NATIONAL SECURITY ASSESSMENT OF THE U.S. BERYLLIUM SECTOR

U.S. DEPARTMENT OF COMMERCE
BUREAU OF EXPORT ADMINISTRATION
OFFICE OF INDUSTRIAL RESOURCE ADMINISTRATION
STRATEGIC ANALYSIS DIVISION

JULY 1993

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Bureau of Export Administration
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July 1993

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EXECUTIVE SUMMARY

The U.S. Department of Commerce, Bureau of Export Administration (BXA), Office of Industrial Resource Administration (OIRA), performed this national security assessment of the U.S. beryllium industry under authority of the Defense Production Act of 1950, as amended, and related Executive Order 12656. The assessment was initiated at the request from the Department of the Navy, Office of the Chief of Naval Operations. The Navy sought to determine the percentage of scrap generated by defense contractors' beryllium operations, as well as the procedures for recycling this scrap. The Navy needed this information to gain oversight of scrap recycling by defense subcontractors.

The request by the Navy evolved from a 1989 technical study by the National Materials Advisory Board titled, "*Beryllium Metal Supply Options*," which examined the processing technology for metallic beryllium and the scrap cycle. It was revealed by the study that insufficient information was available on beryllium fabricators. Moreover, the Board recommended upgrading Brush Wellman's Elmore, Ohio production plant with near net shape capability and gas atomization powder generation to reduce the generation of internal scrap.

In view of the importance of beryllium to the defense industrial base, the collapse of the Soviet Union and the potential for increased exports to raise hard currency, and sharp declines in the demand for metallic beryllium, OIRA accepted the Navy request, but expanded the scope of the study to include: 1) other key beryllium products (i.e., beryllium alloys and beryllium oxide); 2) a review of economic and trade factors; and, 3) how recent global developments may affect the viability of the U.S. beryllium sector.

The importance of beryllium lies in its unique properties. These properties include: 1) light weight, 2) dimensional stability over a wide range of temperatures, 3) the ability to reflect neutrons and transmit x-rays, 4) the ability to greatly strengthen copper, 5) the ability to absorb and distribute heat, and 6) resistance to deformity. While the material is expensive, these properties enable beryllium to play a central role in our national defense, and have contributed greatly to advances in electronics, optics and telecommunications.

Beryllium is offered on the market in three major forms: metallic beryllium, beryllium alloys, and beryllium oxide. In 1992, metallic beryllium constituted about 15 percent of the dollar value of the world market, although in prior years when defense spending was higher,

it was over 20 percent. Beryllium alloys (mostly of beryllium copper), were about 75 percent of the market, up from prior years, while beryllium oxide comprised most of the remaining 10 percent.

The United States is by far the world's largest producer, processor and consumer of beryllium related products. In the 11 years from 1981-1991, U.S. production of beryllium ore accounted for over 64 percent of world production. During the same 11 years, U.S. demand for beryllium related products totaled over 71 percent of the world total, and over 83 percent of the processing of primary beryllium products took place in the United States.

Production of beryllium ore in the United States declined each year since 1986, falling from 237 metric tons that year, to only 174 in 1991, down 27 percent, as demand fell. This resulted in a draw down of industry stock levels, which reached a peak of 255 metric tons in 1983, and then fell steadily to 112 metric tons by the close of 1991. The five-year average demand, 1988-1992, was more than 28 percent lower than the preceding five-year period, 1983-1987. The down trend followed declines in defense/aerospace, electrical equipment, nuclear applications, and slumping sales in electronics markets, particularly mainframe computers.

Brush Wellman Inc., headquartered in Cleveland, Ohio is the only fully integrated producer of metallic beryllium, beryllium alloys, and beryllium oxide powder in the Western world. Between 1981-1992, Brush Wellman averaged $256.5 million in total sales revenues, and $206.2 million (80.5 percent) in beryllium related product sales. The firm has mining and upgrading facilities in Utah, and primary processing facilities in Elmore, Ohio. NGK (Japan) produces beryllium alloys from imported beryl upgraded under a toll-agreement with Brush Wellman in Utah. Through the primary product stage of the beryllium production cycle, OIRA estimates Brush has 85 percent of the market in the United States, and about 70 percent in the world. Brush is also a significant factor in beryllium product fabrication markets.

NATIONAL SECURITY CONCERNS

From a national security perspective, beryllium is a strategic material used in our most sophisticated U.S. weapon systems. Beryllium is used by the military to control reactors on nuclear powered submarines and surface vessels, as a triggering device for nuclear warheads, in precision optical components, inertial guidance systems, and satellite structures,

and in air, land and seaborne electronic equipment. Beryllium has no realistic substitutes in its strategic nuclear applications.

In dollar terms, between 20-25 percent of beryllium consumption is used for military applications, down from about 35 percent in the mid-1980s. Defense buys over 90 percent of the metallic beryllium, about 10 percent of the beryllium alloys, and 20-30 percent of the beryllium oxide. Since Fiscal Year (FY) 1985, the total military procurement budget (in 1993 dollars) fell from $127.2 billion, to only $54.1 billion in FY1993, a dramatic drop exceeding 57 percent. The major decline jeopardizes the continued viability of the metallic beryllium sector, which (in early 1993) reported operating below 30 percent of production capacity.

The long-term health of the beryllium sector is uncertain. The major concerns facing the beryllium sector are as follows: 1) rising environmental control costs; 2) declining defense procurement expenditures (particularly affects metallic beryllium); 3) potential surge in supply of metallic beryllium on the world market at low prices by the former Soviet Union; and, 4) the possible sale of metallic beryllium and beryllium copper master alloy inventories from the National Defense Stockpile.

Environmental costs continue to rise faster than revenues, and at the margin continue to constrain the market potential of beryllium, at both the manufacturing point and among potential customers. The chief health concern associated with the handling of beryllium is chronic beryllium disease, also known as berylliosis. Berylliosis is a disabling lung disease caused by inhaling beryllium dust; handling finished beryllium products does not lead to berylliosis. A small percentage of people exposed to beryllium dust will get this disease; it has been shown that chronic berylliosis has an immunological basis. Progress has been made in reducing the occurrence of berylliosis since the disease was first recognized. However, compliance with OSHA and EPA regulations is a costly endeavor, and has a major impact on Brush Wellman and beryllium product fabricators.

The potential for a surge in supply of beryllium on the world market from the former Soviet Republic of Kazakhstan has increased. This scenario could quite possibly become reality, as in the case of uranium, aluminum and copper from Russia into Western markets. This led to a rapid decline in prices of these commodities and pushed a number of European and American producers toward bankruptcy.

Concerns about the sale of beryllium copper master alloy from the National Defense Stockpile were expressed because of potentially disruptive effects the sale could have on the domestic industry. As a result, beryllium copper master alloy was withdrawn from sale consideration with the signing of the *National Defense Authorization Act for Fiscal Year 1993* on October 23, 1992. However, authorization was given to dispose of the entire inventory of beryl ore within a five year period ending October 1, 1997, unless such disposals are found to be disruptive to markets.

OFFICIAL TRADE STATISTICS INADEQUATE

International trade in beryllium and beryllium products is difficult to accurately assess because of technical difficulties in measuring the content of beryllium in certain traded categories, and lack of complete coverage by the trade statistics.

Imports - Total reported beryllium related imports reached a peak in 1989 at $3.8 million, and since then have declined to $2.1 million in 1991. Imports are comprised mostly of beryllium ore and beryllium product scrap. Excluding beryllium ore, available statistics show that Japan was the major source of beryllium product imports between 1989-1991, accounting for over 65 percent of the total. China was a distant second at just over 21 percent.

Exports - Official statistics only cover metallic beryllium and the metal's waste and scrap, and greatly understate actual exports. For example, the most traded item is beryllium copper alloys, which are not covered. Reported U.S. exports of metallic beryllium and metallic scrap declined rather sharply since the mid-1980s. During the period 1986-1991, the dollar value of these exports dropped from $7.4 to $2.3 million, in part because the major European economies slipped into recessions. Also, major cuts took place in NATO defense spending, and reductions in the European space program. The major destination during these six years was the United Kingdom, followed by France and Germany. These three countries received over 70 percent of the total reported exports. Exports to Japan accounted for over 10 percent of the total, while Canada accounted for about 9 percent.

SCRAP RECYCLING

Beryllium products scrap is generated by processors (home scrap) and fabricators (new scrap). In each case the most scrap arises from machining or stamping operations, where the material is formed and cut into a variety of shapes in preparation for shipment. The amount of home scrap generated from metallic beryllium ranges from about 60-70 percent, beryllium copper, 25-30 percent, and beryllium oxide almost none. New scrap generation will vary by product and fabricator. New metallic beryllium scrap on average ranges between 50-60 percent, but will often exceed 90 percent. New beryllium copper and beryllium oxide scrap each average between 20-30 percent. Very little beryllium old scrap is reclaimed from finished products, because of the difficulty in getting at it, and usually, the low beryllium content in end-products.

The equipment required to recycle beryllium scrap is expensive. In 1988, Brush Wellman opened a $10 million beryllium copper waste recycling plant at its Elmore, Ohio location. The facility has the capacity to recover 2 million pounds of copper and 90,000 pounds of beryllium annually.

Metallic beryllium scrap is too expensive to mix with beryllium copper or beryllium oxide scrap; it is also made in several grades which have different cost structures. Metallic beryllium will range from about 95 percent beryllium to almost 100 percent, depending on its application. The purest and most expensive grade is used for strategic weapons.

OIRA estimates over 80 percent of new scrap is recovered and returned to the manufacturer for recycling. The estimate will vary with scrap prices, which rise during economic upturns and reduce the amount recycled through primary manufacturers. For example, when the demand for beryllium copper is strong, some dealers may purchase metallic scrap and melt it with copper to sell as beryllium copper master alloy. As for other factors, some scrap is lost or winds up in a landfill. Additional amounts are sometimes lost from overseas that cannot be shipped back to the United States economically. Scrap prices range from $40-$70 per pound (contained beryllium), depending on market conditions. Beryllium copper is by far the major source of new scrap, alone providing more than 70 percent of the total. Brush Wellman and NGK have non-binding agreements with almost all of their customers to take back new scrap.

The reduction of scrap generation in the beryllium industry would greatly lower the product's cost, and make it more attractive in the marketplace. Scrap generation adds to the cost and time of production. As with other metals, beryllium scrap is generated, recycled, and produced a second time, generating still more scrap in an endless cycle. Enlarging the gas atomization powder formation capabilities, and pushing the near-net-shape technology at Brush Wellman's Elmore, Ohio facility are part of the solution.

BACKGROUND

Introduction

The U.S. Department of Commerce, Bureau of Export Administration (BXA), performed this national security assessment of the U.S. beryllium industry under authority of the Defense Production Act of 1950 (DPA), as amended, and related Executive Order 12656. The Office of Industrial Resource Administration (OIRA), Strategic Analysis Division, is the BXA organization delegated responsibilty to conduct assessments of this nature. OIRA identifies critical industries; assesses their capabilities to meet national security needs; evaluates current and potential production constraints; and proposes remedial action when necessary.

In the course of an OIRA national security assessment, particular consideration is given to such factors as industry structure, raw material availability, investment, research and development, foreign sourcing, employment, technological factors, market trends, international competitiveness, and the impact of Department of Defense (DOD) spending cuts. Necessary data are collected by the OIRA from the private sector under authority of Section 705(e) of the DPA. Independently, as well as in cooperation with the Department of Defense, OIRA has completed a number of national security assessments, the most recent of which include studies of the antifriction bearings and forging industries.

OIRA initiated this assessment of the beryllium industry in response to a request from the Department of the Navy, Office of the Chief of Naval Operations. The Navy sought to determine the percentage of scrap generated by defense contractors' beryllium operations, as well as the procedures for recycling this scrap. The Navy's efforts were on behalf of the Department of Defense and coordinated with the Department of Energy (nuclear operations) to gain oversight of the recycling of metallic beryllium scrap by defense subcontractors. This could extend the supply and possibly lower the price of the metal. The Department of Energy already maintains control over the disposition of its metallic beryllium scrap.

In view of the collapse of the Soviet Union, and sharp declines in the demand for metallic beryllium, OIRA expanded the scope of the study to include: 1) other key beryllium products (i.e., beryllium alloys and beryllium oxide); 2) a review of economic and trade

factors; and, 3) how recent global developments may affect the viability of the U.S. beryllium sector.

Historical Perspective

Concern over the supply and availability of metallic beryllium by the Departments of Defense and Energy (and the Atomic Energy Commission before it), the principal users of the metal, stretches back to World War II. With the closing of the Cabot Corporation's Hazelton, Pennsylvania facility in 1979, Brush Wellman Inc., in Elmore, Ohio, became the only producer of metallic beryllium in the Western world. A joint Department of Defense and Department of Energy Beryllium Supply Program (BSP) was initiated in 1981, to determine what actions were needed to provide an assured metal supply. A subgroup, the Beryllium Coordinating Committee (BCC), was set up later as a source of technical advice for the BSP.

Much of the Government's concern centered on environmental issues. Beryllium dust generated in the production of metallic beryllium has long been recognized as a serious health problem (although most people are immune to the effects). The environmental and health controls and attendant costs imposed on the production of beryllium have become more stringent over the years. Accidents and equipment failures occasionally (at a decreasing rate) cause beryllium particulates (dust) to exceed safe limits, and lead to periodic plant or work area evacuations. The fear is that rising environmental costs could disrupt production by the sole producer and lead to supply interruptions, if not outright stoppage if the plant were closed or somehow disabled. The BCC developed four production plant options as possible solutions for the future availability of the metal:

1. Construction of a new metallic beryllium production facility;

2. Construction of a metallic beryllium scrap recycling facility;

3. Combination of 1 and 2 in a single facility; and

4. Upgrading the existing production facility to incorporate new production technologies and processes.

The National Materials Advisory Board, a subgroup of the National Academy of Sciences, was asked by the BSP to assess the BCC options, and, as appropriate, present other options. In 1989, the Board issued a technical report "*Beryllium Metal Supply Options*," in which it recommended upgrading the existing facility (option 4) and establishing a separate new scrap recycling facility (option 2). The option to construct a separate scrap recycling facility was later withdrawn, when it was realized it could be disruptive to Brush Wellman. In addition, the National Defense Stockpile contains a multi-year supply of metallic beryllium, which would provide ample time to recover from an interruption in the normal supply pattern.

The Board's report examined the latest developments in alternative chemical and electrolytic metallic beryllium production technologies in an effort to supplant or improve upon the existing process. Methods to reduce the generation of scrap were also examined in detail. The report specifically recommended adding gas atomization powder production to replace existing methods, and near-net-shaping as means to substantially reduce scrap generation. Brush Wellman invested $12 million in near-net-shaping in recent years. Also, a small atomizer was initially provided by the Department of Energy and later sold to Brush Wellman. Brush Wellman upgraded the equipment with private capital. However, a production scale version has yet to be installed.

The report stated that Brush Wellman routinely recycles in-house scrap, whereas Defense subcontractor scrap (was assumed to be) sold on the open market. However, Brush Wellman is also the major user of subcontractor (or external) scrap, although this information was not clear at the time of the 1989 National Material Advisory Board report's release. Also, the Energy Department inventories large amounts of metallic beryllium scrap (about 70,000 pounds at the end of 1992) at the Rocky Flats nuclear facility. Prior to canceling the scrap recycling facility recommendation, it was thought the Defense subcontractor scrap and the Rocky Flats' scrap could supply the new recycling facility.

Methodology and Scope

Survey questionnaires were distributed by OIRA to the only two U.S. beryllium manufacturers, and a representative group of nine U.S. beryllium fabricators and nine scrap dealers to gather information for this assessment. OIRA received responses from each manufacturer and all fabricators surveyed. Five of the nine scrap dealer surveys were completed, although four of the five turned out to be fabricators; one other firm was exempted from the process.

While the questionnaires returned by scrap dealers did not provide as much information about the beryllium scrap sector as we had hoped, we were able to develop an accurate picture of scrap recycling activity through the data on scrap gathered from manufacturers and fabricators. Survey results were supplemented by a review of available literature, a plant visit, and consultations with industry and government officials in each phase of the beryllium production cycle. Extensive consultations were conducted with officials at Brush Wellman, the major firm in the industry, and with the U.S. Department of Interior's Bureau of Mines.

Publicly-available data related to beryllium collected and published by the U.S. Department of Commerce's Bureau of the Census could not be used. Census collects economic statistics on about 460 industries identified under the Standard Industrial Classification system. OIRA's examination of the Census data revealed that beryllium-related products comprise small fractions of several much larger industries, and could not be retrieved in a useable form. International trade statistics (also collected by Census) were used to the greatest extent possible, but are incomplete and limited in scope, and found to be of marginal value.

The Bureau of Mines provided a great deal of statistical information and written material that appears in the agency's *Mineral Yearbooks* and *Mineral Commodity Summaries*, which are both annual publications. Extensive use was made of this information. The aforementioned report issued by the National Materials Advisory Board (*Beryllium Metal Supply Options*) also proved useful.

Following this background material, the report contains six additional sections. The first of these, *Overview of the Beryllium Sector*, provides introductory material on the history of the beryllium sector outlining the ascendence of the U.S. beryllium industry to world leadership after World War II, and the development of its current structure. This is followed by a review of beryllium products, properties, and major markets. Next comes a discussion of the production cycle from initial mining operations to finished products. The section finishes with a description of the industry through the end of 1992.

The next section reviews *National Security Concerns* related to beryllium including the military and commercial importance of the product. Several major issues that threaten the sector are discussed in detail. These include: 1) the National Defense Stockpile, 2) the Beryllium Industry in the Former Soviet Union, and 3) Health and Environmental Issues.

This section is followed by an analysis of the *Beryllium Sector Performance*. The section begins with a statistical profile of beryllium supply patterns from 1981-1991. This is

followed by a review of beryllium prices (1985-1991), and shifting end-market patterns. Then comes an examination of Brush Wellman's public financial statements from 1981-1992. The section ends with a review of fabricator survey information covering 1986-1990. The next section contains a discussion of the limitations of the foreign trade statistics, and a review of available imports and exports from 1986-1991, with updates to 1992.

The last major section of the assessment concerns beryllium *Scrap Recycling Activity*. This section presents a narrative on the scrap process and the major sources of scrap, and their recycling. The section closes with a look at gas atomization and near-net shaping. This section is followed by the major findings of the report.

OVERVIEW OF THE BERYLLIUM SECTOR

__The importance of beryllium lies in its unique properties__. These properties include: 1) light weight, 2) dimensional stability over a wide range of temperatures, 3) the ability to reflect neutrons and transmit x-rays, 4) the ability to greatly strengthen copper, 5) the ability to absorb and distribute heat, and 6) resistance to deformity. While the material is expensive, these properties enable beryllium to play a central role in our national defense, and has contributed greatly to the advances in electronics, optics and telecommunications that have taken place in the last 25 years.

However, if looked at in terms of size, the beryllium sector in the United States is small and inconsequential. Measured by value, annual sales of primary beryllium products totaled less than $200 million in recent years. This amount of business would not qualify the industry for a spot on Fortune Magazine's list of the 500 largest U.S. industrial corporations. The sector's size in terms of actual usage is even more startling. For example, for every 1 pound of beryllium consumed in 1991, the U.S. consumed nearly 400,000 pounds of steel. Stated another way, the average quantity of steel consumed each 80 seconds during 1991, equaled the total annual consumption of beryllium. Likewise, 20 minutes of aluminum consumption, and a little less than an hour's consumption of copper also matched the consumption of beryllium.

1991 Consumption of Beryllium Relative to Steel, Aluminum, and Copper

Metal	Apparent Consumption of Selected Metals, 1991		App. Consumption of Selected Metals per pound of Beryllium consumed (in pounds)
	in metric tons	in pounds (000s)	
Beryllium	203	447.5	1
Steel	80.8 million	178,133,296	398,029
Aluminum	5,235 thousand	11,541,342	25,789
Copper	2,105 thousand	4,640,725	10,369

Source: U.S. Dept. of Interior, Bureau of Mines

History

__Beryllium spent its first 120 years or so as a laboratory curiosity__. In the late eighteenth century, the French mineralogist R. J. Hauy observed that emeralds and the more common mineral beryl (i.e., beryllium ore) had the same optical properties. At Hauy's urging, a French chemist by the name of Vauquelin chemically analyzed the two substances and proved they had the same composition, and contained a previously unknown element. He named the element glucinium because of the sweet taste of its salt, similar to glucose. Beryllium got its current name in 1828, from the German, F. Wohler, who simultaneously with W. Bussy in France, first isolated the pure metal by fusing beryllium chloride and metallic potassium. In 1898, the French chemist P. Lebeau prepared high purity beryllium by the electrolytic process. About 1915, A. Stock and H. Goldschmidt in Germany developed a commercial process using electrolysis of a fluoride salt at temperatures near the melting point of beryllium.

The first reported commercial application in America came in 1918 when a patent was issued (to Cooper) for a beryllium-aluminum base alloy. In 1926, M.G. Corson, an American metallurgist, discovered the important ability of beryllium to age-harden copper with nickel additives, and patented a beryllium-copper-nickel alloy. The same year the German electric company, Siemens, patented beryllium copper and beryllium copper cobalt alloys in Germany. Charles Brush, a man fascinated by the metal, and C. Baldwin Sawyer established Brush Laboratories in Cleveland in 1921 to research the properties and commercial potential of beryllium.

In 1927, the Beryllium Corporation of America, the first U.S. commercial producer of beryllium materials, was founded in Cleveland by Lester Hofheimer. In 1929, the Beryllium Development Corporation was established by Andrew Gahagen. Gahagen soon acquired control of the Beryllium Corporation of America, and shortened its name to The Beryllium Corporation (Berylco) in 1932. In 1931, Brush Labs became a commercial entity, with the establishment of Brush Beryllium Company (Brush). Each of these companies began in Cleveland, although Berylco later moved to Michigan before establishing itself in Reading, Pennsylvania.

__World War II propelled the American industry to world leadership in beryllium__. The three major forms of beryllium - metallic beryllium, beryllium alloys (mostly copper), and beryllium oxide (the ceramic) were produced in rather small amounts in the United States during the 1930s, as European countries took the market lead. In 1939, Clifton Products

Inc. was founded to supply beryllium oxide to the refractory and fluorescent lamp industries. World War II greatly increased demand for beryllium copper alloys, stimulating major growth in the sector. The United States was almost totally dependent on imports of beryl during the War. Imports of the ore (about 4% beryllium content) rose from less than 300,000 pounds in 1938, to a peak of almost 9.7 million pounds in 1943 - a more than 30-fold increase. The principal commercial process for extracting metallic beryllium was developed during the War. (The Allies forbid the Germans from producing beryllium after the War.)

