8	7.95	7	0.87	3
EXTERNAL CAUSES	5.14	2	5.60	1	9.37	10	11.00	10	11.20	9	12.59	12	11.65	11	9.20	8	2.50	2
ALL OTHER CAUSES	7.93	0	10.54	8	5.87	1	17.67	15	21.49	9	10.88	6	25.09	30	23.14	22	3.28	1
UNKNOWN		1						2						2		2		
ALL CAUSES	25.85	9	40.25	25	28.82	22	84.99	74	116.01	111	58.14	57	752.77	150	142.90	135	18.61	19

TABLE XI*
REPRESENTATIVE ENVIRONMENTAL BERYLLIUM CONCENTRATIONS
(Prior to Controls)

Beryllium Operation	Concentration ($\mu g/m^3$)	
	Dust	Fumes
Metal Furnace		
Pouring	1430 to 4710	293
Coke removal	110 to 533	59 to 83
Fluoride Furnace		
3 feet away	59 to 70	
15 feet away	14	
Ore Treatment (Rotary kiln dryer)		
1-1/2 feet to far side of area	50 to 528	

*See reference No. 105

TABLE XII*

REPRESENTATIVE ENVIRONMENTAL EXPOSURE LEVELS IN A BERYLLIUM ALLOY PLANT PRIOR TO INSTITUTION OF CONTROL MEASURES

$\mu g\ Be/m^3$

	11/47	12/47	1/48	2/48
Mix Operation:				
General air	411			
Breathing zone	15,500	42,000		21,000
				590
				16,500
Alloy Operation:				
General air	2,840		2,400	
	1,330		7,060	
Breathing zone	43,300			4,700
Stack Sampling:			1,955	
			2,470	

*See reference No. 106

TABLE XIII*

CHRONIC AND ACUTE-TO-CHRONIC CASES BY PROXIMITY TO SOURCE

Mode of Exposure	Number	Percent
Nonoccupational	6	1.8
Beryllium plant, different building**	15	4.5
Under same roof as source	44	13.2
Direct exposure	267	80.5

*See reference No. 102 and 107

**Building other than one in which beryllium materials are processed.

TABLE XIV*

SAMPLE DISTRIBUTION BY CONCENTRATION FOR
15 BERYLLIUM METALWORKING PLANTS

Stated Concentration $\mu g\ Be/m^3$	No. < Stated Concentration	Percent < Stated Concentration
0.05	84	42.06
0.10	148	63.52
0.20	170	72.96
0.50	198	84.97
1.00	216	92.70
2.00	223	95.70
5.00	225	96.56
10.00	228	97.85
20.00	230	98.71
50.00	232	99.57
100.00	233	100.00

*See reference No. 112

TABLE XV*

TIME-WEIGHTED AVERAGE EXPOSURE FOR PERSONNEL
IN A BERYLLIUM ALLOY PLANT

$\mu g\ Be/m^3$

Master Alloy Production Crew

	6 & 7/53	1 - 6/54	7 - 12/54	1 - 6/55	1 - 6/56	7 - 12/56	1 - 3/57	1 - 6/60
Chief operator	4.5	7.9	17.0	10.3	7.0	11.2	8.8	23.1
Helper	9.5	7.9	16.3	10.0	7.7	18.5	11.8	34.0
Mixer	3.8	53.3	27.8	8.7	6.8	9.2	12.3	28.1
Charger	4.4	4.6	27.8	10.9	13.5	19.1	10.9	54.6

*See reference No. 106

TABLE XVI

REPRESENTATIVE WORKER DAILY WEIGHTED AVERAGE (DWA) EXPOSURES TO BERYLLIUM*

PLANT A

Survey Year	1953	1953	1954	1955	1956	1957	1957 All Employees	1957 Production Employees Only
No. of Employees	213	152	66	61	164	198	132	44
Avg. DWA $\mu g/m^3$	1.0	0.6	1.1	2.4	2.6	1.4	-	-
Max. DWA $\mu g/m^3$	12.6	2.6	3.6	34.0	18.4	11.8	-	-
% Exposed 0-1.0 $\mu g/m^3$	56.3	88.8	60.6	71	-	-	70	16
% Exposed 0-2.0 $\mu g/m^3$	-	-	-	-	67.6	88	-	-
% Exposed 1.1-2.0 $\mu g/m^3$	30.5	7.2	28.8	18	-	-	11	27
% Exposed 2.1-4.0 $\mu g/m^3$	13.2	-	-	-	-	-	.7	50
% Exposed 2.1-5.0 $\mu g/m^3$	-	-	-	-	22	8.5	-	-
% Exposed $>$ 2.0 $\mu g/m^3$	-	4.0	10.6	11.0	-	-	-	-
% Exposed $>$ 4.0 $\mu g/m^3$	0.5	-	-	-	-	-	2	7
% Exposed $>$ 5.0 $\mu g/m^3$	-	-	-	-	10.4	3.5	-	-

*Data supplied by U.S.A.E.C. Health and Safety Laboratory.