The nuclear properties of metallic beryllium give the sector a big push. Before, during and after World War II considerable research was conducted on nuclear fission. Beryllium's nuclear properties made it a material of great interest to atomic scientists. When beryllium atoms are bombarded with alpha particles (i.e., helium nuclei with 2 protons and 2 neutrons) released from radioactive radium, the (helium) nucleus is broken down to yield a large quantity of neutrons. It was this reaction which led to the discovery of the neutron in the 1930s. The radium-beryllium source provided the neutrons for the studies which led Enrico Fermi to the construction of the first nuclear reactor in 1942. After the war a number of Government laboratories became involved in beryllium research. Among these were the Draper Laboratories of MIT, Battelle, the University of Chicago's Argonne Laboratory, Bettis Lab, Oak Ridge, Sandia, Los Alamos, and Lawrence Livermore, and the Ames Laboratory at Iowa State University.[35]

The structure of the industry was greatly affected by two events in the late 1940s. In 1948 a fire destroyed the Lorain, Ohio facility of Brush. Also, an epidemic-like number of Chronic Beryllium Disease cases were occurring at fluorescent lamp plants. In 1949, this led to the abandonment of the use of beryllium-containing phosphors in these lamps. It also led to the failure of Clifton Products since fluorescent lamps were the major market for its only product line.[36] The effect of these events was to establish Brush as the sole supplier of metallic beryllium and beryllium oxide to the U.S. Government, the only user of these products. The beryllium copper market, which had a growing commercial clientele, was left entirely to Berylco.

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[35]"Beryllium and Environmental Aspects", published by Williams and Wilkins, 1991

[36]At this time, the Atomic Energy Commission established air quality standards for beryllium which are followed to this day. The industry has now accumulated over 40 years experience dealing with environmental and health issues, far more than most other sectors.

After the fire destroyed Brush's Lorain facility, the Atomic Energy Commission contracted with Brush to design, build, and operate a Government-owned beryllium production plant. An abandoned World War II magnesium plant in Luckey, Ohio was selected and began beryllium production in 1950. In 1953, Brush constructed a foundry in Elmore, Ohio, near the Luckey operation, and re-entered the beryllium copper business indirectly by selling beryllium copper master alloy to finishing mills, who in turn competed with Berylco.

In 1956, the Atomic Energy Commission wrote separate 5-year contracts with Brush and Berylco to purchase minimum quantities of beryllium from each. Brush added a metallic beryllium operation at Elmore, while Berylco constructed one in Hazelton, Pennsylvania. Both plants commenced operation in 1957. The Government-owned facility in Luckey was closed shortly afterwards.

In 1968, Berylco merged with Kawecki Chemical Company to become Kawecki Berylco Industries (KBI). KBI was acquired by Cabot Corporation in 1978. Cabot withdrew from the metallic beryllium business in 1979, closing the Hazelton facility, citing economic and environmental reasons. In 1986, the Japanese firm, NGK Insulators, Ltd., purchased Cabot's beryllium alloy operations, renaming them NGK Metals, Inc.

The United States was on the road to self-sufficiency in beryllium ore production in 1969. Brush began mining bertrandite (another type of beryllium ore) from deposits at Spor Mountain, Utah in 1969, after constructing a beryllium hydroxide beneficiation plant in nearby Delta, Utah. This essentially made the U.S. self-sufficient, although beryl continued to be imported, chiefly from Brazil, by KBI, and later by Cabot and NGK.[37] In 1971, Brush acquired the S.K. Wellman Division from Abex Corporation, and changed its name to Brush Wellman. (This division was sold in 1986, but the name was retained.)

From the end of World War II until 1980, a large number of companies in the world were engaged in some form of beryllium production and/or fabrication. The number of fabricators expanded over the years, but the number involved in primary production, after reaching as many as four, has steadily declined. The major reason for this has been the effort and attention required to maintain adequate health and safety controls in extracting and producing beryllium and the attendant rising costs, which have constrained market growth.

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[37]In the mid-1970s, Brush and KBI reached an agreement in which Brush would convert KBI's beryl ore on a "toll" basis. This agreement continues today with NGK, although Brush has assumed primary responsibility for ore supply.

Brush Wellman became the Western world's only metallic beryllium producer in 1979. By 1979, with the exit of Cabot from the metallic beryllium sector, Brush was left as the Western world's only producer of metallic beryllium, a product used almost exclusively by the Government.

Beryllium Products, Properties, and Markets

Beryllium's high price limits its appeal in the marketplace to applications based on its unique properties. For instance, the metal's strength, light weight, and wear resistance make it an excellent choice for satellite structures. Considering that the space shuttle launching cost ranges from $3,000-10,000 per pound depending on the orbit height, if steel were used instead, at 4.24 times the weight of beryllium, the increased lifting cost alone would quickly make beryllium a bargain, even at a much higher price. (Beryllium is also stronger and more durable than steel.) Some of the properties of beryllium compared with other metals are shown on the following table.

Selected Physical Properties of Beryllium Compared with Other Metals					
Metals	Melting Point (°F)	[a]Specific Heat (BTU/lb per °F)	[b]Heat of Fusion (BTU. per lb.)	Density at 68°F (lb. per cu. in.)	[c]Modulus of Elasticity (10^6 lb. per sq.in.)
Beryllium	2332	0.45	470	0.067	40-44
Aluminum	1221	0.22	170	0.097	9
Copper	1984	0.09	91	0.324	16
Iron	2800	0.11	118	0.284	28-29

[a]-Amount of heat (BTU's) required to raise the temperature of one pound of a substance one degree.
[b]-Amount of heat (BTU's) required to melt a substance that has just reached its melting point.
[c]-Measures resistance to deformity, or stiffness, at one million pounds per sq. in. Higher numbers indicate greater resistance.

Source: "The Making, Shaping and Treating of Steel", U.S. Steel Corporation, 1972

Beryllium is offered on the market in three major forms: metallic beryllium, beryllium alloys, and beryllium oxide. A fourth, but very small market is composed of other beryllium compounds such as beryllium sulfates, nitrates, carbonates, and silicates. In 1992, metallic beryllium constituted about 15 percent of the dollar value of the world market, although in prior years when defense spending was higher, it was over 20 percent. Beryllium alloys, comprised predominantly of beryllium copper, were about 75 percent of the market, up from prior years. Beryllium oxide makes up most of the remaining 10 percent.

Metallic beryllium - The metallic form of beryllium exhibits a combination of unique physical and mechanical properties that make it the material of choice in a number of high technology applications. It is one of the lightest structural materials known, having a density two-thirds that of aluminum. Beryllium's specific stiffness is six times greater than steel (i.e., on a pound for pound basis). It also has the highest heat absorbing capacity of any metal, and on an equal weight basis, is the best heat conductor among structural metals. High thermal conductivity assures rapid temperature equalization, almost eliminating dimensional distortions over a wide range of temperatures, which makes machining of the metal to close tolerances (millionths of an inch) achievable on conventional machines.

Metallic beryllium is used primarily in aerospace and defense applications. The U.S. Government is the primary user, followed by several foreign governments. In fact, according to the OIRA survey data, over 90 percent of metallic beryllium shipments went to defense or related applications. Beryllium was a key structural and optical element in many of the tactical weapon systems demonstrated in Operation Desert Storm in 1991 (Patriot Missile, Cruise Missiles, M1A1 Abrams Tank, Apache Helicopter, etc.). Beryllium has been used in the structure and instrumentation of satellites, and the deep space probes such as *Galileo* and *Magellan*. Because of its light weight and dimensional stability, beryllium has also been used for window frames, umbilical door frames, and other structural parts on shuttle aircraft. Beryllium was used as the structure supporting the sensor system above the propeller on the U.S. Army's Scout helicopter. The metal's optical properties provide more accurate readings of greater amounts of data. Substrates formed from optical grades of metallic beryllium are used for mirrors and support benches in astronomical telescopes, and strategic and tactical military optical systems such as fire control systems; and in weather surveillance and geological survey satellites. Beryllium's high melting point allows it to be used in ceramic reactors.

Beryllium is also transparent to x-rays, dampens vibrations, and exhibits very good acoustical properties. The nuclear properties of beryllium make the substance an excellent reflector of

neutrons in nuclear reactors. Beryllium acts to scatter leaked neutrons back into the reactor core. Beryllium's high scattering cross section makes it effective in slowing neutron speed to a level required for efficient reactor operation. The metal is also being used in fusion reactor research as a neutron moderator and multiplier. Lastly, Beryllium is used to trigger nuclear bombs.

Beryllium alloys - Beryllium alloys of copper, nickel, and aluminum account for close to 100 percent of beryllium alloy usage, although many other metals are also alloyed with beryllium to make useful products. Beryllium alloys improve the quality, durability and performance of the products where they are used. Beryllium copper alone accounts for over 95 percent of the market. Beryllium copper alloys traditionally averaged about 2 percent (by weight) beryllium content while the rest is mostly copper. However, the faster growing alloys, such as Alloy 174 (0.3 percent beryllium content), have brought the overall average down to about 1.5 percent today. Small amounts of cobalt are added to the beryllium copper alloys to inhibit grain growth and provide uniform heat-treatment responses. Beryllium alloys are sold mostly into high-end commercial products (such as high speed computers), although numerous defense applications are very important.

A wide range of properties are obtainable by modifying the beryllium content of beryllium copper to custom fit specific applications. Beryllium makes copper six times stronger as well as heat treatable. The greater the amount of beryllium, the stronger the material, while less beryllium will increase the electrical and thermal conductivity attributes of the alloy. With 1.5 percent beryllium or more the melting point of copper is severely depressed and fluidity is greatly enhanced, allowing casting of fine detail. This characteristic is important for plastic injection molds. Beryllium copper is used in the computer, electronics, aerospace, automotive, factory automation, telecommunications, appliance, oil-field equipment, and instrumentation industries.

Electronic devices fashioned from beryllium copper include current-carrying springs which will not fatigue or lose their springiness, and connectors that will not expand or shrink with temperature changes. Additional devises include (telephone) diaphragms, electrical contacts, terminals, and fuse clips. Other products include spark-resistant tools used at oil refineries and chemical plants, electromagnetic shields, electrodes, clutch rings, brake drums, and switch gear. A more advanced use of beryllium alloys is in fusion research projects. Large beryllium-copper components are used in assemblies which produce the high magnetic fields required to initiate and control a high-temperature fusion reaction.

In recent years one of the fastest growing markets for beryllium alloys has been in oil and gas drilling equipment. The principal use for large-diameter beryllium copper tubing is in oil and gas drilling equipment. A new jet-assisted drilling system using beryllium copper tubing has been developed by Grace Drilling of Dallas, Texas, and FlowDril Corp. of Kent, Washington. The new drilling system has been successfully tested in several east Texas wells and is nearing commercialization. Jet-assisted drilling reduces wear on bits and is particularly suitable for use where the rock is hard or the formation angle is high.[38]

The use of horizontal drilling can increase the amount of reserves which can be practically exploited from new and existing fields. The high resistance to wear, immunity to chloride stress corrosion cracking, and magnetic transparency of beryllium-copper meet the demanding technical requirements of horizontal drilling, for parts such as bearings, propulsion system transmission shafts and non-magnetic drill collars. Beryllium-copper alloys are also used in more conventional drilling systems in components such as thread saver subs, stabilizers, seals, bearings and drill collars.[39]

Some beryllium alloys such as Alloy 174 have gained new uses in automotive electronics components, and new alloys are being introduced for use as molds for injection-molded plastics. In the plastics industry beryllium alloys are used in precision molds for fabricated plastic products, such as toys, cups, containers, cosmetic packaging and appliance housings. In consumer leisure markets beryllium alloys are used in high quality golf club heads, as well as in consumer electronics such as stereo systems, VCRs, portable telephones, miniature radios and video cameras.[40]

Although demand from the automotive industry has fallen in the recession at the start of the 1990s, the use of electronics in autos has grown rapidly in the last 15 years. Beryllium alloys are in the vanguard of this surge as auto companies seek to increase the performance standards of their vehicles. For example, beryllium-copper alloys such as Brush Wellman's Alloy 174 are replacing brass and phosphor bronze in automotive relays, connectors, surge protectors, leadframes, fuse terminals, switches and other devices which require

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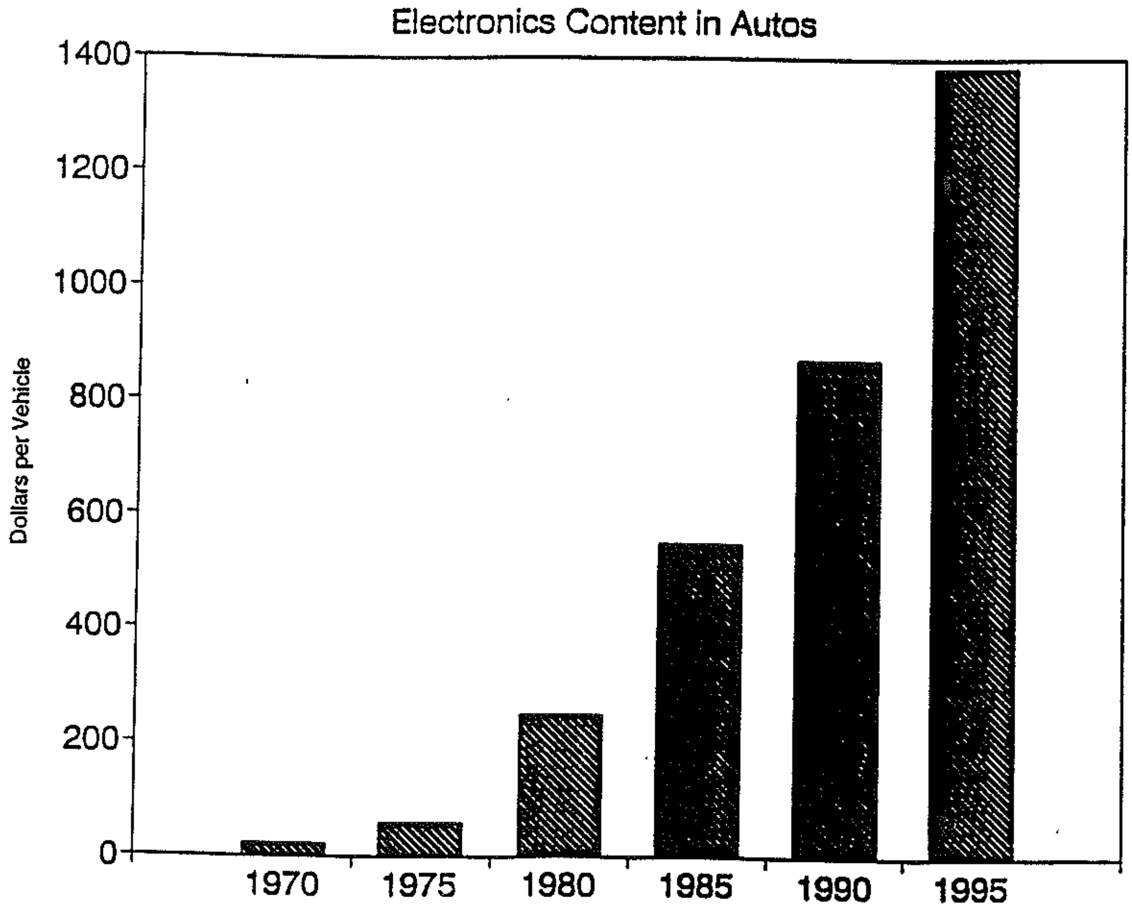
[38] "Mining Annual Review, 1992", The Mining Journal, Ltd., by Judith Chegwidden, Roskill Information Services, Ltd. (London)

[39] Ibid.

[40] Ibid.

miniaturization and reliability at higher operating temperatures.[41]

Beryllium aluminum is also attracting some interest. In 1990, Brush Wellman purchased Electrofusion Corp., based in California, and since has reorganized the operation into the Brush Wellman Advanced Development Center to find new uses for metallic beryllium and beryllium aluminum alloys. The Center has developed a number of aluminum beryllium alloys for space projects, including the NASA's National Aerospace Plane, which is under development. There have been a number of spin-off applications for this alloy in industry. In an alloy containing as little as 25 percent beryllium there is still a significant weight reduction and increase in stiffness. Electrofusion Corp. has made housings for high quality



Source: Ford Motor Company

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[41]Ibid.

speakers and envisages applications in the manufacture of wheels for cars, tennis racquets, wheelchairs, prosthetic devices and racing cars, where the light weight and stiffness of the alloy can be utilized.[42]

Beryllium is also alloyed with nickel for use in electrical springs, contacts and connectors which can be used in thermostats, bellows, diaphragms and burn-in connectors and sockets. Beryllium nickel commonly ranges from 2-3 percent beryllium content, conferring strength and hardness to the alloy. These alloys have found use in precision castings, aircraft engine fuel pumps, surgical instruments, matrices in diamond drill bits, and the inertial switch spring in auto air bags. Beryllium nickel has also shown utility in mold components and forming tools for glass pressware of both optical and container quality.

Beryllium oxide - Beryllium oxide, or beryllia, is the ceramic form of beryllium. By weight, it is about 40 percent beryllium. Beryllia is the only ceramic oxide that dissipates heat. It also is an excellent insulator. With these properties, it has played a major role in the on-going miniaturization of electronics. Beryllia has over six times the thermal conductivity of alumina ceramic substrates. In addition, the dielectric-constant of beryllia is one-third lower than alumina, reducing electrical impedance, and allowing integrated circuits to operate at much higher switching speeds. With circuit densities expected to quadruple by the end of the decade, and with added requirements for higher voltage and faster response speeds, the need for beryllia ceramic is expected to grow.

Beryllia is also used in automotive electronic ignition systems, and radar electronic countermeasure systems. Since it is transparent to microwaves, beryllium oxide is used as windows in microwave communications systems. Beryllium's thermal shock resistance allows its use in "fail-safe" applications such as ignitors in jet engines on major commercial airliners.

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[42]Ibid.

Beryllium Applications

Automotive
- o Electronic ignition modules
- o Electronically controlled auto transmissions
- o Airbag systems
- o Anti-skid brake systems
- o Active suspension systems
- o Automated welding systems
- o Plastic injection molds for the production of dashboards, steering wheels, headlights, etc.

Electronics/Computers
- o Switches, relays, connectors, springs, in electronic equipment
- o Computer storage devices
- o Medical laboratory equipment
- o Medical imaging systems
- o Electronic pacemakers for coronary implant
- o Lasers in medical instrumentation, printing, graphic arts, and entertainment systems
- o Compact discs, stereos, video camcorders
- o Lasers

Telecommunications
- o Cellular phones
- o Cable TV systems
- o Business data networks
- o Fiber optics
- o Satellites

Aerospace and Defense
- o Space probes and telescopes
- o Solar concentrates
- o Earth resource and weather satellites
- o Military and commercial aircraft
- o Mobile acquisition and tracking systems
- o Airborne and ground-based computers and microprocessing
- o Microwave
- o Landing systems - bushings and bearings in aircraft landing gear

Oil and Gas
- o Drill string tubing, especially in horizontal drilling
- o Propulsion system transmission shafts
- o Drill bit bearings
- o Beryllium windows for radioactivity information of geologic formations
- o Lithography tools
- o Thermal management in deep hole electronic packages

Consumer Products
- o Battery powered wrist watches
- o Pocket clips in mechanical pens/pencils
- o Eyeglass frames
- o Stoves, ovens, microwaves
- o Golf clubs

Source: CTC Metals Monthly Report, February, 1992

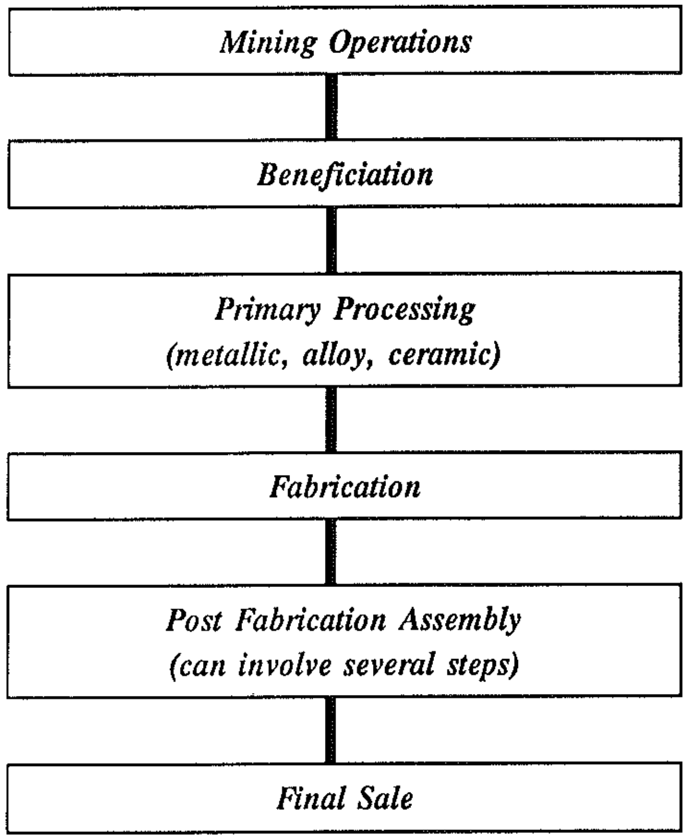
The major markets for beryllia ceramics are microwave tube parts such as cathode supports, envelopes, spacers, helix supports, collector isolators, heat sinks and windows. They are also used in solid state electronic devices such as ceramic substrates and electronic ignitions, and bores or plasma envelopes for ion lasers. Beryllia ceramic powders are used in applications where their high thermal conductivity can be utilized. Even at very high temperatures their thermal conductivity is four times that of dense alumina; between room temperature and 500°C, their thermal conductivity is seven to eight times greater. The ceramics are formed primarily by conventional dry pressing, tape casting and extrusion. Firing is accomplished in conventional tunnel or batch kilns with special environmental protection. Vacuum hot pressing is also used for specialized components.

Beryllium Production Cycle

The beryllium production cycle begins with the mining of beryllium ore (either bertrandite or beryl) and can require passing through as many as seven or eight production stages before reaching a final sale. However, the actual manufacturing of a part or component is usually completed after the fourth or fabrication stage. Rarely would scrap be generated after the fourth stage. The remainder of the cycle involves subassembly and assembly operations, until a final product, such as a computer, is made. The production of beryllium products is very capital intensive. High volume through-put is required for efficient production.

After the ore is mined, it is extracted or beneficiated in the second stage to *beryllium hydroxide* ($Be(OH)_2$), which has about 21 percent contained beryllium. Bertrandite contains only 0.25 percent beryllium, while beryl contains about 4 percent. In brief, the bertrandite and the beryl are treated along independent paths until the beryllium content of each is dissolved as a beryllium sulfate solution. These solutions are then combined and purified by solvent extraction and hydrolysis. This results in the formation of beryllium hydroxide, the basic material used in the production of metallic beryllium, beryllium oxide and alloys in the third stage. It is important to recognize that each of the three major beryllium products is made by an entirely different and specialized process with different cost structures. The major products are not interchangeable. Detailed flow charts and explanations of the principal production processes through the third stage are in Appendix B.

The Beryllium Production Cycle



Metallic beryllium is produced by dissolving the beryllium hydroxide in an ammonium bifluoride solution; this is evaporated to form a salt, which is decomposed at 700-900°C, producing molten anhydrous beryllium fluoride. The mixture is reacted with magnesium to produce metallic beryllium and magnesium fluoride. Cooling, crushing and water leaching this substance yields metallic beryllium and magnesium fluoride. The magnesium fluoride is separated out and discarded; the pebbles of metallic beryllium, along with recycled beryllium scrap, are vacuum melted and cast into ingots. Roughly 90 percent of the ingots are machined into chips and then ground into powders. The other 10 percent of the ingots may be shipped as such. The powders are cold or hot pressed into billets, rod, tube, sheet or

foil, and then frequently machined to meet the customers specifications. Most of the in-house scrap is generated by machining operations. About two-thirds of the metallic beryllium charged to the vacuum melt ultimately winds up as scrap, and is recycled.

Beryllium copper master alloy is produced by first combining beryllium hydroxide, electrolytic copper and carbon (petroleum coke) in an arc furnace. The melted mixture, which contains about 4 percent beryllium, is cast into ingots. These ingots are remelted with additional copper and other additives, producing the desired properties, and then cast into slabs or billets. Slabs are processed into beryllium copper strip, sheet or plate, and billets into tube, rod, bar, and wire products. About 25 percent winds up as scrap and is recycled.

Beryllium oxide is a natural constituent of beryllium containing ores, and retains its identity in beryllium hydroxide. To recover beryllium oxide, beryllium hydroxide is dissolved in sulfuric acid, forming a beryllium sulfate solution, or an intermediate purification step. This solution is filtered, concentrated by evaporation, and cooled. Beryllium sulfate crystals form during the cooling which are decomposed at temperatures as high as 2600°F to form beryllium oxide powder. Virtually no scrap is produced in the process.

Beryllium fabrication is the fourth stage in the production cycle. Fabrication usually results in finished parts or components that in turn are sold to a large variety of assembly operations (the fifth stage), such as circuit board assemblers, lasers, housings, and other subassemblers. In many cases, another two or three stages may be involved before a final sale is made. Metallic beryllium and ceramic fabricators tend to specialize in working with beryllium because of the uniqueness of their production operations, including environmental constraints. Beryllium alloy fabricators, on the other hand, tend to be more versatile, although for many firms, beryllium alloy fabrication constitutes an important, if not major, part of their business. The machinery required to fabricate beryllium alloys is similar to that used to fabricate other metals. Other metals fabricated by these firms often include brass, phosphor bronze, copper, nickel and other alloys. Firm size varies greatly among fabricators; some are small to large operations within huge companies, while others are independent job-shop facilities.

The processes used to fabricate metallic beryllium are similar to those used by fabricators of other metals, with a few modifications. Beryllium sheet and plate can be formed at temperatures ranging from 200-1400°F, using a variety of techniques. Beryllium can also be machined to intricate forms. Chemical milling, electrochemical machining and electric discharge machining are also used. Adhesive bonding and brazing are two methods used to

join beryllium to itself and other metals. For beryllium exposed to hostile environments, coatings have been developed; these can be applied by passivation, chromate conversion, anodization, and electroplating.

Industry Description

The production of beryllium in the Western world is dominated by a single firm, Brush Wellman Inc., headquartered in Cleveland, Ohio. Brush is integrated into the first four stages of the beryllium production cycle with mining operations of bertrandite in the Spor Mountain area of central Utah, and the ore's beneficiation into beryllium hydroxide at Delta, Utah, about 47 miles from the ore site. The Delta plant is the only such operation outside of the now independent Kazakhstan, formerly part of the Soviet Union, and a smaller operation in the Hunan Province of China at a village called Shinkoshan near Hengyang. A very small pilot plant has also been constructed in India.

Brush ships beryllium hydroxide from Utah to Elmore, Ohio, for processing into each of the three major beryllium products. Brush supplies beryllium oxide powder to its own plant in Tucson, Arizona where it is made into beryllia ceramic. A major customer of Brush-Tucson is Kyocera (Japan), for making high performance ceramic substrates for semiconductors. With the purchase of Electrofusion in 1990 (now the Brush Wellman Advanced Technology Center), Brush entered the metallic beryllium and beryllium aluminum alloy fabrication business, with an expanded focus on developing new applications. Brush also fabricates larger pieces of beryllium copper at its Elmore facility and ships beryllium copper strip to its fabrication house in Reading, Pennsylvania. In addition, Brush has European divisions in Theale, England and Stuttgart, Germany and an Asian division in Fukaya, Japan. While these locations can slit the product, they primarily stock and resell to fabricators in their respective markets.

Under a long-standing toll agreement, Brush beneficiates beryl imported mostly from Brazil for NGK Metals Company. In 1992, no beryl was imported as inventories of the material were at excessive levels. Until 1991, NGK processed the beryllium hydroxide it received from Brush into beryllium copper alloys. However, because of poor market conditions and loss of sales to phosphor bronze (at the lower end of the market) NGK Metals now processes the beryllium hydroxide at its Muhlenberg, Pennsylvania plant (near Reading) into beryllium oxide, most of which is shipped to NGK Insulators in Chita, Japan. A small amount is also shipped to Athens, Tennessee where the firm processes beryllium nickel in a small foundry,

and fabricates safety tools, underwater cable parts, and a few other items.

NGK (Japan) processes beryllium oxide into beryllium copper and returns some to NGK in Muhlenberg, where beryllium copper mill products are fabricated to serve the U.S. market. NGK (Japan) also supplies the NGK Berylco companies in France, the U.K., and Germany with beryllium alloys for both reroll and resale to other fabricators.

About 30 firms worldwide are believed to fabricate metallic beryllium. The two largest, Loral American Beryllium Corporation in Tallevast, Florida and Speedring Company in Cullman, Alabama, a subsidiary of Precision Aerotech, Inc., account for a significant share of the business. EG&G fabricates metallic beryllium at the Rocky Flats, Colorado nuclear facilities for the Department of Energy. The dominant fabricators of beryllium oxide powder, other than Brush Wellman (in Tucson, Arizona) are the British firm, Consolidated Beryllium, Ltd. in Wales (U.K.), National Beryllia Division of General Ceramics, Inc. in Haskell, New Jersey, wholly owned (since 1989) by Tokuyama Soda Company, Ltd. (Japan), and Ceradyne, Inc. of Costa Mesa, California. Beryllium alloy fabricators are believed to number about 200-225 firms worldwide. Including domestic and foreign fabricators, distributors, and Brush or NGK subsidiaries, the top 10 of these firms are believed to account for about 15 percent of the business, and the top 20 for over 20 percent.

From time to time firms competing against Brush Wellman in one or more stages of the production cycle have attempted to establish alternative supply channels. Most have been unsuccessful. For example, in 1986, Cyprus Minerals Company and Cabot formed a joint venture to develop Cabot's beryllium deposit, Sierra Blanca, near El Paso, Texas. Cyprus was to operate Sierra Blanca and would have the option to purchase it. Drilling of a test mine began in early 1987; the test mine and feasibility studies were completed by 1988. However, the companies eventually abandoned the project, apparently for economic reasons.

A similar arrangement was made in 1986, between Emery Energy Inc. and Cominco American Inc. to mine and mill bertrandite on Emery's property in Juab County, Utah. Cominco would operate the mine and hold a 51% stake in the venture. Emery later changed its name to Beryllium International Corporation. In 1987, Cominco announced plans to spend up to $600,000 over the next two years for a feasibility study of the property. However, in mid-1990, Cominco sold its share to Inspiration Gold. Inspiration Gold and Beryllium International Corporation originally planned to begin plant construction in 1991, but this project was recently abandoned as well.

In 1987, Cyprus Minerals Company and Cabot teamed up once again to form a new company, called Advanced Metallurgy and Testing Corporation (AMT). The company, which was to produce metallic beryllium for a certain market niche, would lease facilities from NGK Metals.[43] AMT began producing hot-pressed blocks, which were in demand for the National Defense Stockpile (NDS) at the time. However, in 1987 they lost a solicitation for an NDS purchase to Brush Wellman and terminated the operation.[44]

In 1990, Alloy Research, Inc. in New Madrid, Missouri began importing small quantities of beryllium copper master alloy from China under an agreement with Olin Corporation in East Alton, Illinois. Alloy Research processes the master alloy into various shapes and grades of beryllium copper for shipment to Olin for fabrication. The list price for the master alloy has been $160 per pound contained beryllium since 1987, although hefty discounts have prevailed for some time. Imports from China (6,497 pounds in 1990, 6,534 in 1991, and 6,268 pounds in 1992 of contained beryllium) have a Customs value (i.e., foreign port value) of only $94.66 in 1990, $90.29 in 1991, and $103.55 in 1992. Several unanswered questions arise: 1) the reliability and capacity of the China operation to maintain and/or increase the supply; 2) the environmental costs incorporated into the Chinese price,[45] and 3) the presumed inelasticity of demand for these components, which (if true) could be harmful to Brush Wellman by a one-to-one loss of market share.

Given the presence of companies with expertise in the various stages of the beryllium production cycle, it may seem surprising that no other integrated producer has been formed, through a joint venture or acquisition. Through the years, Brush Wellman has been operating profitably, unchallenged, as the Western world's only fully-integrated producer. Experts offer two explanations. First, the demand for beryllium is not great enough to warrant the entry of another fully-integrated manufacturer; Brush Wellman's ore reserves are sufficient to meet demand. Second, the investment required for necessary environmental controls is substantial, and has pushed the "minimum efficient producible quantity" upward,

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[43]Bill Schmitt. "New Cabot Arm Formed to Make Beryllium Metal." American Metal Market. April 13, 1987.

[44]Bill Schmitt. "Brush Wellman Wins $19M Beryllium Bid." American Metal Market. July 8, 1988.

[45]In theory environmental costs are either paid at the source or by society at large, in terms of illness, lost work-days, poisoned food, etc. The cheapest method (for society at large) is actually to capture this cost at its source.

creating a demand constraint because of high prices, while limiting economic production quantities to only one producer.[46]

[46]David Prizinsky. "Brush Wellman May Wind Up Sharing Pact." Crains Cleveland Business. January 25, 1988.

NATIONAL SECURITY CONCERNS

Military and Commercial Importance

From a national security perspective, beryllium is a strategic material used in the most sophisticated U.S. weapon systems. Beryllium is used by the military to control reactors on nuclear powered submarines and surface vessels, as a triggering device for nuclear warheads, in precision optical components, inertial guidance systems, and satellite structures, and in air, land and seaborne electronic equipment. The material's light weight, dimensional stability, fatigue resistance, and thermal and nuclear properties make beryllium crucial to the accuracy of guided missiles, the safe flying of aircraft, the reliability of electronic equipment in hostile environments, and the long range surveillance of enemy forces.

Beryllium has no realistic substitutes in some of its nuclear applications. Validated export licenses have been required to export the metal since shortly after World War II as part of multi-lateral non-proliferation efforts concerning nuclear weapons. In other applications, because of its high cost, beryllium is used where its properties are crucial. Substitution usually results in significant performance penalties. Steel, titanium, or graphite composites can substitute for metallic beryllium in some structural applications, and phosphor bronze for beryllium copper in lower-end electronic applications. Aluminum nitride, a product offered by NGK Insulators, Ltd. (Japan) and many other sources can be used in place of beryllium oxide, but with substantial loss of performance. Some uses of beryllium are being displaced. For example, the use of beryllium in military aircraft brakes has declined as the material is replaced by carbon-fiber reinforced graphite brakes.

In dollar terms, between 20-25 percent of beryllium consumption is used for military applications, down from about 35 percent in the mid-1980s. Defense buys over 90 percent of the metallic beryllium, about 10 percent of the beryllium alloys, and 20-30 percent of the beryllium oxide. Since Fiscal Year (FY) 1985, the <u>total</u> military procurement budget (in constant 1993 dollars) fell from $127.2 billion, to only $54.1 billion in FY1993, a dramatic drop exceeding 57 percent. The defense declines had a major adverse impact on the beryllium sector.

It is quite possible with budget reduction pressures that deeper cuts in the defense budget could be made in the future. Greater emphasis is likely to be placed on advanced systems, which can be deployed with great speed and precision anywhere in the world. Tactical

optical systems, space-based surveillance systems, night vision systems, and smart target acquisition and fire control systems all involve applications for beryllium.[47] However, Brush reports that demand for metallic beryllium for defense applications will continue to decrease. The concern now is that demand for metallic beryllium will decline to the point where through-put will not economically justify production. Brush reports operating its metallic beryllium production operation at below 40 percent, which because of higher unit costs has forced prices upward.

Aside from military procurement, beryllium is also important to the civilian economy in numerous high technology applications. Beryllium products are used in telecommunications satellites, high-speed computers, undersea cable repeater boxes, high-speed printing lasers, medical lasers and x-ray machines, and factory floor microprocessors. Beryllium oxide ceramic is used for the high-end ceramic packaging and substrate material - extremely important to densely packed semiconductor circuits. It is also used in electronic ignitions. Beryllium copper is used in numerous electronic components because of its long life and thermal stability.

The long-term health of the beryllium sector is uncertain. Several major issues continue to threaten the industry, which may not be resolved in a way satisfactory to all concerned. The major concerns facing the beryllium sector, in order of their severity, are as follows:

o rising environmental control costs;

o declining defense procurement expenditures (particularly affects metallic beryllium);

o potential surge of beryllium on the world market at low prices by the former Soviet Union; and,

o the possible sale of metallic beryllium and beryllium copper master alloy inventories from the National Defense Stockpile.

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[47]Brush Wellman has invested nearly $10 million to implement near-net-shape production capability for these types of applications. See Brush Wellman Annual Report, 1991, page 5

National Defense Stockpile

During World War II, America was almost totally dependent on foreign sources for beryl. Recognized as a strategic commodity, the National Defense Stockpile (NDS) has contained beryl ore since 1947. Beryllium copper master alloy and metallic beryllium ingots were added to the stockpile in 1965.[48] In 1969, circumstances changed as Brush Wellman began mining bertrandite in Utah. The development of the bertrandite all but eliminated import dependence, and provided Brush Wellman a steady and dependable supply of beryllium ore. Under these changed circumstances, the Government stopped purchasing beryl for the stockpile in 1974. In July 1985, the President approved National Security Council (NSC) recommendations for modernizing the strategic and critical materials stockpile. Under the NSC proposal, the stockpile would be structured into two tiers. Tier I would contain materials required by military, industrial, and essential civilian users during a military conflict that would not be available from domestic, or reliable foreign sources. Tier II would contain a supplemental reserve of material already possessed by the Government. Under this recommendation beryllium would be placed in tier II. However, the 1985 and 1986 Defense Authorization Acts rejected the two-tier approach and essentially froze all stockpile inventories in place by stating, "...no action may be taken before October 1, 1987, to implement or administer any reduction in a stockpile goal in effect on October 1, 1984."

However, it was recognized by Defense officials that the input/output model used to determine stockpile material requirements, while acceptable for generic materials, was a poor indicator of requirements for a highly specialized product such as beryllium. In fact, nuclear weapons were not factored into the general war scenario. Thus, beryllium and beryllium copper master requirements are determined separately, and are no longer included in the war scenario model to determine stockpile requirements.

In its *1992 Report to the Congress on National Defense Stockpile Requirements*, the Department of Defense announced its intention to sell large portions of the NDS, valued at over $5 billion, in light of revised global threat assessments. Included in the sale, DOD proposed disposing of its entire inventory of beryl ore (653 metric tons, beryllium content) and beryllium copper master alloy (268 metric tons, beryllium content), with a combined value of about $128 million. The goal for metallic beryllium remained the same, at 363

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[48]Audrey A. Soja and Andrew E. Sabin. "Beryllium Availability-Market Economy Countries: A Minerals Availability Appraisal." Bureau of Mines Information Circular. Washington, D.C.: U.S. Department of the Interior, Bureau of Mines, 1986.

metric tons. The sales of beryl ore and beryllium copper master alloy would be undertaken gradually to avoid market disruption, and Defense would proceed with the advice of the Market Impact Committee.[49]

Concerns about the sale of beryllium copper master alloy were expressed by the Market Impact Committee because of potentially disruptive effects the sale could have on Brush Wellman, the only producer of the material in the Western world. As a result, beryllium copper master alloy was withdrawn from consideration with the signing of the *National Defense Authorization Act for Fiscal Year 1993* on October 23, 1992. However, authorization was given to dispose of the entire inventory of beryl ore. The authorization called for disposal within a five year period ending October 1, 1997, unless the Market Impact Committee finds such disposal disruptive to markets.

Year-End National Defense Stockpile Status (short tons, beryllium content)						
	Beryl Ore		Beryllium Copper Master Alloy		Metallic beryllium	
	Inventory	Goal	Inventory	Goal	Inventory	Goal
1987	653	653	268	287	263	363
1988	653	653	268	287	263	363
1989	653	653	268	287	269	363
1990	653	653	268	287	290	363
1991	653	653	268	287	290	363
1992	653	0	268	287	337	363

Source: U.S. Dept. of Interior, Bureau of Mines' Mineral Yearbooks (1987-1991); Mineral Commodity Summaries (1992)

[49]The Market Impact Committee was established under section 10(c) of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98h-1). The Committee is an interagency group, co-chaired by representatives from the Departments of Commerce and State, that advises the manager of the National Defense Stockpile on the projected domestic and foreign economic effects of acquisitions and disposals of materials from the stockpile.

Year-end inventories and goals from 1987-1992, for beryllium related products are presented on the following table. The only change in stockpile goals to occur since 1980 was the zeroing out of beryl ore in October 1992. Inventories for metallic beryllium increased from their 1980 level of 208 metric tons to 263 metric tons with additions in 1984 and 1985.

The locations and inventories of the current beryllium stockpile are shown on the following table.

Location and Current Holdings of Beryllium Stockpile	
Location	Metric Tons
Metallic beryllium	**315***
Summerville, New Jersey	103
New Haven, Indiana	70
Warren, Ohio	63
Hammond, Indiana	54
Clearfield, Utah	25
Beryllium Copper Master Alloy	268
Warren, Ohio	142
Summerville, New Jersey	126
Beryl Ore	563*
Curtis Bay, Maryland	287
Marietta, Pennsylvania	221
New Haven, Indiana	55

* These totals do not include quantities beryl being upgraded to metallic beryllium billets by Brush Wellman, to which DoD retains title. They therefore do not match the levels shown on the previous table.

Source: Dept. of Defense, Defense Logistics Agency

In June 1988, Brush Wellman was awarded a contract to supply 27 metric tons of structural grade vacuum hot-pressed beryllium billets for the NDS. The billets were purchased and delivered during 1989 and 1990. In 1990, Brush Wellman received a $25.6 million contract

to upgrade a portion of the beryl ore in the National Defense Stockpile. Under the contract, the company agreed to convert some of the beryl into 41 metric tons (equal to about $281 per pound) of vacuum hot-pressed beryllium billets. In 1991, the contract was extended to provide for an additional 20 metric tons of beryllium for about $13 million (about $302 per pound) to be delivered in 1993, bringing the total to over 61 metric tons for the three-year period.[50]

The Beryllium Industry In The Former Soviet Union

Until recently very little information about the beryllium industry in the former Soviet Union was available. This changed in September 1990, after an accident occurred at the Ulbinskiy Metallurgical Plant (the Ulba complex) in Ust' Kamenogorsk, Kazakhstan, that produced beryllium, rare earth metals, and nuclear fuels. A fire occurred in the beryllium processing area of the plant, releasing low levels of beryllium and beryllium compounds into the atmosphere. The detrimental effects on people's health and the environment in the surrounding area were widely reported in the Soviet press, and being compared to the Chernobyl accident.[51] However, a survey conducted by the International Atomic Energy Authority found no detrimental effects on the population, despite the claims in the Soviet media.

After the United States, the former Soviet Union was the second largest beryllium producer in the world. In 1990, it was estimated that the U.S.S.R. produced 76 metric tons of contained beryllium, or roughly 20 percent of total world mine production for that year. This is probably much less than in former years under the Soviet Union. A large portion, perhaps 80 percent, of the production was metallic beryllium. Production fell almost 19 percent in 1991, to less than 62 metric tons, and is estimated to have fallen to only 50 metric tons in 1992. The largest demand sector was for military applications. Estimates place about 70 to 75 percent of beryllium shipments to the military sector.

Reserves of beryllium in the former U.S.S.R. are estimated to be slightly over 60,000 metric tons (2,400 m. tons contained beryllium), or 16 percent of the world's total. Major

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[50]Deborah A. Kramer. "Annual Report: Beryllium." Washington, D.C.: U.S. Department of the Interior, Bureau of Mines, 1990 and 1991.

[51]U.S. Dept. of Interior, Bureau of Mines, "The Mineral Industry of U.S.S.R.", 1990

beryllium deposits are found in various parts of the Russian republic. Deposits are located in the Altay region of West Siberia, Kola Peninsula, Russian Far East, Transbaykal, and the Urals.

At the invitation of the Ulba complex, an American delegation that included four representatives from Brush Wellman, and one from the U.S. Department of Commerce, visited the complex in August 1992. The delegation reported that the plant supports a community of about 15,000 people. Perhaps a third (or more) of the people actually work at the plant, while the others provide support services (shopkeepers, farmers, transportation, etc.) to the complex and the surrounding area. The plant essentially manages everything on behalf of the entire community, including living quarters, utilities, and food. The people pay the equivalent of about $1 per month for living quarters, with utilities included.[52] This fits the general model of communal organization typical in the former Soviet society.

The delegation found that environmental control measures in the beryllium section of the plant were below Western standards, although an appreciation of the problems was apparent. For example, the people wore masks instead of being equipped with respirators. Much of the equipment was old and antiquated. The machining area was equipped with a large (perhaps 9,000 ton) forging press; much larger than anything in the West. No cost accounting measures were evident. In fact, cost seemed an alien concept. The research and technical capabilities at the plant were reported to be excellent, and at least equal to Western counterparts. The production is high quality.[53]

With the breakup of the Soviet Union and the emergence of the Commonwealth of Independent States (C.I.S.), each country has its own unique laws and policies concerning mineral production and trade. The evolution of laws and government structures concerning ownership, foreign investment, and export licensing will assist in the difficult transition from

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[52]The Ulba management tried in vain to give the apartment units away. The people refused, realizing their out-of-pocket costs would increase by having to assume utility and maintenance expenses.

[53]Little is known about beryllium end-users in the former Soviet Union, although most are in Russia. Beryllium fabricators are found in various Russian defense sites. In sharp contrast to the Ulba operation, the fabricators house state-of-the-art Japanese and European precision equipment and technology. The Kharkov Physical Technical Institute located in Ukraine, houses a beryllium foil production center.

a centrally planned economy to a market one. However, it is unclear at this time what mineral resource policies will emerge in these new countries, and to what extent they will retain former trade patterns.

In the meantime, the on-going economic disintegration leaves many industries, including beryllium, facing a bleak future. The interdependent system of trade between republics developed under the Soviet system has broken down and inflation continues to run rampant. The beryllium industry, like many others, is currently confronted with an urgent need for hard currency, and greatly reduced demand for beryllium products in the domestic defense market. These developments have increased the likelihood that beryllium products will be offered on the world market, probably at greatly reduced prices. However, such a policy would not provide an adequate return and almost certainly impoverish the 15,000 people in the Ulba complex area in the longer-term.