TABLE XVII

REPRESENTATIVE WORKER DAILY WEIGHTED AVERAGE (DWA) EXPOSURES TO BERYLLIUM*

PLANT B

Survey Year	1958	1957	1960 Production	1960 Other	1961 Production	1961 Other	1962 Production	1962 Other
No. of Employees	116	200	155	58	77	77	37	44
Max. DWA $\mu g/m^3$	10	73	9.8	10.7	6.4	3.2	3.3	4.3
% Exposed 0-2.0 $\mu g/m^3$	82	4.0	25	62	93.5	62	24	43
% Exposed 2.1-5.0 $\mu g/m^3$	11	66.5	50	31	4.0	38	76	57
% Exposed > 5.0 $\mu g/m^3$	7	15.0	25	0	2.5	0	-	-
% Exposed > 10 $\mu g/m^3$	0	14.5	0	7	0	0	-	-
No. Exposed to Instantaneous Level > 25 $\mu g/m^3$	16**	14**	90	4	2	6	0	5
No. Exposed to Instantaneous Level > 100 $\mu g/m^3$	0	19**	2	0	0	0	6	0

*Data supplied by U.S.A.E.C. Health and Safety Laboratory.

**In addition, these operators were also exposed to 29 $\mu g/m^3$ during 6 min. stay in the clothing change room.

TABLE XVIII

REPRESENTATIVE WORKER DAILY WEIGHTED AVERAGE
(DWA) EXPOSURES TO BERYLLIUM*

PLANT C

Survey Year	1957	1958	1958	1959	1959 Production	1959 Other	1960 Production	1960 Other	1961 Production	1961 Other	1961 Production	1961 Other
No. of Employees	75	66	60	56	70	63	72	74	57	76	57	73
Max. DWA $\mu g/m^3$	80	550	130	360	32	2.7	3.8	9.0	55.9	3.2	5.9	3.2
% Exposed 0-1.0 $\mu g/m^3$	8	0	22	0	-	-	-	-	-	-	-	-
% Exposed 0-2.0 $\mu g/m^3$	-	-	-	-	51	92	58	66	31.6	74	26	78
% Exposed 1.1-2.0 $\mu g/m^3$	39	0	23	18	-	-	-	-	-	-	-	-
% Exposed 2.1-4.0 $\mu g/m^3$	14	0	13	59	-	-	-	-	-	-	-	-
% Exposed 2.1-5.0 $\mu g/m^3$	-	-	-	-	40	8	42	30	57.9	26	68	22
% Exposed 4.1-10.0 $\mu g/m^3$	13	50	7	18	-	-	-	-	-	-	-	-
% Exposed 5.1-10.0 $\mu g/m^3$	-	-	-	-	-	-	-	4**	10.5	0	5.2	0
% Exposed 10.1-20.0 $\mu g/m^3$	11	21	-	-	-	-	-	-	-	-	-	-
% Exposed > 10.0 $\mu g/m^3$	25	50	12	5	9	0	0	0	0	0	0	0
% Exposed > 20 $\mu g/m^3$	-	29	23	5	-	-	-	-	-	-	-	-

TABLE XVIII

PLANT C
(Continued)

Survey Year	1957	1958	1958	1959	1959 Production	1959 Other	1960 Production	1960 Other	1961 Production	1961 Other	1961 Production	1961 Other
No. Exposed Instantaneous > 25 $\mu g/m^3$	19	22	23	10	25	-	12***	3	13	3	12	0
No. Exposed Instantaneous > 100 $\mu g/m^3$	15	15	18	5	13	-	6	0	18	0	0	0

*Data supplied by U.S.A.E.C. Health and Safety Laboratory
**These personnel work in laundry.
***In addition, every operator was exposed to 26.4 $\mu g/m^3$ during 10 min. stay in locker room

TABLE XIX

REPRESENTATIVE WORKER DAILY WEIGHTED AVERAGE (DWA) EXPOSURES TO BERYLLIUM*

PLANT D

Survey Year	1952	1953	1955	1956	1957	1958	1959	1960 Production	1960 Other
No. of Employees	120	126	125	123	234	183	159	150	88
Avg. DWA $\mu g/m^3$	1.2	0.3	2.0	2.4	0.5	-	-	-	-
Max. DWA $\mu g/m^3$	6.2	1.0	98.0	14.8	3.0	11.2	5.2	1.3	2.2
% Exposed 0-1 $\mu g/m^3$	70.8	100	70	54	89	68	88	-	-
% Exposed 0-2.0 $\mu g/m^3$	78	-	80	-	-	-	-	100	95
% Exposed 1.1-2.0 $\mu g/m^3$	6.7	-	10	13	10	21	0	-	-
% Exposed 2.1-4.0 $\mu g/m^3$	16	-	14	-	1	7	-	-	-
% Exposed 2.1-5.0 $\mu g/m^3$	-	-	-	-	-	-	12	0	5
% Exposed 2.1-10.0 $\mu g/m^3$	-	-	19	30	-	-	-	-	-
% Exposed 4.1-10.0 $\mu g/m^3$	7	-	5	-	0	4	-	-	-
% Exposed $>$ 2.0 $\mu g/m^3$	5.8	-	-	-	1	-	-	-	-
% Exposed $>$ 10.0 $\mu g/m^3$	1	2	0	0	-	-	-	-	-
No. Exposed to Instantaneous Level $>$ 25 $\mu g/m^3$	-	-	2	6	0	11	7	0	0

*Data supplied by U.S.A.E.C. Health and Safety Laboratory

TABLE XX

REPRESENTATIVE WORKER DAILY WEIGHTED AVERAGE (DWA) EXPOSURES TO BERYLLIUM*

PLANT E

	1961	
	Production	Other
No. of Employees	46	7
Max. DWA $\mu g/m^3$	73	4.0
% Exposed 0–2 $\mu g/m^3$	0	0
% Exposed 2–5 $\mu g/m^3$	4	100
% Exposed 5–10 $\mu g/m^3$	20	0
% Exposed >10 $\mu g/m^3$	76	0
No. Exposed to Instantaneous Level >25 $\mu g/m^3$	16**	3**
No. Exposed to Instantaneous Level >100 $\mu g/m^3$	21**	

*Data supplied by U.S.A.E.C. Health and Safety Laboratory

**In addition, 29 workers were exposed to general air concentrations in the 25–100 μg range.

TABLE XXI

REPRESENTATIVE AVERAGE BREATHING ZONE CONCENTRATIONS
FOR VARIOUS PLANT OPERATIONS*
$\mu g/m^3$
PLANT A

Operation	1950	1950	1953	1953	1954	1955	1956	1956	1957	1957
Removing Plug from Beryl Furnace-Operating Tilt Controls during Pouring	5.5	1.3	--	--	14.6	--	--	5.5	7.42	--
Operating Controls While Elevating Frit Cage to Frit Shaker Platform	--	6.6	--	--	7.6	--	--	--	--	--
Opening Frit Cage for Drainage and Shoveling in Excess Frit	3.1	39.0	--	--	45	--	--	--	--	--
Placing Frit into Frit Shaker	2.8	8.5	--	--	22.6	--	--	--	--	--
Replacing Cover with Grate on Sulfate Mill	--	--	4.3	3.2	2.1	3.7	84.5	--	3.03	--
Taking Specific Gravity Reading at Sulfate Mill	--	--	6.5	6.3	14.4	7.4	--	--	--	--
Placing Cover on Sulfate Mill	--	--	5.0	29	0.8	--	--	--	--	--
Cleaning Burner End of Sulfate Mill	--	--	6.0	0.8	16.9	660	314	--	1.75	--
Lighting Burner End of Sulfate Mill	--	--	3.8	--	55.1	15000	278	11.1	5.28	--
Sampling Ground Ore Bin	--	--	12.5	28	3.3	20	--	--	--	--
Sampling at Sulfate Mill	--	--	6.4	--	29.7	--	--	--	--	--
Changing Hydroxide Drum	--	--	15	16	20.6	52	23.7	15.6	4.73	11
Sampling and Weighing Drums	--	--	--	--	--	--	30.2	6.5	3.71	--
Changing Discharge Drum	--	--	--	--	--	--	--	--	4.21	1.0
Washing Down Area	--	--	--	--	--	--	29.8	--	2.38	--
Discharging One Drum into Ball Mill	--	--	--	--	--	--	--	12.7	21.69	16
Weighing Up BeF_2 Charge	--	--	--	--	--	--	43.0	19.4	9.22	26
Charging Furnace	--	--	--	--	--	--	16.42	116.7	4.20	9
Vacuuming Buggy, Removing to Cooling Area	--	--	--	--	--	--	156.2	11.3	2.15	--
Replacing Drum at Melts Crusher	--	--	--	--	--	--	16.2	65.9	25.3	--
Melts Buggy Operation	--	--	--	--	--	--	466.5	159.3	19.44	--

TABLE XXI

PLANT A (continued)

Operation	1950	1950	1953	1953	1954	1955	1956	1956	1957	1957
Melts Crushing	--	--	--	--	--	--	705	80.0	503.19	--
High Frequency Fluoride										
Removing and Replacing Feed Drum	--	--	--	--	--	--	18.65	25.2	3.71	1.3
Removing and Displacing Discharge Drum	--	--	--	--	--	--	28.5	103.2	7.52	6.4
Vacuum Cast Furnace Operator										
Making Up Charge in Weigh Hood	--	--	--	--	--	--	21.4	12.7	66	44
Breaking Vacuum and Pouring	--	--	--	--	--	--	19.8	24.8	3.45	4
Scraping Dross into Mold	--	--	--	--	--	--	--	--	6.41	20
Extracting Mold from Furnace	--	--	--	--	--	--	49.4	8.9	6.01	6
Dumping Silent Butler	--	--	--	--	--	--	--	686	7.5	--
Extracting Billet from Mold	--	--	--	--	--	--	116.5	8.1	8.6	--
Place Billet in Transfer Can	--	--	--	--	--	--	--	12.3	31.7	--
Sandblast Operator										
Placing Billet in Sandblast Hood	--	--	--	--	--	--	437.3	--	10.25	19
Fill Billet Core, Sandblast and Clean Billet	--	--	--	--	--	--	51.56	--	2.15	1.3
Stamp Billet, Remove Billet	--	--	--	--	--	--	95.5	--	3.00	5
Composite Pebble Sample	--	--	--	--	--	--	--	--	20.47	--
Weighing Sampled Composite	--	--	--	--	--	--	--	--	25.35	--
Sample Grinder										
Vacuuming Grinding Hood	--	--	--	--	--	--	--	--	55	--
Riffling Ground Sample	--	--	--	--	--	--	27	--	7.67	--
Sintering Technicians										
Inverting Be Powder Drum, Dump and Clean Can	--	--	--	--	--	--	5.39	--	1.04	--