Currently, the beryllium producing facilities (including mining) are under-utilized. The managements of these facilities are confronted with the problems of maintaining employment levels and avoiding plant closures. Many plant managers are willing to produce almost anything in order to maintain facility operations. To their disadvantage, the managements of beryllium-producing facilities lack a real understanding of the concept of defense industry conversion, and the urgent need for them to convert their facilities to a quality required to compete in the world market. This requires the modernization of facilities and a major reduction in the size of the workforce, virtually a whole new mind-set. Moreover, the civilian market for beryllium in the former Soviet Union is not large enough by itself to support a world class production operation.

However, the potential for a surge in supply of beryllium on the world market has increased. This scenario could quite possibly become reality, as in the case of uranium, aluminum and copper. Russians desperate for foreign currency sold these materials in Western markets. This led to a rapid decline in prices of these commodities and pushed a number of European and American producers toward bankruptcy. In addition to the potential impact on the U.S. beryllium industry, a related concern is that nuclear grade beryllium could fall into the wrong hands.

The implications for the U.S. beryllium industry, and the domestic metallic beryllium industry in particular, could be far-reaching. According to industry analysts, Russia possesses a 30-year supply of mined beryllium ore (this was not actually seen by the delegation), the majority of it having been mined for ultimate use in the former Soviet

Union's defense sector. Before the dissolution of the Soviet Union, this ore would be shipped to Kazakhstan for processing into metallic beryllium. Now, such a shipment may not yield an adequate return, or no payment will be received at all. There remain many unanswered questions.

As for the United States, there is an admission and time-lag charge into the defense business in terms of qualification standards and certifications. Brush Wellman has already gained admission, but the qualification processes would delay imports of metallic beryllium imports from the Ulba complex. Also, the United States has many years experience in the production and, more importantly, the application of beryllium oxides and beryllium alloys, that is lacking in the former Soviet Union. The threat to these sectors is not immediate, but in the long-term (perhaps by decade's end) could be very severe. By then the entire situation may have changed.

A Kazakhstani group visiting the U.S. Commerce Department mentioned the possibility of using beryllium to make bicycles, because of the metal's light weight, rigidity, and strength. At $200-300 per pound (in U.S.), such a use seems impractical. However, the American Bicycle Manufacturing Company advertized the first beryllium bicycle for $25,000 in the February-March, 1993 issue of "Men's Health" magazine. The bike contains only 2 pounds of beryllium. (A half-inch diameter bar of beryllium weighing two pounds would be about 12-feet long.) This is potentially a new market, which would not take market share from existing producers. The lower prices the Kazakhs are willing to accept may make this feasible.

Health and Environmental Issues

While there are important uses for beryllium, there is also a need for a safe and clean environment. Environmental costs continue to rise faster than revenues, and at the margin continue to constrain the market potential for beryllium, at both the manufacturing point and among potential customers. Health problems connected to beryllium became apparent during the 1930s. Beryllium disease was first described in reports from Germany, Italy and the Soviet Union. Workers employed in the extraction plants where beryllium is separated from its ore were becoming acutely ill, and a small portion were dying. Many inhaled the corrosive salts, such as the fluoride. The symptoms of this type of poisoning were chills, fever, coughing, and fluid in the lungs, similar to poisoning by irritating gases such as chlorine.

The disease was recognized in the United States in the mid-1940s. There were isolated epidemics of the disease in extraction plants, alloy production, and the fluorescent lamp and neon sign industries. However, these ceased once the problem was recognized and controls instituted. New cases continue to appear in other industries as new ways of using beryllium are found by industry or the government concerned with military projects and space exploration. Accidental overexposures will probably continue to occur occasionally, but all other forms of exposure are clearly preventable.

The chief health concern associated with the handling of beryllium is chronic beryllium disease, also known as berylliosis. Berylliosis is a disabling lung disease caused by inhaling beryllium dust; handling finished beryllium products does not lead to berylliosis. Not all people exposed to beryllium dust will get this disease; it has been shown that chronic berylliosis has an immunological basis. It results from overproduction of white blood cells caused by the body's reaction to a toxic substance.[54] So, if an individual does not display an immunological responsiveness, then he or she will not get the disease. While it is treatable, it is fatal in about 30 percent of cases.[55] The effects range from diminished lung capacity during exercise, to difficulty breathing while at rest, and, finally, to heart failure and death.

Berylliosis is a difficult disease to study; for several reasons. Only a few percent of those exposed actually develop the disease. The symptoms may develop many years after the last known exposure. Also, there is no known relation between the extent of exposure and the severity of the disease.[56]

Concerns regarding the health dangers of exposure to beryllium dust and fumes have led to the imposition of a variety of exposure standards for the workplace as well as the water and air in the surrounding environment. Occupational Safety and Health Administration (OSHA) standards currently limit the 8-hour exposure level to an average of 2 micrograms per cubic meter, with a peak of 25 micrograms per cubic meter not to exceed 30 minutes, and a ceiling

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[54]Ibid.

[55]Keith Schneider. "U.S. Will Examine a Metal's Effects." The New York Times. January 17, 1990.

[56] Wallace E. Griffitts and David N. Skilleter, Chapter on Beryllium in Metals and Compounds in the Environment, ed. by Ernest Merian.

concentration of 5 micrograms per cubic meter.[57]

In addition, the Environmental Protection Agency (EPA) included a standard for beryllium in its Clean Air Act. Beryllium emissions for plants processing beryllium are limited to 10 grams of beryllium over a 24-hour period. In the Clean Water Act, the EPA set a concentration level of 130 micrograms of beryllium per liter to protect aquatic life from acute health effects, and a level of 5.3 micrograms to protect these organisms from chronic health effects. Also included was a level of 3.7 nanograms per liter to protect human health during the ingestion of fish.[58] In December 1992, this was revised to remove the numeric values and bio-concentration effects of beryllium.

Because of concerns over the health dangers associated with exposure to beryllium, some occupational health experts and union leaders have sought tighter exposure limits. There is some clinical support for their efforts. Workers from a precious metals refinery were examined at the Yale Occupational Medicine Clinic. Berylliosis was discovered in five employees; four had worked in the plant's furnace area where the amount of beryllium in the air fell below established OSHA limits, and the fifth worked in an area where higher levels of beryllium were present. As part of a plant safety program, the workers had been required to wear respirators to filter out airborne particles since 1981. However, in all but one case, symptoms of berylliosis had appeared before 1981. At the end of the study, the researchers estimated that between 2.9 and 3.6 percent of the plant's workers likely had berylliosis.[59]

Currently, doctors at the National Jewish Center for Immunology and Respiratory Medicine and the University of Colorado Medical School are studying the impact of exposure to beryllium on about 750 employees at the Department of Energy's Rocky Flats nuclear weapons plant, where the metal is used in the manufacture of plutonium triggers. The study, begun in 1987, is expected to be completed in 1993 and is being funded by the Energy Department and the National Institutes of Health. As of January 1990, the study had tested almost 400 of the employees and discovered 8 current and 4 retired Rocky Flats employees who tested positive for berylliosis. The researchers hope to develop tests that will indicate

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[57]Minerals Yearbook: Beryllium. 1991.

[58]Ibid.

[59]Rebecca Kolberg. "Workplace Hazard: Experts Warn of Beryllium Exposure." United Press International. January 24, 1989.

whether or not a worker is susceptible to the disease.[60]

According to sources in the press, private industry and government agencies have resisted stiffening the exposure limits, and OSHA has left them at 2 milligrams of beryllium per cubic meter of air - twice as high as what some health activists want.[61] In 1977, when OSHA proposed reducing the average daily and maximum concentration levels, the industry objected, stating that the new standard was based on highly dubious animal data and it would be technologically impossible to meet. The Departments of Defense and Energy also objected, fearing that firms would abandon beryllium production rather than try to meet the standards. In addition, Supreme Court decisions reached in the early 1980s on two other chemical standards cast doubt on the viability of the proposed beryllium standard, which was, according to private industry, DOD and DOE, both economically and technologically infeasible.[62]

In spite of the potential dangers associated with dealing with beryllium, great progress has been made in reducing the occurrence of berylliosis since the disease was first recognized. Compliance with OSHA and EPA regulations is a costly endeavor. There are physical plant costs, including in-plant ventilation systems which collect airborne beryllium particles at the point of generation, cleaning and filtering the air before releasing it to the outside. Also, air sampling equipment is used to check the concentration of airborne beryllium both inside and outside the plant. Additionally, there are costs associated with training employees in the proper operation of equipment and safe handling of hazardous materials. Waste water from manufacturing operations must be treated before release. In-plant laundry facilities are used so that employees do not carry beryllium particles out of the plant on their clothing. There are also medical surveillance costs.

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[60]"12 Rocky Flats Workers Exposed to Beryllium Have Lung Disease." The Associated Press. January 13, 1990.

[61]"Workplace Hazard: Experts Warn of Beryllium Exposure."

[62]B. Powers. "History of Beryllium," in Beryllium: Biomedical and Environmental Aspects, ed. by Milton D. Rossman, Otto P. Preuss, and Martin B. Powers. Baltimore, MD. 1991.

The following is a list of equipment and processes the beryllium manufacturers reported necessary to comply with OSHA and environmental standards:

- Collector Systems
- Make-Up Air Units
- Waste Water Treatment Facilities
- Landfills
- Laundries/Controlled Locker Rooms
- Air Sampling-In and Outside Plants
- Assorted Engineering Controls
- Medical Surveillance Programs
- Tailing Ponds
- Ventilation Systems
- Dust Collectors
- Venturi Scrubbers

Surveyed fabricators reported the use of air ducting, filtration and neutralization systems, special hoods and modification of standard equipment for use with beryllium oxide. One firm reported housing all equipment in negative pressure glove boxes within a negative pressure room. Also mentioned were air and water pollutant control equipment. Environmental controls have encouraged the development of better processing methods to improve yields, and lower the amount of contaminants generated per unit output.

1992, to 190 metric tons. The five-year average demand, 1988-1992, was more than 28 percent lower than the preceding five-year period, 1983-1987. Contributing to these trends were declines in defense/aerospace, electrical equipment, nuclear applications, and slumping sales in electronics markets, particularly mainframe computers.

Beryllium Supply Patterns, 1981-1991
(metric tons of contained beryllium)

Year	Production U.S.	Production Other	Production World	U.S. Imports Ore	U.S. Imports Other	U.S. Stocks Jan 1	U.S. Stocks Dec 31	Stockpile Purchases	U.S. Exports	Total U.S. Demand
1981	266	119	385	78	1	49	81	-	35	278
1982	197	121	318	96	8	81	185	-	61	136
1983	242	119	361	80	8	185	255	-	17	243
1984	219	141	360	48	32	255	205	28	18	303
1985	209	117	326	60	51	205	181	27	54	263
1986	237	119	356	54	19	181	177	-	36	278
1987	220	125	345	83	50	177	164	-	77	289
1988	212	120	332	35	12	164	158	-	37	228
1989	184	117	301	24	14	158	153	6	34	187
1990	182	103	285	14	11	153	119	21	45	175
1991	174	[e]90	264	12	*43	119	112	-	33	*203

[e]Estimated

*The 43 metric tons reportedly imported in 1991 included a large shipment of "metallic beryllium waste and scrap". The bulk of the shipment was oil and other sludge collected with the metallic beryllium. The actual import number was probably closer to 10 than to 43. The total demand figure, shown as 203 on the table, would than be 170, which is more realistic considering economic conditions then prevailing.

Note: World production figures are most likely understated. For example, China is not included in the above data, although recent estimates report production in China of more than 50 metric tons.

Source: U.S. Dept. of Interior, Bureau of Mines, Annual Report - Beryllium, 1991

Production of Beryllium Ore

As previously reported, two minerals are exploited commercially for their beryllium content: bertrandite, which is mined in Utah, and beryl, which is mined primarily in the rest of the world. Small quantities of beryl are also mined in the United States in several locations mostly as a by-product of pegmatite mining operations. Similarly, much of the beryl produced in the Western world is secondary to other mining operations, and often hand-sorted or hand-cobbed. Primary extraction occurs in some places. China, Brazil, and the former Soviet Union reportedly produce some beryl for its own sake. However, as a secondary product, and the relatively small quantities in demand, production of beryl tends to be volatile, and may not respond to direct market forces in the same way as other commodities.[64] Aside from these two minerals, over 90 other minerals are known to contain beryllium, but in concentrations too small or areas too isolated to justify commercial production.

The production of bertrandite is different. Brush Wellman's market dominance and size was a key factor that allowed the firm to vertically integrate into the mining of bertrandite and absorb the entire production internally. The quantities involved also justified the use of modern mechanized methods to mine the ore, as well as the construction of modern facilities in nearby Delta, Utah to beneficiate the ore. It is interesting to note that global consumption of beryllium would barely support two such operations.

Bertrandite contains about 5 pounds of metallic beryllium to the short ton, in contrast to beryl, which averages about 80 pounds to the short ton. However, the economics of beneficiating beryl in Brazil, or other countries where it is produced, apparently do not match those of the larger volume facility in Utah. Thus, the beryl, which contains 1,920 pounds of waste per each ton in addition to the 80 pounds of metallic beryllium, is more cheaply transported the great distances to Delta, Utah for upgrading. After the bertrandite is beneficiated to beryllium hydroxide, the beryllium content rises to about 420 pounds per

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[64]Beryl production methods in Zimbabwe provide an example of how it is done in much of the world. In Zimbabwe beryl is hand sorted by unskilled laborers. The decision about whether to work in the beryl mines is mainly economic. If, for example, they can make more money picking tobacco or cotton, they will do that instead. So, the supply of labor is not consistent. Also, on occasion the owner of the mine, for whatever reason, may decide to close it temporarily. In these circumstances, the production of beryl tends to be volatile and not always in response to market demands.

short ton.

World production of bertrandite and beryl in 1991 totaled 6,607 metric tons (264 metric tons contained beryllium). This is down almost 26 percent from 1986, when world production was 8,891 metric tons (356 metric tons contained beryllium). The trend in world production has been down every year since 1983, as demand declined,[65] especially in the United States and the former Soviet Union.

Six countries account for almost all of the beryllium ore production. These six are shown on the table that follows. Other countries reported production from time to time. These include South Africa, Mozambique, Madagascar and Rwanda in Africa, and Portugal in Europe. In addition, Bolivia and Namibia may also produce beryl, but available information does not allow reliable estimates. Nepal produces small amounts.

Beryl: Top Six Producers, by Country, and World Total (gross metric tons)

Country	1986	1987	1988	1989	1990	1991
U.S.[1] (mine shipments)	5,927	5,499	5,313	4,592	4,548	4,339
China[e,2]	na	na	na	na	1,375	1,375
U.S.S.R.[e]	1,900	2,000	2,000	2,000	1,600	1,300
Brazil	908	1,000	913	800	[e]850	850
Argentina	50	46	39	89	[e]85	80
Zimbabwe (concentrate, gross weight)	103	83	33	46	28	30
World Total	8,891	8,632	8,302	7,532	7,138	6,607

[e] Estimated
[1] Includes bertrandite ore, calculated as equivalent to beryl containing 11% beryllium oxide, which would in fact be 16 times the tonnage shown on the table.
[2] Not included in totals
Source: U.S. Dept. of Interior, Bureau of Mines

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[65]Several factors impact beryllium ore demand: 1) decrease in the market, 2) decrease in the average beryllium content of alloys, and 3) improved productivity/process efficiencies and improved yields.

Trends in Beryllium Prices

The Bureau of Mines lists annual prices of selected beryllium products in its annual Yearbook taken from the Metal Statistics publication of American Metal Market, and cleared through Brush Wellman before publication. The prices are "listed" prices, which may be different, and in some cases very different, from actual transaction prices. Transaction prices may include shipping costs, quantity discounts, term discounts, cash discounts, old customer discounts, insurance costs, and returned merchandise allowances, and may reflect market conditions. List prices report on a specific material, and sometimes specific

Listed Prices of Metallic Beryllium, Beryllium Oxide, and Selected Beryllium Alloys, and Other Metals

Product\Year	1985	1986	1987	1988	1989	1990	1991
Metallic Beryllium, 98.5% pure (dollars/pound)							
Powder Blend	196.00	204.00	229.00	244.00	261.00	268.83	280.00
Vacuum Cast Ingots	225.00	225.00	225.00	225.00	225.00	225.00	225.00
Beryllium Oxide (dollars/pound)							
Powder	55.70	55.70	55.70	65.65	65.65	72.50	72.50
Beryllium Containing Alloys (dollars/pound)							
BeCu Master Alloy ($/Be Cnt)	144	152	160	160	160	160	160
BeCu Casting Alloy	5.10-5.70	5.40-6.00	5.40-6.00	5.40-6.00	5.40-6.00	5.40-6.00	5.40-6.00
BeCu Rod, Bar, Wire	8.05	8.50	8.90	8.90	9.85	10.24	10.24
BeCu Strip	7.25	7.65	8.00	8.00	8.90	9.25	9.25
Beryllium Aluminum	236	248	260	260	260	260	260
Prices of Other Metals (cents/pound unless otherwise indicated)							
Gold, $/Troy oz.	459.64	368.24	447.95	438.31	382.58	384.93	363.29
Aluminum, U.S. spot	59.80	55.90	72.30	110.10	87.80	74.00	59.50
Copper, U.S. cathode	84.20	66.05	82.50	120.51	130.95	123.16	109.30
Steel, midwest cbn plate	23.04	18.27	19.29	21.64	23.50	23.75	24.50

Source: U.S. Dept. of Interior, Bureau of Mines, Annual Yearbooks

purchase quantities, without consideration of discounts and market conditions. Metallic beryllium, especially, is sold in many different forms and purities, and may range from much less than the 1991 $280 list price, to thousands of dollars a pound. Beryllium alloys are also made in various forms, with varying beryllium content. A list price is only an indication, and should not be thought of as the price.

Industry officials indicated that the beryllium oxide and beryllium alloy listed prices are representative of actual transaction prices, with the exception of beryllium copper master alloy. The master alloy sells at a considerable discount below list price as imports from China (less than $100 per pound contained beryllium) have demonstrated. However, only a small percentage of total alloy shipments are the master alloy. The metallic beryllium prices are not representative, according to the same officials. Also, very little of the vacuum cast metal ingot is sold anymore, which has made updating the price difficult.

Beryllium oxide has about 40 percent contained beryllium. The 1991 price of $72.50 per pound would translate into about $181 per pound contained beryllium. Among the alloys, which have a lower content of beryllium, beryllium copper strip is used primarily for electronic applications. The rod, bar and wire are more likely to be used in structural applications, and therefore, contain more beryllium. These differences are reflected in the price.

Despite the beryllium sector being a near monopoly structure, beryllium product prices are determined by supply and demand. However, most of the price is a factor of the high cost of bringing beryllium to market, and thereby is set very high. This high cost is due to the low concentration levels of beryllium in beryllium ores, and very expensive and capital intensive processing of the product into usable forms. Above this threshold the supply of beryllium is very elastic, and would expand rapidly with a small incremental increase in price. At this high threshold price, the demand for beryllium is limited to high performance applications and can be viewed as inelastic. In conversations with industry officials, the price would have to drop by major proportions before the demand curve would turn elastic, because of competing (and much lower cost) materials already used in more common end-products with lower performance requirements.

On the demand side, because of beryllium's high cost, several beryllium product fabricators reported they are constantly on the look out for cheaper alternatives to beryllium, or ways to reduce the beryllium content in their products. This stimulates Brush Wellman to look for improved processing efficiencies to reduce costs as well as new markets to maintain or

expand through-put.

Beryllium Market Patterns

The volumetric distribution of beryllium products to various end-markets has shifted dramatically since the early 1980s. The near total stoppage of many nuclear activities has

Trends in Beryllium End-Markets, 1981-1991
(metric tons of beryllium content; percents of total demand)

Year	Nuclear Reactors		Aerospace		Electrical		Electronic Components		Other		Total Demand
	tons	%	tons	%	tons	%	tons	%	tons	%	tons
1981	54	19%	51	18%	101	36%	46	17%	26	9%	278
1982	29	21%	25	18%	49	36%	24	18%	9	7%	136
1983	52	21%	46	19%	87	36%	41	17%	17	7%	243
1984	73	24%	46	15%	105	35%	53	17%	26	9%	303
1985	65	25%	39	15%	91	35%	46	17%	22	8%	263
1986	45	16%	41	15%	108	39%	62	22%	22	8%	278
1987	41	14%	44	15%	109	38%	68	23%	27	9%	289
1988	18	8%	51	22%	66	29%	80	35%	13	6%	228
1989	10	5%	44	24%	36	19%	88	47%	9	5%	187
1990	5	3%	46	26%	35	20%	79	45%	10	6%	175
1991	2	1%	49	24%	32	16%	99	49%	21	10%	*203

*The 203 figure for Total Demand in 1991 is overstated because it includes a bulk import shipment that contained mostly oil and sludge that was counted as metallic beryllium scrap. OIRA estimates actual total demand was closer to 170 than 203 in 1991.

Source: U.S. Dept. of Interior, Bureau of Mines, Beryllium Annual Report, 1991

reduced that sector's demand for beryllium from over 20 percent of the total to less than 5

percent in the 1990s. Electrical equipment and devices fell from the nearly 40 percent, to less than 20 percent in recent years. During the same time, electronic components rose from less than 20 percent of total demand to almost 50 percent in recent years. Aerospace applications have remained steady since the mid-1980s, although as a percent of the total rose as the overall market shrank. We are also seeing a decline in the beryllium content of beryllium copper alloys. In the wake of these shifts, the relative demand for metallic beryllium declined, while that of beryllium alloys has increased.

The nuclear reactor market peaked in 1984, at 73 metric tons of mostly metallic beryllium. However, demand went down every year since then, reaching only 2 metric tons in 1991. The electrical equipment market peaked in 1987, at 109 metric tons, but dropped over 70 percent by 1991, to only 32 metric tons. Electronic components, which ranged below 50 metric tons in the early 1980s, rose to over 80 metric tons by the late 1980s, and finished the period at 99 metric tons in 1991.

The drop in the nuclear market has been across the board. Construction of nuclear power plants for utility plants, nuclear submarines, and surface vessels has almost completely stopped, although some is going on overseas. Also, the Rocky Flats installation of the Department of Energy was closed in 1989 for an environmental audit. Since then, the operation has not re-opened because of a declining cold war threat.

Both electrical equipment and electronic components (these two markets overlap to an extent) were driven by mainframe computers until the mid-to-late 1980s. However, with the rapid decline in the mainframe market since then, the electrical equipment sector, in particular, has fallen sharply. Current carrying devices such as springs, switches, and connectors were most affected. Electronic components have penetrated new markets, which helped offset the fading mainframe market. These include computer work stations, automotive electronics, factory automation, avionics, and telecommunications. The aerospace market remains very important in terms of beryllium structural parts, instrumentation, and electronics for satellites and aircraft. Much of the aerospace business is vulnerable to government budget constraints worldwide, and the vicissitudes of the economy.