*Data Supplied by U.S.A.E.C. Health and Safety Laboratory

TABLE XXII

REPRESENTATIVE AVERAGE BREATHING ZONE CONCENTRATIONS
FOR VARIOUS PLANT OPERATIONS*
$\mu g/m^3$
PLANT B

Operation	1958	1958	1959	1960	1961	1962
Beryl Furnace						
Pour Beryl Furnace	15	2.2	30.7	3.3	0.9	--
Raise Frit Basket	--	--	4.7	0.2	1.8	--
Sulfate Mill						
Take Out Door, Put in Grate	11	24	--	12.5	4.1	1.6
Take Out Grate, Put in Door	--	--	15.9	28.1	--	--
Thickener - Hydroxide						
Change Discharge Drum	--	13	20.3	11.7	--	--
Reduction Furnace						
Charge Furnace	6.9	3.1	17.0	4.5	0.3	4.7
Change Drums in Charge Cart	23	--	106	8.1	1.6	10.8
Probe Melt	--	2.0	17.7	3.9	1.3	6.8
Pour Furnace	19	8.3	8.7	16.0	0.7	3.3
Melts Crusher and Ball Mill						
Put Steel Balls in Mill	--	2.7	3.1	2.3	1.6	--
Rotate Mill to Dump	--	--	4.9	2.1	1.8	--
Pebble Inspection						
Inspect Pebbles	--	--	11.3	3.0	0.5	--
Remove Discharge Drum	--	--	--	7.8	0.9	--
Pebble Floatation						
Rake Pebbles through Floatation	--	--	11.0	2.2	2.6	--
Remove Discharge Drum	--	--	--	15.7	7.5	--
Vacuum Cast						
Charge Furnace	--	6.0	7.5	5.0	2.7	22.4
Probe Melt	--	2.3	--	5.5	6.0	4.0
Pour Furnace	--	5.9	10.5	5.6	4.0	7.4
Remove Probe Rod Assembly	--	--	--	9.0	2.8	64.5
Remove Billet Mold, Install Dross Mold	--	--	7.3	7.8	--	--
Remove Dross Mold, Install Billet Mold	--	--	--	30.6	5.5	10.4

TABLE XXII

PLANT B (continued)

Operation	1958	1958	1959	1960	1961	1962
Sand Blast						
Operate Sand Blast	--	4.0	8.6	11.3	1.8	3.8
Remove Billet from Sand Blast	--	8.0	24.7	27.5	--	--
Chipping Lathe						
Install Billet in Lathe	--	--	--	1.9	--	--
Change Chip Pick Up Drum	--	--	--	14.2	--	--
Magnetic Chip Inspection						
Vacuum Chips Out of Feed Drum	--	--	--	9.6	--	--
Inspect Chips	--	--	--	3.5	--	--
Attrition Mill						
Install Feed Drum	--	--	16.4	14.0	--	--
Change Discharge Drum	--	--	22.2	30.6	--	--
Compact Load						
Change Feed Drum on Transfer Unit	--	--	--	25.5	--	--
Change Receiving Drum on Transfer Unit	--	--	--	6.7	--	--
Sinter Furnace						
Load Die into Furnace	--	--	--	5.6	--	--
Put Lid on Furnace	--	--	--	2.1	--	--
Degreaser And Dryer						
Place Chips into Degreaser	--	--	--	5.5	--	--
Chip Inspection						
Inspect Chips	--	--	--	6.6	--	--
Remove Discharge Drum	--	--	--	13.5	--	--
Magnetic Separator						
Place Feed Drum into Dump Position	--	--	--	46.2	--	--
Remove Sample	--	--	--	33.5	--	--
Remove Discharge Drum	--	--	--	42.0	--	--
Chip Crusher						
Operate Crusher	--	--	--	21.3	--	--
Laundry						
Loading Dirty Outer Clothing into Washer	--	--	--	11.9	11.4	28.5
Loading Dirty Under Clothing into Washer	--	--	--	26.4	24.9	16.7

*Data Supplied by U.S.A.E.C. Health and Safety Laboratory

TABLE XXIII
REPRESENTATIVE AVERAGE BREATHING ZONE CONCENTRATIONS
FOR VARIOUS PLANT OPERATIONS*
$\mu g/m^3$

PLANT C

Operation	1957	1958	1958	1959	1959	1960	1961	1961
Holo-Flite Drum Change	4	79	13	Not Performed	80	5.2	-	-
Slurry Mixing	415	4000	22	7.5	15	9.5	8.4	2.2
Clean Sparkler Filter	1	22	13	10.6	6.3	3.1	5.4	-
Burwell Filter Press Breakdown	61	2600	29	17	12	28.3	3.1	14
Calciner Discharge	-	1500	155	Discontinued	-	-	-	-
Charge Ribbon Blender - Oxide	8.5	5800	14	Discontinued	-	-	-	-
Charge Blender - Bifluoride	-	-	13		-	-	-	-
Charge Slurry Tank - Bifluoride				5	23	5.1	0.8	-
Ribbon Blender Discharge	-	220	30	Discontinued	-	-	-	-
Fluoride Furnace Feed	7.3	4200	330	Automatic	-	-	-	-
Reduction Furnace Charge	40	1050	10	24	2.4	18.2	13	17
Reduction Furnace Pour	3.7	58	20	22	15	57.3	30	9.6
Reduction Furnace (Puddle Melt) Stir	3.6	-	9.3	18	16	-	-	-
Reduction Furnace Discharge Drum Change	125	180	38	48	27	12.3	45	-
Break Melt - Air Hammer	1	1550	8.5	11	5.7	15	8.8	-
Prepare Reduction Furnace Charge	930		1100		-	-	-	-
Patterson Mill Charge	2	1550	12	8	6.8	4.7	-	-
Prepare Patterson Mill Charge	-	-	27	110	103	3.4	-	-
Flotation Separation	-	12	5.9	1.2	2.3	3.7	1.3	14
Pebble Separation	11	58	1.8	28	31	2.4	23	11
Vacuum Furnace - Open and Clean			22	72	14	1.3	3.4	7.2
Remove Billet from Furnace			550		-	-	-	10
Remove Billet from Mold			4900	2900	78	84.8	160	-
Grinding Billet			6		-	-	-	-
Crucible Cleanout			22		9.5	-	-	-
Laundry - Dump Work Clothes			82	12	8.9	-	5.9	4.1

TABLE XXIV
REPRESENTATIVE AVERAGE BREATHING ZONE CONCENTRATIONS
FOR VARIOUS PLANT OPERATIONS*
$\mu g/m^3$

PLANT D

Operation	1952	1953	1955	1956	1957	1958	1959	1960
Operating Do-All Saws	4.0	1.1	1.5	.9	0.4			1.4
Operating Lathes	2.3	.4	2.4	5.8	1.2			
Operating Surface Grinder	5.3	.6	2.0	.8	1.1			
Operating Milling Machines	3.8	.9	7.2	.5	0.8			1.2
Engraving Be Pieces			2.0	.5				
Operating Chipping Lathe				1.1	0.7	8.5		
Changing Chip Drum				10.1				
Transferring Chips from Drum to Bottles	57		1660.	21.3	10.1	6.1	1.6	
Changing Bottles on Attrition Mill		1.8	14.4	6.1	4.4	12	15	
Loading Blender	11.7		9.5	32.3	1.7	2.4	17	
Transferring Blender to Rollers	20	.4	1400	5.5	5.1			
Placing Blender on Compact Loading Hood		2.0	110.	10.2	8.0	100		
Filling Sintering Dies	10.8	.8	7.0	31.4	4.2	10		
Loading Vertical Furnace		.3		1.5				
Unloading Vertical Furnace		.5	1.8	2.5				
Stripping Die in Decontamination Room	63	.3	81.	128.				
Unloading 12" Vacuum Furnace				37.1	0.8			
Dismantling and Cleaning Mold from 12" Furnace				3.3				
Machine Tools					1.2	1.6	0.6	
Be Oxide Powder Furnace Loading					2.8	3.8	4.7	
Stripping Be Oxide Furnace						8.0	2.0	

*Data Supplied by U.S.A.E.C. Health and Safety Laboratory

TABLE XXV

REPRESENTATIVE AVERAGE BREATHING ZONE CONCENTRATIONS
FOR VARIOUS PLANT OPERATIONS*
$\mu g/m^3$

PLANT E

Operation	1961
Ore Hauler	
Cutting burlap bags and dumping ore into crusher	160
Ore Mill Operator	
Taking specific gravity reading at ore mill	15
Cleaning screen at ore mill	4.8
Ore Weigher	
Weighing barrel of ore from drum dryer and removing to storage area	27
Weigh-Up Man	
Weighing up mix	21
Simpson Mixer Operator	
Charging Simpson mixer	17
Discharging Simpson mixer	76
Lancaster Mixer Operator	
Charging Lancaster mixer	85
Discharging Lancaster mixer into wheelbarrow and transporting to extruder	45

TABLE XXV

PLANT E (Continued)

Operation	1961 Average
Extruder Operator	
Hoeing down mix into extruder	10
Extruder Helper	
Removing bricks from extuder to cart	9.2
Transporting cart to storage area	8.6
Sinter Furnace Operator	
Loading sinter car with briquettes	6.0
Broom sweeping in loading area	21
Tranferring sintered briquettes into crusher	66
Leach Operator Helper	
Opening and discharging Shriver press	660
Closing Shriver press	1800
Drumming press discharge	330
Laundry Man	
Placing wet clothes into washer	2.4
Transferring clothes from tub to weigh up scale	2.1
Transferring dirty socks from basket to net bag, then to washer	31