The miniaturization of electronic components has reduced the per unit material content and cost, but expanded the overall material usage by increasing the number of electronic laden end-products. So far, the special thermal and other properties of beryllium have permitted the material to grow into this market. While this market is extremely important economically to the beryllium sector, the dynamic is reaching its limits on the quantity of

beryllium ultimately used. Moreover, the competition is very intense to find ever better (and cheaper) replacement materials, such as aluminum nitrides and phosphor bronzes. Photonics is another technology that may soon make an appearance in the component market and impact beryllium.

As long as metallic beryllium, beryllium alloys and beryllium oxide remain expensive to process, the long-term economic viability of the beryllium industry rests in developing new high performance products wherever the opportunity presents itself.

Brush Wellman Financial Data, 1981-1991

Brush Wellman was incorporated in Ohio on January 9, 1931 as the Brush Beryllium Company; the current name was adopted in October, 1971. Brush is the only fully integrated producer of metallic beryllium, beryllium alloys, and beryllium oxide powder in the Western world. NGK produces beryllium alloys from imported beryl toll-refined by Brush. However, through the third-stage of the beryllium production cycle, OIRA estimates Brush has 85 percent of the market in the United States, and about 70 percent in the world. Brush is also a significant factor in the beryllium fabrication market, but the firm's market share is considerably less than at third-stage levels.

Between 1981-1992, Brush averaged $256.5 million in sales revenues, of which $206.2 million, or 80.5 percent, was of beryllium related products. Net profits before taxes averaged $29.6 million, which were 11.5 percent of total sales. The company invested an average of $21 million per year, or 8.2 percent of sales revenues, and $5.9 million in research and development, equal to about 2.3 percent of sales. International sales, including exports and value added operations in foreign countries averaged 25 percent. The company employed an average of 2,049 people, who averaged $125,000 in sales per employee over the 12 year period.

Total sales and beryllium sales each peaked in 1988; total sales at $345.8 million, and beryllium at $252 million. However, total sales fell steadily since then to $265 million in 1992, down 23 percent, while beryllium sales fell to $211 million, off 16 percent. The drop in total sales was partly due to the divestiture of Bucyrus Blades in 1989, which made ground engaging cutting blades for the power dozer and grader aftermarket (annual sales about $30 million). If this were removed, most of the decline was related to falling beryllium revenues. The defense, nuclear, and mainframe computer markets led the drop. The company also reported two subsidiaries, Technical Materials (purchased in 1982 for $47

million), and Williams Gold Refining Company (purchased in 1986 for $14 million), did not perform up to expectations.

Brush Wellman's Financial Results, 1981-1991 *(in $millions)*										
Year	Total Sales	Beryllium Sales	Net Profit Before Taxes		Capital Investment		R&D		Int'l Sales	Employ-ment (actual)
			Value	%	Value	%	Value	%		
1981	144.1	124	29.6	20.5%	12.2	8.5%	na	na	na	1,517
1982	157.1	na	29.7	18.9%	16.2	10.3%	na	na	na	1,675
1983	210.2	na	41.9	19.9%	19.8	9.4%	3.9	1.8%	31	1,906
1984	281.1	204	69.1	24.6%	29.6	10.5%	4.5	1.6%	45	2,190
1985	242.9	188	48.2	19.8%	44.2	18.2%	5.0	2.0%	44	1,860
1986	241.4	189	10.3	4.3%	25.2	10.4%	5.3	2.2%	50	2,266
1987	307.6	214	45.8	14.9%	18.5	6.0%	6.5	2.1%	81	2,564
1988	345.8	252	51.9	15.0%	22.6	6.5%	6.5	1.9%	84	2,602
1989	317.8	242	26.3	8.3%	19.9	6.3%	6.1	1.9%	77	2,160
1990	297.4	224	24.8	8.3%	16.2	5.5%	6.6	2.2%	80	2,079
1991	267.5	214	*-36.2	-13.5	13.6	5.1%	7.6	2.9%	76	1,943
1992	265.0	211	13.7	5.2%	13.6	5.1%	7.3	2.8%	71	1,831

* This included writing down the asset values of Brush's specialty metals operation, and complying with FAS 106, which established a liability fund toward paying current employees medical insurance when they retire.

Source: Brush Wellman Annual Reports

Profits before taxes were very high between 1981-1986, averaging 18 percent on revenues, more than twice the all manufacturing average. Sales of beryllium rose over 50 percent from 1981-1986 (and doubled by 1988) in the wake of the defense build-up and at a time of rising prices. However, Brush also poured more than 11.5 percent of sales into new plant and equipment expenditures during those years. In the latter period, 1987-1992, before tax profits fell to only 6.4 percent, and investment to 5.8 percent of sales, as markets shrank and price discounts prevailed. Research and development expenditures (available from 1983-1992) were increased 36 percent in the latter five years, despite the fall in profitability. The

company is focusing on new product and market development, and reducing the costs of production.

International sales (available from 1983-1992) rose from 19.2 percent of sales in the first five years, to 26.1 percent in the second five years. The increase in nominal dollars is almost 55 percent, averaging $50 million (1983-1987) and $78 million (1988-1992). The increase is related to increased operations in the Pacific rim, and establishment of distribution and customer service operations in Fukaya, Japan in 1986. Weakness in the dollar in exchange markets has also helped. The European business slump, and declines in NATO defense spending prevented these numbers from being even more impressive. Brush expects further growth in the international sector in the future.

Employment at Brush peaked in 1988, at 2,602. Since then, employment fell almost 30 percent to 1,831 in 1992. The sharpest one year drop came in 1989, with the sales of Bucyrus Blades. At the end of 1989, the company employed 2,160. Sales per employee have trended upward, although the highest level was attained in 1989, at $147,000 per employee. In 1992, sales per employee increased 5.1 percent over the 1991 figure to almost $145 million.

The company reported a huge loss in 1991, as the firm complied with Financial Accounting Standard 106, which requires establishing a liability fund for paying current employees' medical insurance when they retire. The company also lowered the asset value carried on its books of its specialty metal group, Technical Materials and Williams, for performing below expectations. Both of these were paper losses, rather than out-of-pocket expenses. Otherwise, the company had a small operating profit in 1991, of about $3 million, or 1 percent of sales. Steps have been taken to cut costs. The firm is financially sound with a current ratio (current assets/current liabilities) well over two, and a relatively small debt burden. Social costs such as health and retirement liabilities are rising faster than labor productivity. This may ultimately lead to further reductions in employment.

Beryllium Fabricators

Survey information was received from three metallic beryllium, two beryllium oxide, and four beryllium copper fabricators. Aggregate statistical information on shipments, investment and employment was tallied for the metallic and beryllium oxide fabricators. Statistical information could not be extracted with any accuracy from the survey responses of

beryllium copper fabricators, and therefore was not used. For instance, one beryllium copper fabricator reported several thousand employees, but fewer than 5 percent of these were actually involved with beryllium copper fabrication. However, foreign sourcing information provided by the beryllium copper fabricators was acceptable and could be used.

Shipments by the metallic beryllium and beryllium oxide fabricators ranged from $45-62 million between 1986-1990. OIRA estimates shipments reported by these fabricators represented about half the total of all shipments of this type. As shown on the table on the following page, the predominance (over 70 percent) of defense shipments is mostly due to the very high percentage attributed to metallic beryllium, although beryllium oxide is also used extensively (about 30 percent) in defense applications. In telephone conversations with these fabricators, defense business has fallen sharply since 1990, reducing business especially in the metallic beryllium sector. Employment at the two major metallic beryllium firms has fallen almost 50 percent between 1990, and the end of 1992, with few signs of improvement in the future.

These firms are trying to develop commercial markets with less than satisfactory results. There are some medical uses (such as bone replacements) that have shown promise. However, the sector is primarily dependent on Defense and other Federal spending, particularly by NASA and the Department of Energy, and similar foreign government programs, for its livelihood. As discussed earlier, this market shrinkage has been transmitted back to Brush Wellman. Since the production of metallic beryllium is capital intensive, the low plant utilization rates at Brush's Elmore plant have forced prices higher, further aggravating the fabricator's situation. The market pressures on beryllium oxide fabricators are less severe, but still are a cause for concern.

Capital investment by the five companies ranged from over 12 percent of sales (1988) to only 2.1 percent (1990). With a small number of firms, the actual volatility of investment at the firm level is more visible, and not hidden by large numbers. In the case of beryllium product fabricators, capital investment is sometimes targeted toward filling specific contracts from major defense contractors that may extend over several years, or the lifetime of a weapon system. Some equipment, such as electrical discharge machines, or coordinate measurement equipment, can also be very expensive and difficult to utilize optimally.

The following table presents survey shipments, new capital investment, and employment totals for metallic and beryllium oxide fabricators.

Shipment and Employment Data for Selected Metallic Beryllium and Beryllium Oxide Fabricators, 1986-1990					
Shipments	(in millions of dollars)				
	1986	1987	1988	1989	1990
Defense	43.0	40.9	31.1	37.7	47.2
Non-Defense	15.3	17.2	13.5	17.4	15.0
Total Shipments	58.3	58.1	44.7	55.2	62.3
% to Defense	74%	70%	70%	68%	76%
Shipments per Employee (in thousands of dollars)					
Beryllium Fabricators	$79.7	$75.1	$57.1	$73.7	$88.5
All Manufacturers	$123.0	$130.7	$140.1	$146.7	$152.5
New Capital Investment	(in thousands of dollars)				
Buildings and Plant	3,894	380	460	238	207
Machinery and Equipment	1,722	1,570	5,013	1,237	1,129
Total Investment	5,616	1,650	5,472	1,475	1,336
% to Shipments	9.6%	2.8%	12.2%	2.7%	2.1%
Employment	1986	1987	1988	1989	1990
Scientists and Engineers	53	45	40	36	36
Production Workers	479	509	506	489	452
All Other	199	220	236	223	216
All Employees	731	774	782	748	704
% Production Workers to All Employees					
Beryllium Fabricators	66%	66%	65%	65%	64%
All Manufacturers	64%	66%	65%	65%	64%

Source: Dept. of Commerce, OIRA Industry Survey and Bureau of the Census, Annual Survey of Manufacturers, AS-1(1991)

Research and development - Research into product development is playing an increasingly important role, as these firms contend to develop new product outlets. One beryllium oxide fabricator stated that as an established technology, competitiveness requires continuous improvement in quality and cost reduction. In general, new applications are becoming more demanding, calling for tighter tolerances, less material and longer life expectancies. This can be viewed as a favorable (long-term) trend for beryllium related products. As a group, fabricators reportedly spend about 2-3 percent of sales on research and development.

Foreign relationships - Three of the nine surveyed fabricators reported a total of eight foreign relationships in six different countries. These countries included Belgium, France, the Netherlands, and Switzerland in Europe, and China and Japan on the Pacific rim. The relationships ranged from wholly-owned subsidiaries to value added operations and sales offices.

One fabricator reported reliance on its Swiss operations for technical support, and also received regular shipments of parts from a second operation in Switzerland. Another fabricator further fabricated strips in Belgium supplied from their U.S. operations. Still another respondent reported wholly-owned subsidiaries in France, Holland, Switzerland, and Japan that it used to sell into those markets. Loss of these operations would impose some economic penalties on the firms, but would not undermine their ability to supply defense requirements.

Four of the nine fabricators reported using foreign made machine tools and other equipment. The machine tools came from Japan, Switzerland, and Germany. Japan was reported as the country of origin five times (2 CNC Lathes, milling machines, jig borers and an electrical discharge machine). Reasons for sourcing the machines from Japanese producers were superior quality and reliability (5 times), lower cost (3 times), and quicker delivery (3 times). Switzerland was named three times (a jig bore, presses, screw machines). Reasons included better quality and reliability (3 times), and lower cost (1 time) and quicker delivery (1 time). Germany was reported once for coordinate measuring equipments because of better quality and reliability. Switzerland was also named as a source for gauges, again because of superior quality and reliability. Another fabricator reported sourcing miscellaneous products from Singapore because of their lower cost.

One fabricator (with no foreign relationships or foreign sourcing) commented that the Japanese market is difficult to access, and that they protect their own sources of supply.

FOREIGN TRADE INFORMATION

Limitations of Foreign Trade Statistics

Foreign trade statistics for beryllium do not provide a true picture of trade patterns. International trade in beryllium and beryllium products is difficult to accurately assess because of technical difficulties in measuring the content of beryllium in certain traded categories, and lack of complete coverage by the trade statistics. Import and export data covering beryllium related products are now collected under the Harmonized System (HS), which replaced both the *Tariff Schedule of the United States*, and the older system for collecting export data referred to as *Schedule B*. The HS was instituted on January 1, 1989. Under the new system imports are classified under the *Harmonized Tariff Schedule* (HTS), and exports under the *Harmonized System, Schedule B* (informally).

Under the HS system, the first 6-digits are the same for imports and exports. However, export classifications generally have less detail. Only exports of metallic beryllium, wrought and unwrought, and metallic waste and scrap are available. In the case of beryllium alloys and oxides, the export data are included in general categories so that the information is not retrievable.

Certain product categories appearing in the old tariff schedule do not entirely match the categories in the Harmonized System. For example, the categories appearing in the old system, beryllium oxide and carbonate and other beryllium compounds, n.s.p.f., were not carried into the new schedule intact. The HTS includes a revised category, beryllium oxide and hydroxide, which absorbed parts from both of the older categories, while discarding others. Beryllium carbonate and several other beryllium compounds are now submerged in general chemical categories.[66] However, these "other beryllium chemicals" are of minor concern since insignificant amounts are traded. The revised HTS category contains the most relevant parts (i.e., the oxide and hydroxide) from the old classifications. In another revision, the old system combined unwrought beryllium metal, and beryllium waste and scrap into a single category. In the new system, these are listed separately.

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[66]Various beryllium compounds are now classified in the Harmonized System under general categories as follows (first 6-digits): beryllium sulfate under *Other Sulfates* (283329); beryllium nitrate under *Other Nitrates* (283429); beryllium carbonate under *Other Carbonates* (283699); and zinc beryllium silicate under *Other Silicates* (284290).

Beryllium copper is the most exported beryllium product, and the United States is the world's major source. However, export statistics are buried in general categories. Small quantities of beryllium copper or beryllium copper master alloy are imported into the United States. While import data is available on the master alloy, very little is available on beryllium copper. The HTS established three separate categories, one each for beryllium copper plate, sheet and strip, which were not available under the old system. Other forms of beryllium copper (i.e., billet, rod, bar, tube and foil) remain under general categories, and cannot be retrieved. A comparison of the old and new tariff numbers is shown in the following table.

Comparison of Old and New Tariff Schedules for Beryllium Products
(Most Favored Nation Tariff)

Tariff Schedule of U.S.	TSUS No.	Tariff	Harmonized Tariff Schedule	HTS No.	Tariff
Ore and Concentrate	601.09	Free	Ore and concentrate	2617.90.0030	Free
Unwrought beryllium; beryllium waste and scrap	628.05	8.5%	Beryllium waste and scrap	8112.11.3000	Free
			Unwrought beryllium	8112.11.6000	8.5%
Beryllium, wrought	628.10	9.0%	Beryllium, wrought	8112.19.0000	5.5%
Beryllium copper master alloy	612.20	6.0%	Beryllium copper master alloy	7405.00.6030	6.0%
			Beryllium copper plate Beryllium copper sheets Beryllium copper strip	7409.90.1030 7409.90.5030 7409.90.9030	5.1% 1.7% 5.1%
Beryllium oxide or carbonate	417.90	3.7%	Beryllium oxide or hydroxide	2825.90.1000	3.7%
Other beryllium compounds	417.92	3.7%			

Source: U.S. International Trade Commission

The Bureau of Mines has utilized the Journal of Commerce *Port Import/Export Reporting Service* (PIERS) to obtain some information covering beryllium copper alloy trade, although only for materials imported or exported by sea. The information, therefore, does not include trade with Canada or Mexico, or any by airfreight. Moreover, pricing information is not available.

Exports and Imports of Beryllium Copper Alloys Reported Under PIERS *(pounds of contained beryllium)*				
Reported Exports of Beryllium Copper			Reported Imports of Beryllium Copper	
Year	Lbs.	Indicated Destination	Lbs.	Indicated Country of Origin
1987	10,472	mostly France and Taiwan		
1988	37,838	mostly France	19,176	mostly Japan
1989	26,515	France-80%	8,502	Japan
1990	37,919	Japan-50%; France-37%	10,141	Japan-50%
1991	10,317	Japan-79%; Germany-8%	15,629	Japan-69%; France-18%; Holland-8%; UK-5%
Reported Exports of Beryllium Copper Master Alloy			Reported Imports of Beryllium Copper Scrap	
Year	Lbs.	Indicated Destination	Lbs.	Indicated Country of Origin
1988	1,065	Belgium, France, Germany, Brazil		
1989	2,602	France-63%; Germany-33%; Brazil-4%	3,603	Germany-45%; Belgium-32%; Netherlands-22%
1990	1,852	France-87%; Brazil-13%	1,720	Japan-50%
1991	small	Brazil	1,351	UK-62%; Japan-38%

Note: Beryllium content for beryllium copper and scrap calculated as 2% of reported number; master alloy calculated as 4% of reported number.

Source: U.S. Dept. of Interior, Bureau of Mines

Beryllium Related Imports (Official U.S. Statistics)

For reasons discussed in the *Limitations of Foreign Trade Statistics*, the following numbers should be viewed knowing their limitations. Total reported beryllium imports (i.e., ore, products, and scrap) reached a peak in 1989 at $3.8 million, and since then have declined to $2.1 million. In terms of pounds of contained beryllium, imports peaked in 1987, at 308,558 pounds, 60 percent of which was beryl ore, and another 30 percent was most likely wrought beryllium scrap. Almost none of the imports are finished beryllium product. After

1987, the imported poundage dropped sharply as beryl imports declined. A resurgence of imports was reported for 1991, based mostly on a large shipment of beryllium waste and scrap from Europe. Preliminary figures for 1992, show imports falling over 80 percent to only 23,788 pounds, and the dollar value to slightly less than $1.25 million.

The almost 94,000 pounds of metallic beryllium waste and scrap imported in 1991, was valued at only $145,000. This would equate to an average price of only $1.55 a pound. However, beryllium scrap normally sells for $50-$70 per pound. The shipment undoubtedly contained oils and other residues that account for the bulk of the weight. If, for example, we assumed the beryllium value to be $40 per pound, the contained beryllium would only be 3,625 pounds, more than 90,000 pounds less than reported. As a more realistic example, in 1990, a shipment of 9,606 pounds came in from Canada under the same HTS category at a value of $49.61 per pound.

With Brush Wellman the only producer of metallic beryllium outside of Kazakhstan and China, almost no metallic beryllium is imported into the United States. Brush may occasionally export metallic beryllium to Canada, the U.K., France or Germany where it is fabricated, or partially fabricated, and sold back into the United States. It is unclear, however, if a partially fabricated *all beryllium optical device*, for instance, would re-enter the United States under the beryllium HTS code, or some other category. For example, 7 pounds of unwrought beryllium was received from Japan in 1991, at an average value of almost $4,000 per pound. Could this have been out of a laboratory? It is very difficult to know. Nevertheless, the totals are insignificant.

Imports of beryllium copper master alloy have increased somewhat because of the Alloy Research-Olin connection to China. However, the quantities amount to only 3 or 4 metric tons of contained beryllium in a 150 metric ton market. The quantity (contained beryllium) peaked in 1990, at 8,785 pounds, but fell in 1991, to about 6,500 pounds. Preliminary figures for 1992 show an increase to almost 8,600 pounds, valued at $814,000. The average value of the master alloy was only $90.29 per pound (contained beryllium) in 1991, almost $70 dollars less than the listed price reported by the Bureau of Mines. That is over a 43 percent discount from list, indicating continued softness in the market, or quite possibly the dumping of product to gain market share.

Imports of Beryllium Products under Tariff Schedule of the U.S. (pounds of contained beryllium; thousands of dollars)						
Category	1986		1987		1988	
	pounds	($000s)	pounds	($000s)	pounds	($000s)
Ore and Concentrate	120,767	1,324	184,195	1,944	77,962	911
Unwrought beryllium waste and scrap	22,487	55	18,294	159	3,391	84
Beryllium, wrought	20,467	50	92,422	290	21,911	66
Beryllium copper master alloy	966	114	2,152	246	8,421	936
Beryllium oxide or carbonate	99	3	2,668	99	-	-
Other beryllium compounds	603	42	8,827	90	23,387	183
Totals:	165,389	1,588	308,558	2,828	135,072	2,180

Source: U.S. Dept. of Commerce, Bureau of the Census

Imports of Beryllium Products under Harmonized Tariff System (pounds of contained beryllium; thousands of dollars)						
Category	1989		1990		1991	
	pounds	($000s)	pounds	($000s)	pounds	($000s)
Ore and Concentrate	53,039	655	30,150	418	25,382	394
Beryllium waste and scrap	28,453	266	24,176	91	93,837	145
Beryllium, unwrought	112	28	33	39	9	30
Beryllium, wrought	3,170	49	2	2	1,021	53
Beryllium copper master alloy	1,676	216	8,785	871	6,534	590
Beryllium copper plate	1,609	652	2,601	981	1,394	332
Beryllium copper sheet	-	-	-	-	4	201
Beryllium copper strip	5,807	1,885	188	69	2,070	339
Beryllium oxide or hydroxide	11,945	40	520	28	1,067	21
Totals:	105,395	3,791	66,455	2,499	131,318	2,105

Source: U.S. Dept. of Commerce, Bureau of the Census

Reported imports of beryllium copper plate, sheet and strip understate total beryllium copper imports by an undetermined amount because of the absence of billets, tubes, etc. which are buried in general HTS categories. However, the known and unknown imports are almost totally from NGK Insulators in Chita, Japan. In 1991, official Japanese Trade Statistics reported Japan imported 83,466 pounds (contained beryllium) of beryllium oxide from the United States, at a value of $2,048,000 (Yen 255,952,000). NGK processed the beryllium oxide into beryllium alloys, mostly for the Japanese market, and returned some to the United States. In 1992, preliminary reported imports of beryllium copper plate, sheet, and strip into the United States almost doubled to 6,872 pounds from less than 3,500 in 1991. The 1992 imports are entirely from Japan. In fact, 99 percent (or more) of the reported imports between 1989-1992, came from Japan.

Available statistics show that Japan was the major source of beryllium product imports (excluding beryl) between 1989-1991, accounting for over 65 percent of the total. China was a distant second at just over 21 percent. Both countries supplied finished or semifinished product, while all the others were primarily returning scrap for recycling.

Total Beryllium Related Imports, Except Ore, by Country, 1989-1991

Country	Imports (in $000)	Percent of Total
Japan	$4,392	65.24%
China	1,422	21.15%
France	236	3.51%
Hong Kong	227	3.38%
Germany	181	2.69%
United Kingdom	135	2.01%
All Other	129	1.92%
World	$6,722	100.00%

Source: U.S. Dept. of Commerce, Bureau of the Census

U.S. Imports of Beryllium Ore

The amount of imported beryl ore, which is (now imported and) toll-processed by Brush Wellman for NGK Metals, dropped rapidly after 1987, due to excessive and rising inventories of the commodity, and weakness in the beryllium copper market in the United States, Japan, and Europe. In fact, no imports of beryl were recorded in 1992. In 1991, in a move to rationalize redundant capacity, NGK Metals consolidated certain operations with its parent firm, NGK Insulators, Ltd. in Chita, Japan. NGK Metals no longer produces beryllium copper in Pennsylvania. Now NGK processes the beryllium hydroxide delivered by Brush Wellman under the toll-agreement into beryllium oxide (which increases the contained beryllium from 420 to 800 pounds per short ton), and ships the material to Japan for processing into beryllium copper. NGK Metals then orders the beryllium copper it requires from Japan to service the U.S. market. NGK's European operations are now also supplied beryllium copper from Japan.

Between 1986-1991, the United States imported beryl chiefly from Brazil. In 1990, Brazil was the only import source. In the 1986-1988 period, France sold beryl into the United States from the stockpile the country maintained for national security reasons. Imports of beryl peaked in 1987, at 2,088 metric tons (83 metric tons of contained beryllium), and a value of $1.94 million. Imported beryllium ore and concentrates enter duty free. The average calculated price per pound of contained beryllium in the beryl rose during the period, from $10.96 per pound in 1986, to $15.51 in 1991.

U.S. Imports for Consumption of Beryl, By Country							
Country	1986	1987	1988	1989	1990	1991	1992
	(in thousands of dollars)						
Argentina	$18	$33	-	-	-	-	-
Brazil	646	748	$677	$572	$418	$347	-
China	497	490	161	44	-	-	-
France	112	552	10	-	-	-	-
Hong Kong	-	49	55	-	-	-	-
Italy	-	-	-	-	-	$47	-
Macao	4	-	-	-	-	-	-
Madagascar	8	-	8	-	-	-	-
Morocco	-	-	-	20	-	-	-
Mozambique	12	-	-	-	-	-	-
Rep. of South Africa	27	-	-	-	-	-	-
United Kingdom	-	8	-	-	-	-	-
Zimbabwe	-	64	-	19	-	-	-
TOTAL	$1,324	$1,944	$911	$655	$418	$394	$0
	(in metric tons)						
Argentina	18	32	-	-	-	-	-
Brazil	689	801	664	526	342	252	-
China	455	462	122	35	-	-	-
France	139	654	58	-	-	-	-
Hong Kong	-	45	30	-	-	-	-
Italy	-	-	-	-	-	36	-
Macao	5	-	-	-	-	-	-
Madagascar	12	-	10	-	-	-	-
Morocco	-	-	-	22	-	-	-
Mozambique	16	-	-	-	-	-	-
Rep. of South Africa	35	-	-	-	-	-	-
United Kingdom	-	21	-	-	-	-	-
Zimbabwe	-	73	-	18	-	-	-
TOTAL	1,369	2,088	884	601	342	288	0

Source: U.S. Dept. of Commerce, Bureau of the Census

Beryllium Related Exports (Official U.S. Statistics)

The only export statistics available for beryllium products are for metallic beryllium and the metal's waste and scrap. Over 30 nations received exports from the United States under this category between 1986-1991, although a small group of these receive the most in terms of value. Overall, reported U.S. exports of metallic beryllium and metal scrap declined rather sharply since the mid-1980s. During the period 1986-1991, the dollar value of these exports dropped from $7.4 to $2.3 million, in part because the major European economies slipped into recessions. Also, major cuts took place in NATO defense spending, and in the European space program. The major destination during these six years was the United Kingdom, followed by France and Germany. These three countries received over 70 percent of the total reported exports. Exports to Japan accounted for over 10 percent of the total, while Canada accounted for about 9 percent.

U.S. Exports of Metallic Beryllium, Wrought or Unwrought, and Metallic Beryllium Waste and Scrap, by Country

Year	Top Five Destinations					Top 5 Totals		Grand Total
	U.K.	France	Germany	Japan	Canada	Top 5	Percent	
	(in thousands of dollars)							
1986	$2,697	$1,264	$2,066	$477	$224	$6,728	91.0%	$7,394
1987	886	1,243	555	887	469	4,040	80.6	5,013
1988	1,778	2,271	1,145	808	331	6,333	91.9	6,894
1989	1,062	784	353	285	524	3,008	78.2	3,847
1990	1,565	430	1,220	180	859	4,254	88.1	4,831
1991	244	309	488	598	297	1,936	72.0	2,690
	(in pounds)							
1986	11,363	7,817	8,527	3,530	6,471	37,708	47.4%	79,556
1987	4,371	5,590	4,699	3,551	10,799	29,010	17.0	170,408
1988	3,965	5,604	4,944	2,277	2,102	18,892	50.2	37,599
1989	16,391	4,308	2,006	1,579	7,529	31,813	42.1	75,532
1990	19,515	1,786	3,580	1,047	65,162	91,090	91.4	99,708
1991	551	615	16,058	2,370	26,116	45,711	62.6	73,021

Source: U.S. Dept. of Commerce, Bureau of the Census

Reported exports of beryllium by volume peaked in 1987, as a large shipment of nearly 130,000 pounds of waste and scrap went to Taiwan. The value of the shipment was only $390,000, equating to $3 per pound. The contained beryllium would be much less. Assuming $40 per pound, the beryllium content would be estimated at only 9,750 pounds. The volume measure of reported exports is of limited use.

Calculating the average prices of beryllium to various destinations provides some indication of where the finished metal and the waste and scrap are going. For example, over the six years, the average price of beryllium exports to France was $245 per pound; to Germany, $146; to the United Kingdom, $147; and to Japan, $225 per pound. These countries were receiving mostly finished metal. In contrast, the average price to Canada was $23; to Taiwan, $4; to Spain, $3; and the Netherlands, $45. These countries apparently were receiving mostly waste and scrap, although in some years Canada and the Netherlands averaged over $150 per pound. The lower price destinations were also much less consistent. Spain only appeared once in the statistics in 1986. And exports to Taiwan in 1991 totaled only 11 pounds, valued at over $2,000 per pound.

Brush Wellman reported total exports from the United States in its *Annual Reports* until 1989. These averaged about 10 percent of the beryllium related segment of the firm's business. International sales are larger than exports, in some years by well over 100 percent because of value added sales, and customer service revenues in foreign countries. Brush has European operations in Stuttgart, Germany and Theale (near Reading), England, that have minor manufacturing and finishing capabilities, including beryllia ceramic fabrication in Theale. A sales distribution center is located in France, and sales and customer service representatives are located in many other countries. Brush also established operations in Fukaya, Japan in the mid-1980s to serve the Asian markets. The Asian market was about 25 percent the size of the European market, but has grown recently in the wake of the European slump.

Exports by Brush are mostly beryllium alloys to foreign fabricators, particularly beryllium copper strip and rod. Smaller amounts of finished product are also exported. The estimated exports by Brush are presented on the table below. The $2 million shipment of beryllium oxide to NGK Insulators in Japan in 1991, is also shown on the table.

Estimated Exports of Beryllium Related Products by Brush Wellman and NGK Metals, 1986-1991 (in $millions)

Year	Exports by Brush Wellman	Exports by NGK
1986	$20.5	na
1987	20.9	na
1988	25.9	na
1989	22.8	na
1990	25.3	na
1991	28.0	2.0
1992	25.3	na

Source: Brush Wellman's Annual Reports, Import Statistics of Japan

SCRAP RECYCLING ACTIVITIES

Survey questionnaire responses concerning scrap recycling activities were received from both beryllium manufacturers, Brush Wellman and NGK Metals Corporation, 13 beryllium product fabricators, and a major scrap dealer. Of the 13, six responses were received from fabricators of beryllium copper, five responses from processors of metallic beryllium, and two from beryllium oxide fabricators. In addition, Brush Wellman provided a list of over 200 beryllium copper customers and scrap dealers, and quantities of beryllium copper scrap returned from each during 1990.

Beryllium Scrap Process

The reduction of scrap generation in the beryllium industry, not an easy task, would greatly lower the product's cost, and make it more attractive in the marketplace. Scrap generation adds to the cost and time of production. Scrap is generated, recycled, and produced a second time, generating still more scrap in an endless cycle.

Like other metal scrap, metallic beryllium and beryllium alloys have three principal sources. These are: 1) home or internal scrap, 2) new scrap, and 3) old scrap. Home scrap is generated and recycled at the same location. New scrap is generated at the fabricators location, collected and usually returned to the manufacturer for recycling. Old scrap is reclaimed from worn out, obsolete or discarded finished products, and only occasionally returned to the manufacturer for recycling.

The great bulk of both home and new scrap arises from machining or stamping operations, where the material is formed and cut into a variety of shapes in preparation for shipment. The amount of scrap varies directly with the amount of machining performed on the metal. Additional scrap can arise from off-spec or contaminated material. The amount of home scrap generated from a production batch also differs for each beryllium product. Metallic beryllium ranges from about 60-70 percent, beryllium copper, 25-30 percent, and beryllium oxide almost none. New scrap generation will vary by product and vendor. Metallic beryllium on average ranges between 50-60 percent, but will often exceed 90 percent. Beryllium copper and beryllium oxide average between 20-30 percent.

Manufacturers recycle home scrap and new scrap after careful screening and preparation. Scrap chips are degreased, separated using a sink-float method, sized, hand-inspected, and magnetically screened to remove any iron.[67] Before being re-introduced into the production stream, the chips are compacted into pucks; the pucks are more responsive to vacuum melting, because they melt faster than loose chips. Scrap solids are sized, weighed, inspected and analyzed before they, too, are combined with beryllium pebbles at the vacuum-melt stage.[68]

The equipment required to recycle beryllium scrap is expensive. In 1988, Brush Wellman opened a $10 million beryllium copper waste recycling plant at its Elmore, Ohio location. The facility has the capacity to recover 2 million pounds of copper and 90,000 pounds of beryllium annually.[69]

Calculating the Production:Shipment Ratio

Production will exceed shipments by the amount of home and new scrap generated. The degree to which production exceeds shipments will determine the *production:shipment* (P:S) ratio. A separate P:S ratio can be calculated for home and new scrap. For example, if two-thirds of the production of metallic beryllium is home scrap, and one-third is shipped to a fabricator, the production:shipment ratio for home scrap would be 3:1 (3 pounds production for 1 pound shipped). If the fabricator generates half scrap and half finished product, his ratio would be 2:1 for new scrap. Combining the two levels would yield a 6:1 production:shipment ratio for metallic beryllium (i.e., 3:1 x 2:1=3 x 2:1 x 1=6:1). The calculations of the ratios for the major beryllium products are presented on the following table.

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[67] "Producing Defect-free Beryllium and Beryllium Oxide", Brush Wellman Incorporated, May 1985.

[68] Beryllium Metal Supply Options. National Materials Advisory Board. National Academy Press. Washington, DC. 1989.

[69] Barbara Weiss. "Brush Wellman Spends $11M to Retool at Elmore." Metalworking News. May 1, 1989.

Relation of Scrap Generation and Beryllium Product Production:Shipment Ratios (based on 1992 market distribution, 1,000 pounds contained beryllium)				
Event Sequence	Metallic Beryllium	Beryllium Alloys	Beryllium Oxide	Composite
Production	450	1,000	100	1,550
less Home Scrap	300	250	-	550
Home Scrap P:S Ratio	3:1	4:3	1:1	1.55:1
Producer Shipments	150	750	100	1,000
less New Scrap	75	187.5	25	297.5
New Scrap P:S Ratio	2:1	4:3	4:3	1.4:1
Fabricator Shipments	75	562.5	75	712.5
Combined P:S Ratio	6:1	16:9	4:3	2.18:1

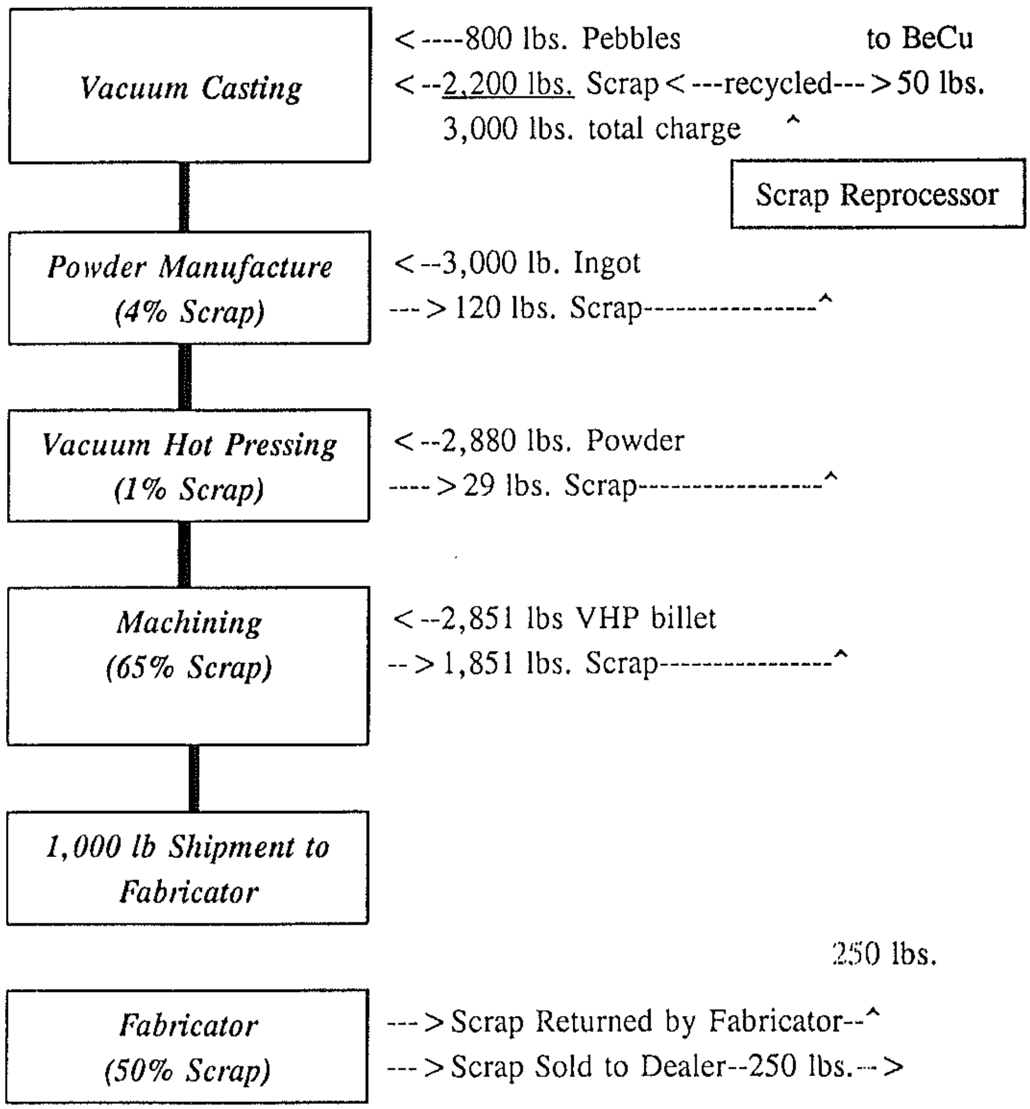
Source: U.S. Dept. of Commerce, OIRA Surveys; and telephone conversations with industry officials

Recycling Home Scrap

Metallic beryllium is not a high volume product, where certain shapes in high demand would warrant mass production, and thereby greatly reduce scrap generation. As a custom product, the material faces a number of trade-offs to accommodate the market. The manufacturer can provide a variety of general shapes, such as wire, tube, cylinders, and bars, which normally require machining to dimensions the fabricator specifies. The fabricator desires to purchase the least amount of beryllium possible to satisfy his customer, and thus avoid (new) scrap generation.

The fabricator's customer might require something unusual like a hollow spherical shape, with holes distributed evenly on the surface (similar to a whiffle ball). The manufacturer may offer cylindrical shapes perhaps two inches greater in diameter than the fabricator desires, and five times too long, but will shave the two inches down for a higher price. While the initial dimensions have to be larger than the ultimate dimensions of the end product, reducing a cylinder from a 12 to 10-inch diameter reduces the volume by almost 31 percent (all scrap), and rounding may take another 30 percent. The fabricator will then

hollow the preform, and possibly wind up generating a combined (home and new) total of 95 percent scrap. While this is an extreme example, it is a case where 20 pounds of scrap would be generated to produce one pound of end product. The beryllium cost alone will be 20 times the beryllium content in the final product, such as $4,000-$5,000 per pound. A flow diagram of metallic beryllium scrap generation is shown below.



Source: U.S. Dept. of Commerce, OIRA; and conversations with industry officials

Metallic beryllium will range from about 95 percent beryllium to almost 100 percent, depending on its application. The purest grade is used for strategic weapons. The 95 percent grade is commonly used in instrumentation where the important property may be dimensional stability and stiffness. Structural grade may be 98-99 percent where lightness and strength are important. In recycling metallic beryllium, the grade is critical. An industry official said that often nothing but scrap is used when making instrument grade metallic beryllium. However, greater care must is used when making higher purities. In addition, the higher purity scraps are actually too expensive to recycle into an instrument grade batch. Metallic beryllium scrap, except for sweepings and some new scrap, is generally to expensive too feed into the beryllium copper stream.

Recycling New Scrap

New beryllium scrap is generated in the form of chips, solids or swarf (sludge) mostly by the action of metal cutting and grinding machines. Additional scrap is generated in the form of off-spec, cracked or otherwise defective parts. Beryllium copper is by far the major source of new scrap, alone providing more than 70 percent of the total.

In good times the price of new scrap tends to rise, making it less attractive to recycle. However, in the last few years the market for beryllium products, especially the metallic forms, has been depressed, increasing the relative amount of scrap that is recycled. We estimate over 80 percent of the new scrap generated is recovered and returned to the manufacturer for recycling. Perhaps 5 percent of the scrap is lost or winds up in a landfill. Additional amounts of scrap are generated (primarily in Europe) overseas and that may not be economically shipped back to the United States for recycling. Also, some dealers may purchase metallic scrap when the price is low enough, melt it with copper and sell it as beryllium copper master alloy. These are called "Gypsy Masters," because they appear then disappear. The Gypsy Master volumes are comparatively small. The scrap price ranges from $40-$70 per pound (contained beryllium), depending on market conditions, the presence of contaminants, oiliness, and form (chips, particles, solids, etc.). About 90 percent of scrap returned to the manufacturer is accepted. The other 10 percent is not economical to clean up or process, and is discarded.

Brush Wellman and NGK[35] have non-binding agreements with almost all of its customers to take back new scrap. Brush will either pay them or give them credit toward their next purchase. Brush has also contracted with certain dealers to collect and return scrap. Dealers collect primarily beryllium copper scrap, which does not present special handling problems, although in unusual cases, they may recover metallic beryllium scrap, such as discarded non-spark tools (old scrap). Nearly all the new beryllium oxide scrap generated by ceramic fabricators is returned to Brush by the fabricators. The small number of ceramic fabricators and the special handling and shipping required of the scrap apparently deters dealers involvement. However, the relatively small amount of beryllium oxide scrap will often be recycled with beryllium copper. About 25 percent of new beryllium copper scrap is channeled through dealers; the rest is collected and returned to Brush by beryllium copper fabricators.

New Beryllium Copper Scrap (about 2% Be content) Returned to Brush Wellman for Recycling by Fabricators and Scrap Dealers, 1990

Fabricators and Dealers	Accumulated Pounds	Accumulated Percent	Incremental Pounds	Incremental Percent
Top 5	1,186,376	28.4%	1,186,376	28.4%
Top 10	1,854,114	44.4%	667,738	16.0%
Top 20	2,604,389	62.4%	750,275	18.0%
Top 50	3,452,999	82.7%	848,610	20.3%
all other	4,175,589	100.0	722,590	17.3%
Total	4,175,589	100.0	4,175,589	100.0

Source: Brush Wellman

Fabricators reported using a variety of steps to prepare scrap for recycling. Beryllium chips are gathered from machining operations by way of a vacuum recovery system, then transported to a central area, placed in steel drums and shipped. One beryllium oxide

[35] NGK stopped making beryllium copper in the United States in 1992, shortly after completing the survey. NGK's customers still sell scrap to NGK for recycling.

fabricator reported that "high-fired ceramic grinding sludge" is collected and returned to the manufacturer. The previous table shows beryllium copper scrap returned and accepted by Brush Wellman in 1990.

Recycling of Old Scrap

If old beryllium scrap were available in large quantities, which it is not, the price of beryllium could fall dramatically. It is much cheaper to recycle scrap than it is to process virgin material. Virgin material has to go through the entire production process. Scrap is entered closer to the end of the process. Old scrap also differs from home or new scrap by actually adding to the supply, and may substitute for virgin material. However, in the case of beryllium, old scrap is comparatively rare. According to one source, compared with the amount of scrap recovered from manufacturing operations, very little beryllium old scrap is reclaimed from finished products, because of the difficulty in getting at it, and usually, the low beryllium content in end-products.[36] Beryllium copper, for example, is used in tiny amounts in thermostats for water heaters and other appliances, or may represent a few grams of material inside a work-station computer. In either case, the beryllium would cost more to recover than its scrap value. Also, the use of beryllium in bombs, missiles, and satellites usually precludes reclamation.

A beryllium oxide fabricator has an open deal with its customers to take old scrap back if it's in (nearly) the same form originally sold. This has resulted in about 20-30 percent of the annual sales volume being returned. However, this appears to be an exceptional case in which the beryllium ceramic is a key component of ion lasers used in the print media. The lasers have a 10,000 hour life after which the beryllia piece is replaced and the old one returned to the fabricator. This source of old scrap probably accounts for less than 1 percent of the overall beryllium market.

The military has become a source of old scrap from finished products, particularly metallic beryllium. For example, during 1990, the Defense Reutilization and Marketing Service (DRMS) offered over 66,000 pounds of beryllium-base scrap, mainly from worn aircraft

[36]Wallace R. Griffitts and David N. Skilleter. Ch. on Beryllium in Metals and Their Compounds in the Environment. Ed. by Ernest Merian. 1991.

brake disks and other components of aircraft brake assemblies.[37] The offering also included beryllium scrap from inertial guidance systems.

In another brake deal, the DRMS sold two additional lots of beryllium scrap to Brush Wellman - one totaling 6,634 pounds of metallic beryllium aircraft brake parts, including rotor segments, liners, stators and retractor plates at $54.68 a pound, and the other totaling 51,611 pounds of brake assemblies (39 percent contained beryllium) for $20.16 a pound. In that deal, eight scrap processors asserted they were discouraged by the need to come up with large amounts of money. They claimed that had the material been broken down into smaller lots, it might have resulted in higher bids as well as more bidders. The military is replacing some beryllium brake discs with those made of carbon-fiber reinforced graphite. However, this will provide a relatively short-term supply of beryllium scrap.[38]

Comparative Scrap Cycle for Selected Metals, 1990
(in metric tons)

Category	Beryllium (m. tons)	Steel (in millions)	Aluminum (in 000s)	Copper (in 000s)
Virgin Material	182	58.8	4,000	1,670
Old Scrap	10	35.4	1,600	530
Overall P:S Ratio	2.2:1	3:2	3:2	1.7:1
Production	419	141.2	8,250	3,700
Shipments	192	94.2	5,600	2,200
Home Scrap	143	24.9	1,650	740
New Scrap	84	22.1	1,000	760
Old Scrap	10	35.4	1,600	530

Note: Home scrap for aluminum and copper estimated at 20 percent of production
Source: U.S. Dept. of Interior, Bureau of Mines, and U.S. Dept. of Commerce, OIRA estimates

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[37] Minerals Yearbook: Beryllium. 1990.