*Data supplied by U.S.A.E.C. Health and Safety Laboratory

TABLE XXVI

REPRESENTATIVE AVERAGE GENERAL AIR CONCENTRATIONS FOR VARIOUS PLANT AREAS* $\mu g/m^3$

PLANT A

Survey Year	1952	1953	1954	1955	1956	1957	1957
Area							
Beryl Furnace	-	1.1	0.6	-	-	2.0	0.1
Sulfate Mill	1.4	0.5	0.2	5.9	2.3	0.4	-
Heat Treat and Grind	3.0	1.0	0.4	5.8	1.5	2.6	-
Hydroxide	2.9	1.1	3.6	1.5	4.2	1.6	2.7
Leach Shop	2.8	2.8	1.1	2.2	2.7	1.7	-
Boiler	1.4	0.6	0.2	0.7	-	-	-
Boiler Office	3.4	0.2	0.4	0.5	-	-	-
Wet Metal	1.5	1.0	0.5	0.5	2.5	1.0	0.2
Control Laboratory	1.1	0.4	0.6	0.4	-	-	0.5
Inplant Maintenance	-	0.1	0.4	0.5	-	-	0.2
Electrical Shop	0.8	0.5	0.5	0.1	-	-	0.2
Steelroom	0.2	0.2	0.3	0.6	-	-	-
Laundry	0.3	0.5	1.2	0.3	-	-	0.4
Fluoride Furnace	-	0.5	1.0	0.5	3.6	0.7	1.5
Production Superintendent's Office	-	0.3	1.2	0.3	-	-	0.3
Sewing Room	1.7	0.07	0.6	0.4	-	-	0.2
Lunch Room	0.8	0.2	0.3	0.9	0.6	0.8	0.3
Locker Room	0.8	0.2	0.4	1.0	2.2	0.7	1.6
Machine Shop	0.2	0.5	0.3	0.5	2.9	-	-
Garage	0.1	-	0.1	0.3	-	-	0.03
Guard House	0.05	0.03	0.2	0.2	-	-	0.03
Process Development	0.15	0.09	2.0	1.4	-	-	10.2
Air Laboratory	0.1	0.2	0.3	1.0	-	-	2.2
Air Laboratory Office	0.98	-	0.4	0.6	-	-	-
Office Building	0.07	0.1	0.1	0.2	-	-	0.02

TABLE XXVI
PLANT A
(Continued)

Survey Year	1952	1953	1954	1955	1956	1957	1957
Area							
Maintenance Office	1.5	1.1	1.5	0.6	-	-	0.2
Sintering Area	-	-	-	-	-	1.4	-
High Frequency - Reduction Furnace	-	-	-	-	1.8	.62	0.8
Furnace Rebuild	-	0.7	0.7	-	0.3	4.7	6.1
Vacuum Casting Area	-	-	-	-	6.2	0.6	0.5
Flotation	1.7	0.9	1.2	-	0.9	1.1	0.4
Sand Blasting	-	-	-	-	1.3	0.7	0.5

*Data supplied by U.S.A.E.C. Health and Safety Laboratory.

TABLE XXVII

REPRESENTATIVE AVERAGE GENERAL AIR CONCENTRATIONS FOR VARIOUS PLANT AREAS*
$\mu g/m^3$

PLANT B

Area	1958	1958	1959	1960	1961	1962
Ore Storage	10.4	0.6	2.4	-	-	
Beryl Furnace	6.9	1.8	13.6	0.9	1.6	
Heat Treater & Grind	3.8	1.8	3.3	1.4	0.8	1.6
Hardinge Mill	19	1.0	-	-	-	
Sulfate Mill	2.7	29	4.4	1.7	0.9	2.1
Leach and Thickening	1.8	1.9	3.6	2.3	0.9	2.6
Hydroxide Control Panel	0.65	-	-	-	-	-
Hydroxide Area	1.6	1.4	1.6	2.4		2.6
Wet Metal Area - ground floor	1.7	0.6	4.0	1.9	1.0	1.1
-platform	25	-	-			
Salt Evaporator Platform	18	0.8	3.2	2.3	1.5	0.6
Salt Centrifuge Area	26	1.8	3.2			
Fluoride Furnace Platform	14	1.2	-	-		
Fluoride Furnace - ground floor	24	0.8	5.3	1.3	1.0	2.0
Patterson Mill Platform	6.2	-	5.8			
Reduction Furnace Platform	2.7	1.1	-	-		
Reduction Furnace Area	5.5	1.4	5.4	3.3	0.5	2.5
Maintenance Area	2.9	1.1	1.8			0.6
Chemical Storage Area	1.3	0.2				
Boiler Area	5.5	0.7	3.7	2.8	0.3	4.1
Maintenance Office	3.7	0.2				
Control Laboratory	0.7	-		0.5	3.5	2.0

TABLE XXVII

PLANT B
(continued)

Area	1958	1958	1959	1960	1961	1962
Superintendent's Office	1.7	0.4				
Lunch Room	1.9	0.6	4.4	0.9	1.0	2.2
Locker Room	1.0	29		2.3	1.2	1.0
Shoe Change Room	16	-	28.9	1.9	9.8	25.2
Oxide Furnace Area	3.7	-				
Pebble Sorting	7.8	-	4.2	2.5	0.5	1.1
Laundry	0.5	0.2		0.6	1.4	1.2
Magnetic Separation Platform	6.2	1.4				
Vacuum Casting Furnace Area	9.1	1.1	4.1	2.4	1.3	2.5
Dispensary	2.7	-	-	2.2		
Furnace Rebuild		1.5	18.2	2.7	0.8	2.7
Chemical Laboratory		0.4	2.3			
Sandblast and Sample Drill			34.4	4.4	1.3	3.1
Attrition Mill			10.9	8.8		
Sintering Furnace			3.8	3.8		
Chipping Lathe Room			5.5	1.8		

*Data supplied by U.S.A.E.C. Health and Safety Laboratory.