[38] Judith Chegwidden. "Beryllium." The Mining Journal, Ltd., Mining Annual Review. London. Roskill Information Services Ltd. 1991.

Efforts to Reduce Scrap Generation

Inert gas atomization is a method of producing beryllium powder that is deemed superior to more traditional methods, particularly when forming parts via near-net-shape processing. With gas atomization, pellets and scrap are vacuum melted and inert-gas atomized in one step in a closed system. The powder produced is spherical (as opposed to flaky by attritioning, angular by impact grinding, or blocky by ball milling) and gives a packing density of 65 percent. Higher packing densities are desirable because they minimize the shrinkage that will occur during later processing.

In near-net-shape processing, beryllium powder is poured into a steel container of an appropriate size and shape: the shrinkage expected with the increase of density from 65-100 percent must be accommodated. One advantage of near-net-shape processing is that significantly better yields are achieved from the powder. For example, with the more-traditional vacuum-hot-press method, 140 pounds of powder would result in about 30 pounds of preformed shapes, which is then machined down to about 6 pounds.[39] This makes beryllium a high-cost material. With a shaped container and hot isostatic pressing to near-net shape, only about 25 to 45 percent of the powder used initially in the vacuum-hot-pressing method would be needed.[40] Minimal machining is required to convert near net shape parts into finished parts. Since beryllium competes with other, less expensive materials, any reduction in cost gives it competitive strength. Apart from the cost savings associated with lower powder requirements, since less machining is required, the amount of scrap generated is lower with near-net-shape processing. Near-net-shape is most attractive where the scrap ratio for a particular end-product (such as the whiffle ball example) is very high.

Using gas atomization and near-net shape processing has environmental advantages as well. Older methods for producing powder involve machining to produce chips from beryllium ingots, then attritioning, impact-grinding or ball-milling to make powder. More powder handling occurs in container-loading, compacting and machining to a final shape. All of these operations provide the opportunity for beryllium dust to escape, contaminating the

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[39] "Beryllium Metal Supply Options." National Materials Advisory Board, National Academy Press. Washington, DC. 1989.

[40] Barbara Weiss. "Brush Wellman Spends $11M to Retool at Elmore." Metalworking News. May 1, 1989.

environment. Gas atomization and near-net-shape processing can be carried out in a virtually closed environment, thus reducing the possibility of contaminating the atmosphere.

For manufacturers and fabricators, inert gas atomization and near-net shape processing provide benefits in the form of material savings and environmental safety. These benefits, in the long run, will pay for the capital investment required, and also lower the price of beryllium products, making them more competitive with products made from other materials.

FINDINGS

The beryllium sector is trying to maneuver through a transition period of rapidly declining demands for traditional beryllium-laden products, while dealing with rising environmental costs and ever higher social payments, such as health insurance for employees. The sector urgently needs to reduce costs and find new outlets for its products. The decline in defense spending has devastated the metallic beryllium sector, which is operating below 30 percent of its production capacity. The content of beryllium in beryllium copper alloys is falling as some structural applications (which used a higher percentage of beryllium) for the product are disappearing, and other uses such as mainframe computers are losing market share to powerful smaller units. However, other applications such as computer disk drives and automotive electronics are growing. Specifically this assessment found that:

- An assured source of beryllium and an economically viable, technologically capable ability to process that material is critical to the national security. In addition to being a source of beryllium material, the domestic sector continues to research and develop advanced applications for the metal important for future defense uses. In a major war, or protracted regional conflicts, the demand for beryllium products (metallic beryllium, beryllium alloys and ceramic) may rise because of its use in the most sophisticated weapons as precision optical components, inertial guidance systems, night vision systems, and structural components. Moreover, future weapon systems, missiles in particular, will continue to rely on advanced beryllium products. (DOD plans to acquire fewer total future systems due to defense cutbacks.)

- Because of its very high price, environmental and health risks, the demand for beryllium products is limited to applications where beryllium's special properties are crucial, and difficult to substitute for without a substantial decline in performance. Nuclear military applications will continue to decline.

- The limited business available in the beryllium sector provides major economic barriers to new entrants, and has resulted in a single integrated producer, Brush Wellman, supplying most of the Western world. However, this producer cannot be expected to compete over the long-term against state supported operations in China and the former Soviet province of Kazakhstan. Brush Wellman currently has an advantage in that its product is the only material having passed qualification testing

for U.S. military applications -- qualification testing is both expensive and lengthy.

- The U.S. metallic beryllium sector may shutdown because of very low levels of military demand. If the metallic sector were to shutdown, U.S., European and Japanese users would have to turn to Kazakhstan or Mainland China for alternative sources.

- Reduced profitability and projected low demand for beryllium products are making it difficult for Brush Wellman to justify investment in new capital equipment and research and development. Further efforts to develop commercial applications through defense conversion for high beryllium content items will help stabilize this industry in the long-term.

- Recycling of beryllium scrap by defense subcontractors (and others) was found to be near its optimal cost effective level based on current technology and manufacturing practices.

- Greater economic gains can be made by reducing the generation of scrap. A previous study by the National Material Advisory Board sponsored by the Department of Defense and the Department of Energy reported that investments in gas atomization should substantially reduce environmental contamination and processing costs and further improvements in near net shape technology can potentially greatly reduce scrap rates by more than half in the production of metallic beryllium. This could reduce costs of producing metallic beryllium considerably. Brush Wellman could pursue this avenue through DOD's ManTech program.

- Goals and inventories for the National Defense Stockpile of beryllium copper master alloy and metallic beryllium should be carefully reexamined for national defense requirements taking into account the availability of material from the sole supplier. If excess inventories exist, then any disposals of excess inventories should be carefully studied by the Market Impact Committee to determine the effect on the sole Western World supplier.

APPENDIX A

LETTER FROM DOD REQUESTING STUDY

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, DC 20350-2000

IN REPLY REFER TO
4000
Ser 402F1/0U594105
21 Jun 90

From: Chief of Naval Operations
To: U.S. Department of Commerce, Bureau of Export Administration, Under Secretary for Export Administration (Attn: Dennis Kloske)

Subj: BERYLLIUM METAL STUDY

Encl: (1) Beryllium Study Major Questions
(2) Beryllium Fabrication Sources - Domestic

RECEIVED
1990 JUN 28 P 3:

1. Beryllium metal because of its unique properties (low weight, high strength, stiffness and corrosion resistance) is a vital industrial resource to a number of critical and strategic government programs. Only one western world supplier exists today, Brush Wellman, Inc. (BWI), which supplies the quality and quantity of metal to the government. A critical situation occurs if this supply chain is broken.

2. A joint Department of Defense (DOD) and Department of Energy (DOE) Beryllium Supply Program (BSP) was initiated in 1981 to determine actions required to assure continuous quality and quantities of beryllium supply. The Beryllium Coordinating Committee (BCC) was established at a later date to provide technical advice for the BSP and technical guidance to DOE, Albuquerque, New Mexico.

3. The BCC has examined the current beryllium metal manufacturing processes and identified areas and actions required that will promote improvements in the process. During the BCC quarterly meeting held 7-8 November 1989, DOD tasked the Navy to conduct a study on the DOD manufacturers' percentage of beryllium metal scrap generated and the disposition (including processes and procedures) of the scrap. Major questions to be answered by prime contractors and manufacturers as well as their subcontractors are contained in enclosure (1). Enclosure (2) lists known contractors and subcontractors. This list is not inclusive and as a result of this study additional beryllium metal users may be identified.

4. Previous cooperative efforts between your Office of Industrial Resource Administration, Strategic Analysis Division, and the Department of Defense/Armed Services in studies of the gas turbine engine, ball and roller bearing, and precision optics industries have resulted in mutually beneficial and well-received reports. Based on your expertise in preparing industry surveys and collecting industry data pursuant to the Defense Production

849080

Subj: BERYLLIUM METAL STUDY

Act of 1950, request your assistance in the initial planning, survey, and data collection analysis for this study. As in our other joint efforts, we will guarantee the confidentiality of the data provided. The data is needed by 15 October 1990.

5. The point of contact for this matter within the Navy is Edward Purcell, OPNAV (OP-402F1), at (202) 695-3293 or Patricia Whitington, NAVSUP (SUP521B), at (202) 692-5300.

S. R. ARTHUR
Deputy Chief of Naval
Operations (Logistics)

BERYLLIUM STUDY
Major Questions

1. How much beryllium scrap is generated at each manufacturer, prime contractor and subcontractor?

2. What methods, procedures are followed after scrap is generated?

3. Does the scrap get disposed or distributed to another activity?

4. Where does the scrap get distributed?

5. If the manufacturer is selling the scrap, to whom is he selling, how much, and is the government reimbursed or provided a part of the profits?

Enclosure (1)

Bureau of Export Administration
Washington, D.C. 20230

July 6, 1990

Mr. S.R. Arthur
Deputy Chief of Naval Operations (Logistics)
Department of the Navy
Washington, DC 20350-2000

Dear Mr. Arthur:

Thank you for your letter to Under Secretary Kloske requesting our agency's support for your upcoming study of the beryllium metal industry.

We will be pleased to work with your staff in the planning, survey, data collection and data analysis for this study. Our point of contact for this effort will be Brad Botwin at (202) 377-4060 or Edward Levy at (202) 377-3795. We will be contacting you in the next few days to schedule an organizational meeting.

Sincerely,

John A. Richards
Deputy Assistant Secretary for
Industrial Resource Administration

APPENDIX B

PRODUCTION PROCESSES

EXTRACTION PROCESSES

BERTRANDITE PROCESS

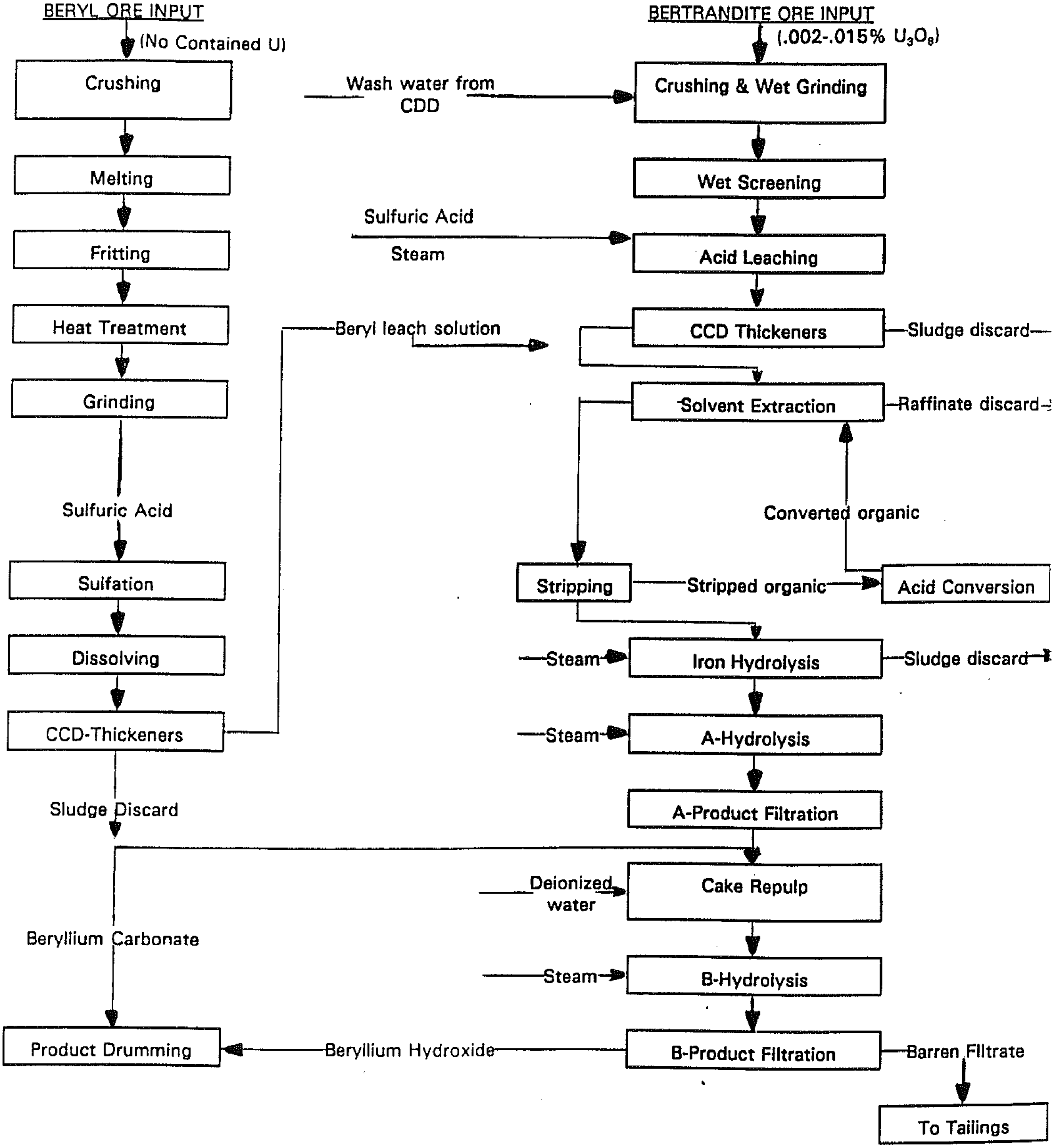
The ore is transported by truck from the Spor Mountain deposit to Brush's extraction facility near Delta, Utah, a distance of 47 miles. The ore is wet milled to provide a slurry of -20 mesh particles, which is leached with sulfuric acid at temperatures near the boiling point. An aqueous solution containing dissolved beryllium sulfate is separated from the solids by counter-current decantation thickener operations. The resulting solution contains 0.4-0.7 g/L Be, 4-7 g/L Al, 3-5 g/L Mg, and 1.5 g/L Fe, plus assorted other minor impurities.

A beryllium concentrate is produced from the leach solution by a counter-current solvent extraction process using di-2-ethylhexyl-phosphoric acid in kerosene as the organic extraction. This process has been described in detail by Maddox and Foos. The raffinate from this operation contains most of the aluminum and all of the magnesium present in the original leach solution. The loaded organic phase is stripped of its beryllium content with aqueous ammonium carbonate. The strip solution is heated to 70°C precipitating the coextracted iron and aluminum, which are removed by filtration. Heating the solution to 95°C causes nearly quantitative precipitation of beryllium basic carbonate 2 $BeCo_3Be(OH)_2$. After filtration and repulping in deionized water, further heating to 165°C yields a beryllium hydroxide product. This hydroxide is the common input to either beryllium-copper alloy, beryllium oxide ceramics, or pure beryllium metal manufacture.

BERYL PROCESS

Unlike bertrandite, the silicate structure of beryl is not acid-soluble. The Kjellgren sulfate process used at the Delta, Utah mill of Brush first melts the ore at 1,650°C followed by quenching in water to destroy the original silicate structure. The fritted beryl is then given a further heat treatment at 900-1000°C in a rotary kiln to increase the reactivity with sulfuric acid. A slurry of the powdered beryl frit with sulfuric acid is heated to 250-300°C converting the beryllium and aluminum contents to water-soluble sulfates. The silica is present in the water-insoluble dehydrated form and is discarded.

The original Kjellgren process proceeded to separate aluminum and other impurities from beryllium by a series of crystallization and precipitation steps. Brush's practice today is to introduce the aluminum-beryllium sulfate solution into the solvent extraction plant operating with bertrandite feed combining the two streams when beryl is being processed. Thus, the product of beryl extraction is again beryllium hydroxide Be(OH)2.


BERYL ORE INPUT
(No Contained U)
Crushing
Melting
Fritting
Heat Treatment
Grinding
Sulfuric Acid
Sulfation
Dissolving
CCD-Thickeners
Sludge Discard
Beryllium Carbonate
Product Drumming
BERTRANDITE ORE INPUT
(.002-.015% U_3O_8)
Wash water from CDD
Crushing & Wet Grinding
Wet Screening
Sulfuric Acid
Steam
Acid Leaching
Beryl leach solution
CCD Thickeners
Sludge discard
Solvent Extraction
Raffinate discard
Converted organic
Stripping
Stripped organic
Acid Conversion
Steam
Iron Hydrolysis
Sludge discard
Steam
A-Hydrolysis
A-Product Filtration
Deionized water
Cake Repulp
Steam
B-Hydrolysis
B-Product Filtration
Beryllium Hydroxide
Barren Filtrate
To Tailings

PRODUCTION OF PRIMARY BERYLLIUM

MAGNESIUM REDUCTION OF BERYLLIUM FLUORIDE

The primary beryllium produced in the United States since World War II has nearly all been manufactured by the magnesium reduction of anhydrous beryllium fluoride. The fluoride cannot be directly prepared by an aqueous route. The crude beryllium hydroxide from the extraction plant is dissolved in ammonium bifluoride solution, purified by precipitation treatments for a variety of impurities and ammonium fluoroberyllate, $(NH_4)2BeF_4$, is crystallized from the purified aqueous solution. This salt is thermally decomposed to beryllium fluoride at about 900-1000°C, producing NH_4F gas and molten BeF_2, which is cast into small pigs.

The reaction between beryllium fluoride and magnesium, producing beryllium and magnesium fluoride, is carried out in large graphite crucibles that are incrementally charged with the fluoride and magnesium to control the exotherm from the reaction, which initiates at about 900°C. In order to obtain good separation of molten beryllium from the molten magnesium fluoride, excess beryllium fluoride is provided in the charges (i.e., magnesium is supplied to reduce about 75% of the BeF_2 present) decreasing the slag viscosity. After reaction, the charge temperature is taken above the melting point of beryllium, the metal collecting in a biscuit that floats on the slag. As this biscuit contains substantial quantities of entrapped slag, the molten charge is poured into a cold receiver breaking up the beryllium biscuit into pea-to marble-sized pebbles that are relatively slag-free. After cooling, the charge is water leached in a ball mill readily separating the magnesium fluoride and beryllium pebble and dissolving the excess beryllium fluoride for recycle.

ELECTROWINNING OF BERYLLIUM

The electrowinning of beryllium has been the objective of many research efforts but has not been used to produce substantial quantities of the metal. Early work in Germany resulted in the use of fused salt electrolysis of beryllium chloride-sodium chloride during World War II. This procedure was used in the U.S. for a short time by Clifton Products Inc., and in France by Pechiney but is not known to be in commercial use today.

Electrorefining of beryllium using a $KCl\text{-}LiCl\text{-}BeCl_2$ bath has also been operated in the U.S. by Brush and Kawecki Berylco Industries, but again, is not being practiced today. This remains a preferred route to beryllium of exceptionally high purity.

VACUUM CASTING

The final processing step for beryllium pebbles is vacuum casting to remove any remaining reduction slag and magnesium metal. The processing of electrolytic material has incorporated the same step to remove any entrapped salt from the electrolysis bath. This operation also provides a recycle point for beryllium-machining chips or other high quality forms of beryllium scrap. The pebble and scrap are co-melted in a MgO crucible and poured into a graphite mold

resulting in a 400-lb ingot in present production practice.

POWDER MANUFACTURING

Beryllium normally is supplied as a powder metallurgy product at a density of 99% of theoretical or higher. Beryllium can he cast successfully by a number of techniques, but the resulting grain size has been at best in the 80-100 μm size range. The strength, ductility, and machining characteristics of beryllium are all greatly enhanced by powder metallurgy processing as compared to coarse-grained material derived from casting technology.

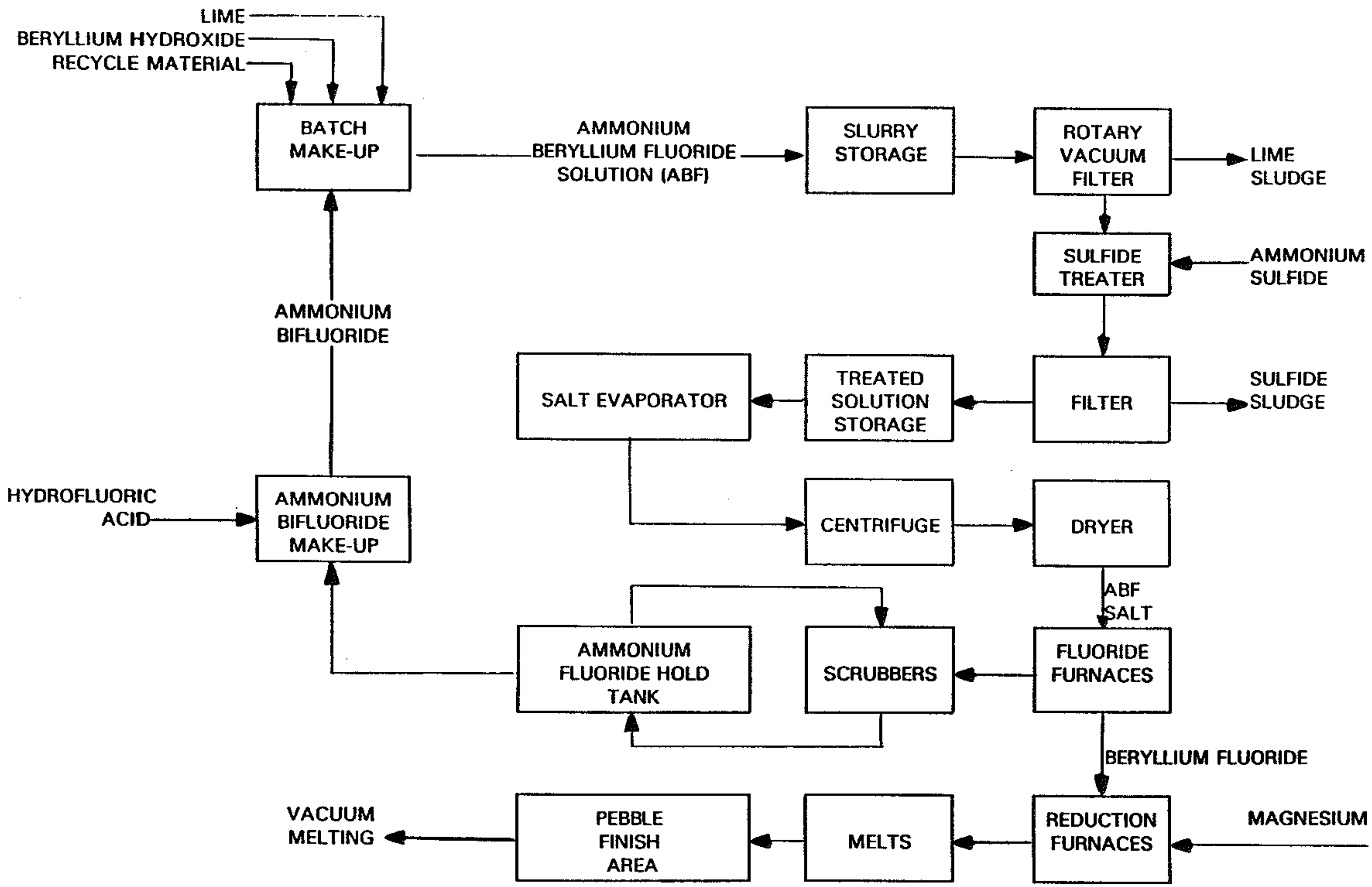
No acceptable chemical procedure for the direct production of beryllium powder has as yet been developed. Mechanical methods are used, therefore, exclusively. The vacuum cast ingots from primary metal production are first reduced to machine chips on lathes with multiple cutters and then fed to either attrition mills, impact grinding units, or a ball mill. The attrition mill is similar to the old flour mill in that the beryllium chips are fed between a stationary and a rotating beryllium plate. Size reduction proceeds primarily by basal plane cleavage resulting in a tendency for such powder to have a shape factor approaching platelets. This grinding procedure is being replaced with impact grinding, which involves the pneumatic blasting of beryllium chips against a beryllium target. Additional fracture mechanisms are involved yielding a powder that is much more equiaxed than attritioned powder. For very fine powders, ball milling is the preferred manufacturing technique. Most beryllium powder is prepared as -325 mesh powder with the subsieve particle size distribution controlled with Coulter counter measuring techniques.