TABLE XXVIII

REPRESENTATIVE AVERAGE GENERAL AIR CONCENTRATIONS FOR VARIOUS PLANT AREAS*
$\mu g/m^3$

PLANT C

Location	1957	1958	1958	1959	1959	1961	1961
Chemical Storage	0.2	11	3.4	-	-	-	-
Precipitation Area	0.6	4.3	3.7	1.4	0.6	-	-
Burwell Platform-Hydroxide Purification	3.3	9.1	8.0	1.8	2.7	3.4	2.0
Burwell Room	9.1	800	260	-	-	-	-
Fluoride Furnace Area	14	27	2.0	2.5	1.2	2.0	5.2
Reduction Furnace Area	1.6	13	2.5	9.0	1.3	2.5	3.0
Patterson Mill Area	1.3	21	4.7	1.0	2.0	-	-
Vacuum Furnace Area	-	-	4.5	2.1	2.7	1.3	4.5
Furnace Repair	-	-	11	4.0	2.0	2.2	2.5
Analytical Laboratory	0.2	24	0.8	2.5	1.0	0.3	1.6
Sample Grind Laboratory	-	3.7	2.0	0.3	0.4	-	-
Spectrographic Laboratory	5.8	8.2	0.5	8.3	1.1	-	-
Maintenance Area	0.5	0.7	0.3	2.8	3.6	1.3	1.1
Laundry	0.4	3.2	0.7	0.6	1.4	0.5	0.5
Change Room-Work Dress	0.7	0.3	0.7	2.1	1.9	4.3	3.3
Lunch Room	1.0	0.7	0.8	2.0	2.5	3.6	3.5
Electricians Shop	-	-	0.4	4.0	-	-	-
Plant Corridors	-	-	3.1	0.7	-	-	-
Calcine Furnace Area	1.9	13	2.1	1.7	-	-	-
Motor Generator Room	1.7	2.2	6.6	0.3	0.5	0.5	-
Boiler Room	0.1	0.7	0.2	1.4	0.1	0.2	-
Warehouse	0.4	-	0.2	1.8	-	-	-
Spent Salt Area	0.6	-	7.8	1.9	2.0	2.4	2.1
Ore Handling thru Leaching	0.8	10	2.4	-		-	

*Data supplied by U.S.A.E.C. Health and Safety Laboratory.

TABLE XXIX

REPRESENTATIVE AVERAGE GENERAL AIR CONCENTRATIONS FOR VARIOUS PLANT AREAS*
$\mu g/m^3$

PLANT D

Area	1952	1952	1953	1955	1956	1957	1958	1959	1960
Machine Shop	0.3	1.0	0.1	1.8	10.5	0.4	0.7	0.2	1.1
Jig Bore Room	-	-	-	-	-	0.2		-	
Precision Parts Room	-	-	-	-	-	0.3	0.2	0.3	
Chipping Lathe Room	-	-	-	-	-	0.7	3.8	-	
Machine Shop Office	-	-	0.2	0.1	0.2	0.1	-	0.8	0.07
Guard Office	-	-	0.1	0.3	0.1	0.1	0.3	-	
Shipping & Receiving	-	-	0.2	0.4	0.4	0.3	0.2	0.4	
Inspection Room	-	-	-	0.6	0.5	0.1	0.2	0.3	0.1
Lunch Room	0.2	1.5	0.3	0.5	1.0	0.3	0.4	0.5	0.4
Locker Room	0.3	0.9	0.2	2.8	1.3	0.7	0.8	0.4	0.08
Attrition Mills	0.4	1.0	0.2	1.0	0.7	0.6	9.0	2.2	
Vapor Blast Area	-	-	-	-	-	0.1	-	-	
Powder Room Laboratory	-	-	-	0.7	0.8	0.1	2.0	4.5	
Compact Filling Room	-	-	-	-	-	0.7	1.0	1.8	
Sintering Furnace Area	0.3	0.3	0.2	0.3	0.3	0.4	2.1	1.1	
Powder Blender	-	-	-	1.5	0.2	0.1	-	-	
Chemistry Office	-	-	-	-	-	0.1	-	-	
Chemistry Laboratory	-	-	0.1	0.1	0.1	0.2	0.2	0.3	0.06
Powder Laboratory	-	-	-	0.7	0.8	0.1	-	0.3	
Metallurgical Laboratory	-	-	-	1.1	2.5	0.7	0.3	0.3	
Administrative Offices	0.02	0.2	0.2	0.2	0.1	0.3	0.2	-	0.02
Ceramics Laboratory	-	-	-	0.2	0.4	0.9	2.6	0.4	0.8
Electrical Shop	-	-	0.1	0.1	0.0	0.2	-	-	
Sintering Area Office	-	-	-	0.3	31.8	0.2	-	-	
Alpine Classifier	-	-	-	-	-	31	-	-	

*Data supplied by U.S.A.E.C. Health and Safety Laboratory.

TABLE XXX

REPRESENTATIVE AVERAGE GENERAL AIR CONCENTRATIONS FOR VARIOUS PLANT AREAS*
$\mu g/m^3$

PLANT E

Area	1961
Ore Mill Area	3.2
Wet Mill Area	14
Mixing Platform	7.3
Extruding Area	3.2
Sinter Furnace Area	14
Leach Platform	32
Precipitation Tank Area	10
Shriver Press Area	38
Laundry Room	1.8
Oxide Control Laboratory	3.7
Oxide Foreman's Office	10
Lunch Room	4.4
Locker Room Area	12

*Data supplied by U.S.A.E.C. Health and Safety Laboratory.

FIGURE 1

JOB ANALYSIS SHEET*

OPERATOR Vacuum Furnace Operator 1 MEN/SHIFT: 3 SHIFTS/DAY: 3 MEN/DAY

Operation or Operating Area	Time Per Opera. (Min.)	Opera. Per Shift	Time Per Shift (Min) (T)	No. of Samples	Concentration $\mu g/M^3$ Low	High	(C) Avge.	Avg. Conc'n.* Times Total Time (T X C)
BZ Cleaning and removing billet from furnace	13	3	39	4	7.6	22	15	590
BZ Weighing furnace charge	6	3	18	4	3.5	12	6	110
BZ Charging furnace	2	3	6	5	4	37	19	110
GA Vacuum furnace area			351	11	0.6	4.1	1.7	600
GA Spent salt area			45	9	0.3	2.2	0.9	41
GA Lunch room			30	4	0.2	0.5	0.4	12
GA Locker room, before shift			10	5	0.2	0.6	0.4	4
GA Locker room, after shift			15	5	1.5	4.8	2.7	41

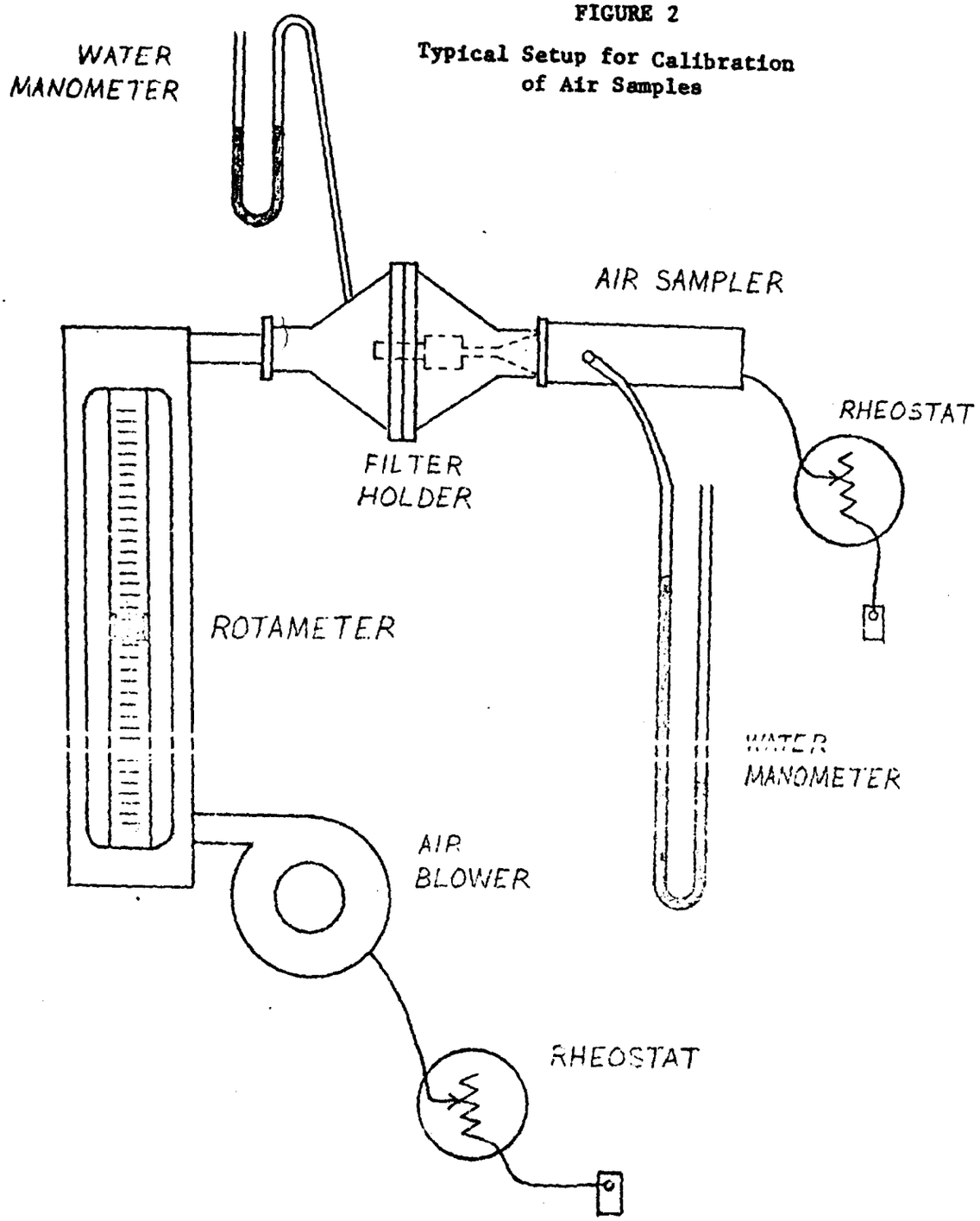
*Adjusted to two significant figures.

$\frac{\Sigma(TXC)}{\Sigma(T)}$ = 2.9 $\mu g/M^3$ ΣT 510 = $\Sigma(T \times C)$ 1500 Times the Maximum Allowable Concentration

*Courtesy U.S.A.E.C. Health and Safety Laboratory.

FIGURE 2

Typical Setup for Calibration of Air Samples



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