Gas atomization is currently under study as a potentially promising technique for producing beryllium powder.

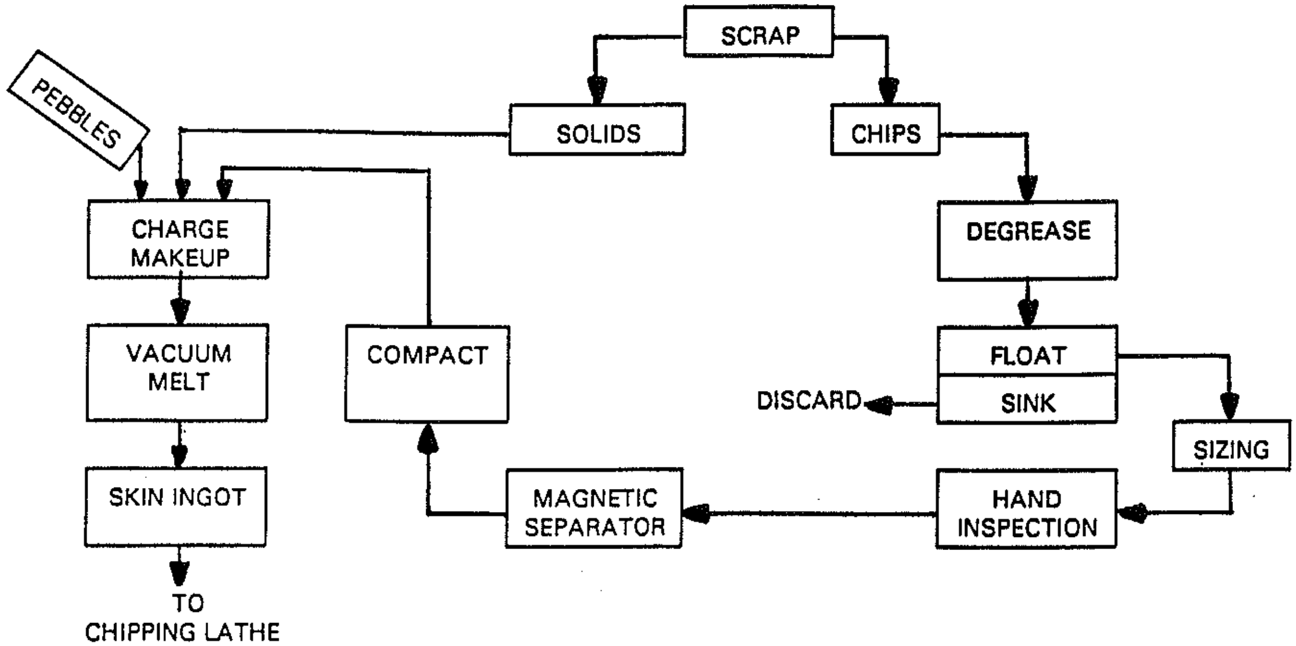
POWDER CONSOLIDATION

Vacuum hot pressing in the temperature range of 1025-1125°C is the primary procedure for consolidating beryllium powder into 99+% of theoretical density beryllium billets. Pressures on the order of 1200 psi are applied to the powder column contained in graphite or IN-100 dies at the sintering temperature. Capacity exists to make pressings up to 72 inches in diameter, although the majority of the pressings made fall between 9 and 20 inches in diameter with L:D ratios of 7.4:3.1, respectively. Hot pressings are usually made in the shape of right cylinders.

Alternative powder metallurgy techniques such as cold press-sinter-coin are used where sufficient production volume is attained to warrant the necessary engineering and tooling, as was the case with aircraft brake components for the F-14 and S3A aircraft. Currently, hot isostatic pressing (HIP), both containerless HIP and direct HIP of powder are under major development to provide components produced via near-net-shape consolidation for production program requirements. Brush has a 30-inch diameter by 65-inch hot isostatic press in operation in its production facility at Elmore, Ohio.



Process Flow Diagram for Beryllium Pebble Production
(SOURCE: "Producing Defect Free Beryllium and Beryllium Oxide", Brush Wellman Incorporated)


SCRAP
SOLIDS
CHIPS
PEBBLES
CHARGE MAKEUP
DEGREASE
VACUUM MELT
COMPACT
FLOAT
SINK
DISCARD
SIZING
SKIN INGOT
MAGNETIC SEPARATOR
HAND INSPECTION
TO CHIPPING LATHE

FABRICATION

Most users of beryllium purchase hot-pressed beryllium from the material supplier in the form of rough-machined shapes that are close to the desired final form. The conversion of the rough-machined "blank" to the final component is accomplished by the final user or by one of a number of precision machine shops that have been established for that purpose. Because of beryllium's stability, components are readily machined to tolerances of ±0.0005 inches and, on occasion, to ±0.00005 inches.

Although most beryllium components are produced by machining, billets of hot-pressed material are extruded into tubular shapes using a specialized extrusion procedure that involves "canning" the hot-pressed billet in a mild steel can. Nuclear Metals, Inc., of Concord, Massachusetts, produces beryllium tubing in a wide range of diameters and wall thicknesses for use in space hardware.

Using a process developed at Brush, under U.S. Air Force sponsorship, hot-pressed rolling billets are rolled into sheet and plate in thicknesses from 0.25-.020 inch and then further rolled to foil in thicknesses from 0.020 down to 0.0003 inch.

PRODUCTION OF BERYLLIUM-COPPER ALLOYS

MASTER ALLOY PRODUCTION

The same crude beryllium hydroxide product of the extraction plant used in the production of metallic beryllium is used in the production of beryllium-copper master alloy. After calcining to drive off the excess water, the alloy grade beryllium oxide thus formed is mixed with an appropriate amount of carbon dust and "pelletized" into pellets of approximately 0.250-inch diameter. These pellets are then mixed with dross (or slag) fines and fed into a large electric arc furnace along with copper chips. At the high arc furnace temperature (3400/3500°F, 1871/1927°C) in the presence of carbon, the beryllium oxide is reduced to beryllium, which immediately dissolves in the molten copper. This bath is poured into a ladle and allowed to cool to approximately 2600°F (1427°C) from its original 3400°F (1871°C) temperature. During the cooling, unreduced beryllium oxide, beryllium carbide, and other reaction products float to the surface and are removed as dross. The molten beryllium-copper master alloy, containing approximately 4% beryllium, is poured from the ladle into molds to produce 15-lb ingots.

ALLOYING

Although some of the ingots produced are sold as master alloy for a variety of casting applications, most are consumed internally in the production of a range of beryllium-copper alloy rolling and extrusion billets. Ingot copper, copper-cobalt master alloy, recycled beryllium copper, and beryllium-copper master alloy are charged into a 12,000-lb coreless induction furnace. The alloy constituents in the furnace are controlled to meet the specifications of the various alloy grades produced. The vigorous stirring action generated by the induction current

ensures adequate mixing of the alloying constituents to provide for uniform distribution of beryllium throughout the melt.

After sampling to ensure chemical composition, and after degassing, the melt is poured into water-cooled copper molds to produce continuously cast billets. Billets for strip production, approximately 4½ x 16 inches in cross-section, are poured two at a time. Extrusion billets of several cross-sections are cast in a similar manner as needed.

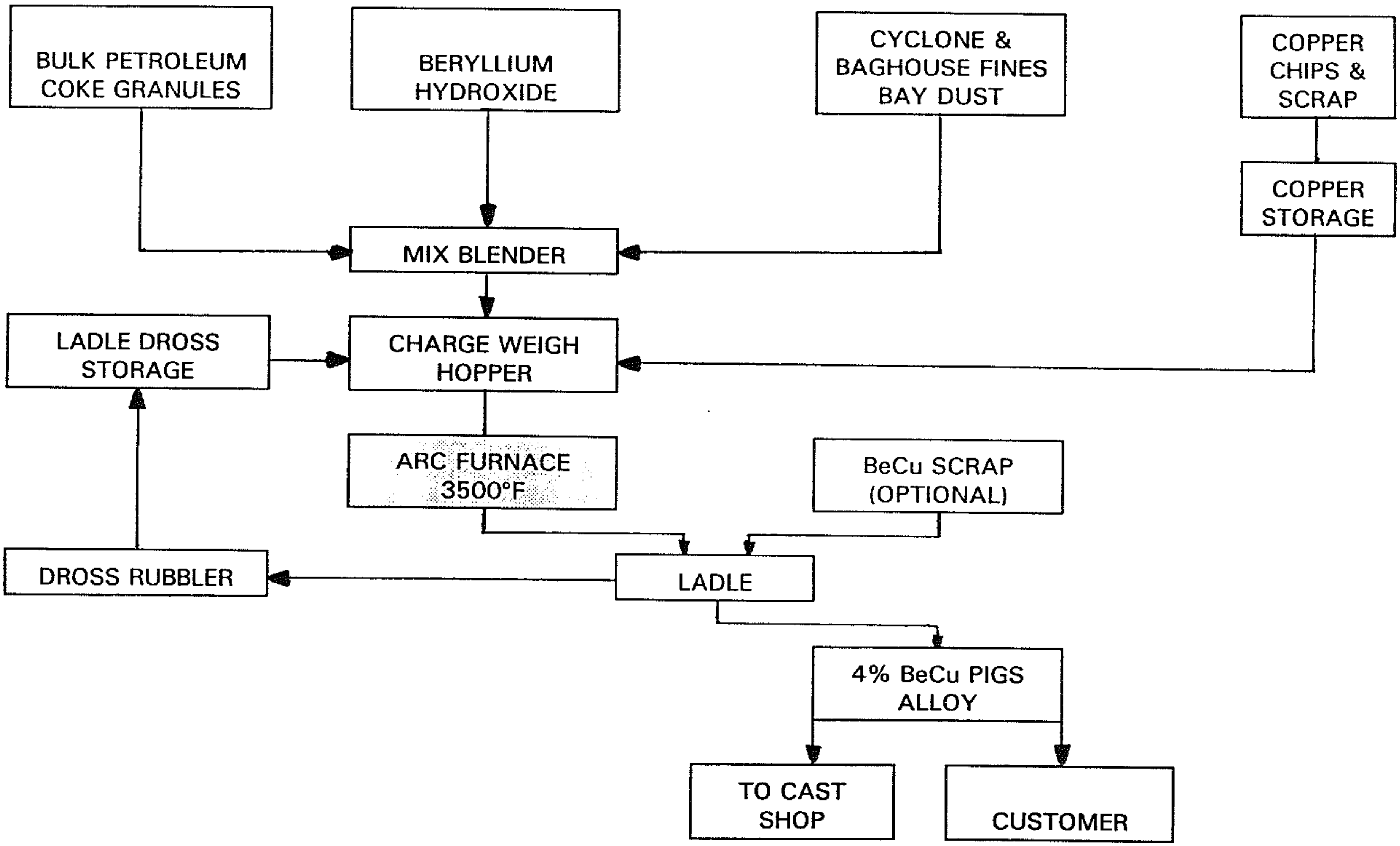
ROLLING

The continuous cast-rolling billets are preheated prior to hot rolling, and then are hot rolled from approximately 4.5 inches thick to 0.3 inches thick in a two-high reversing hot mill using a series of quick passes. The two 0.3-inch thick billets originating from the same melt are then coiled and welded together, end-to-end, to make one large coil for farther processing.

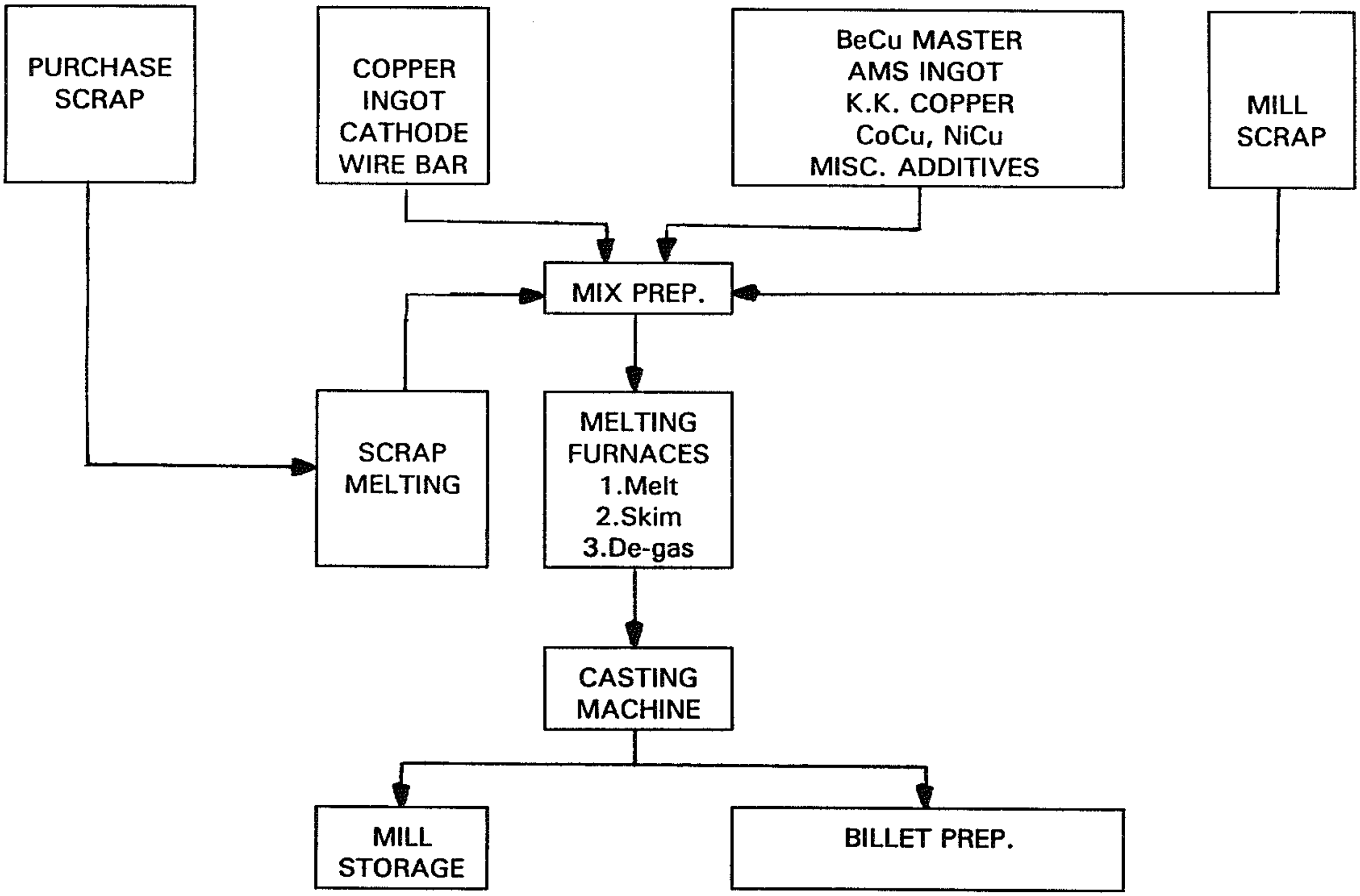
After welding, the coil is strand annealed, water quenched, and milled to remove 0.020 inch from each side. This 0.020 inch removes a thin layer of beta phase from the surface. The 0.3-inch thick coil is then cold rolled to 0.090 inch in several passes on a four-high rolling mill. The 0.090-inch product is then strand annealed, cleaned and pickled, and prepared either for shipment to customers or for further rolling. Much of the product is finish rolled in mills such as a Sendzimir Mill down to strip thicknesses of 0.002 inch thick. At these thicknesses, the material is shipped to customers and distribution centers throughout North America, Europe, and Asia.

EXTRUSION

Although most beryllium copper is used in strip form, there are a number of interesting requirements for rod and tube. These are produced by extrusion. When required, the induction alloying furnace will cast a continuous cylindrical billet that is subsequently prepared for the extrusion press. Beryllium copper is readily extrudable into a range of sizes and shapes in a hot extrusion process.



BULK PETROLEUM COKE GRANULES
BERYLLIUM HYDROXIDE
CYCLONE & BAGHOUSE FINES BAY DUST
COPPER CHIPS & SCRAP
COPPER STORAGE
MIX BLENDER
LADLE DROSS STORAGE
CHARGE WEIGH HOPPER
ARC FURNACE 3500°F
BeCu SCRAP (OPTIONAL)
DROSS RUBBLER
LADLE
4% BeCu PIGS ALLOY
TO CAST SHOP
CUSTOMER


PURCHASE SCRAP
COPPER INGOT CATHODE WIRE BAR
BeCu MASTER AMS INGOT K.K. COPPER CoCu, NiCu MISC. ADDITIVES
MILL SCRAP
MIX PREP.
SCRAP MELTING
MELTING FURNACES 1.Melt 2.Skim 3.De-gas
CASTING MACHINE
MILL STORAGE
BILLET PREP.

PRODUCTION OF BERYLLIA CERAMICS

BeO POWDER

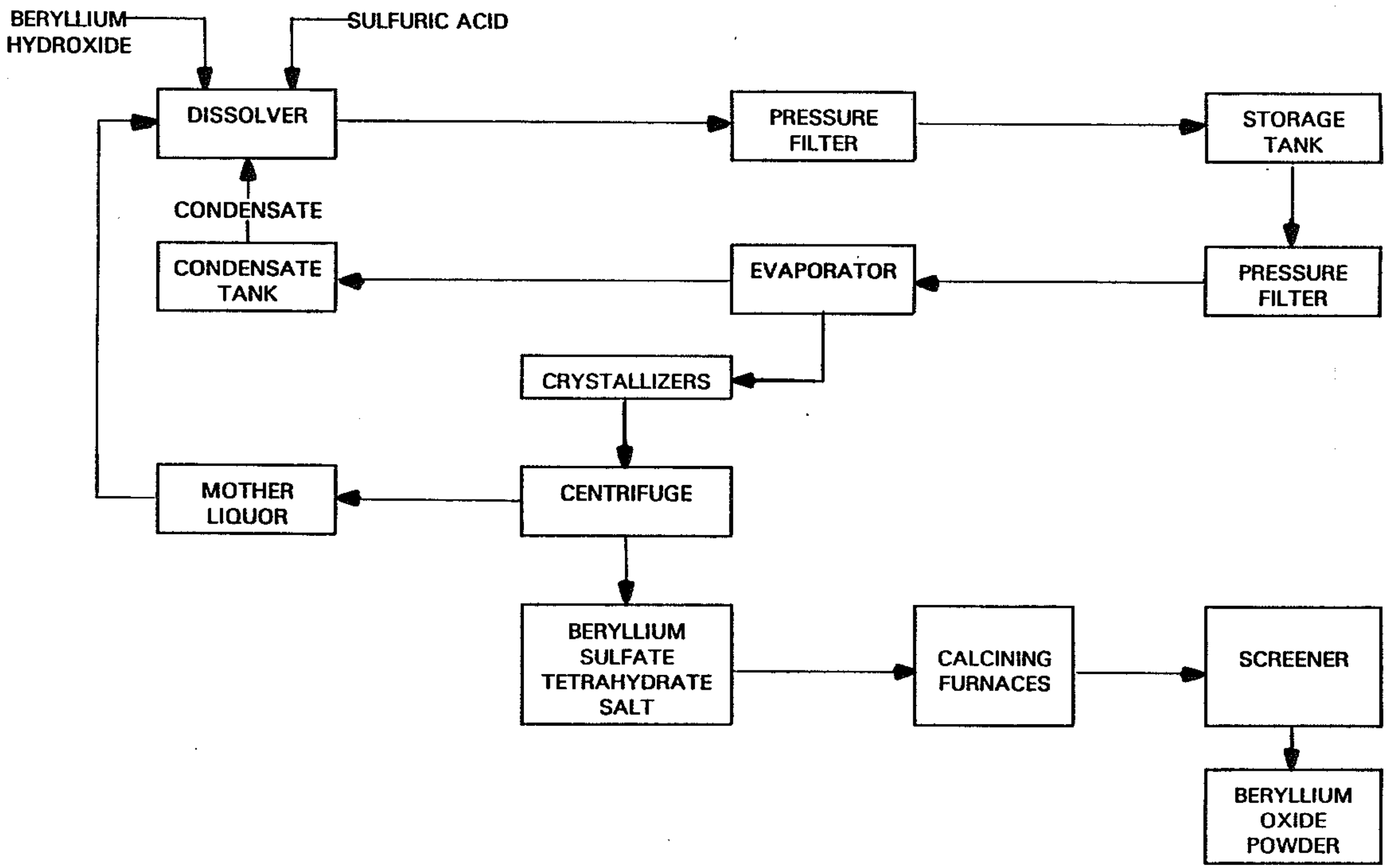
Once again, the impure beryllium hydroxide product from the extraction process is the starting material for the production of high purity, ceramic grade, beryllium oxide powder. The hydroxide is dissolved in sulfuric acid, forming a beryllium sulfate solution. The solution is filtered, then transferred to a glass-lined vessel, where water is evaporated and the solution becomes saturated. It is then transferred to another glass-lined vessel, where it is super-saturated by cooling. During cooling, beryllium sulfate tetrahydrate salt crystallizes.

The wet salt crystals are removed from the solution by a centrifuge. They are then ready for conversion into beryllium oxide powder in a calcining furnace, During the calcining cycle, the salt is heated as high as 1430°C. This drives off the water and decomposes the salt to beryllium oxide and two byproduct gases, sulfur dioxide and sulfur trioxide. Scrubbers remove the pollutants from stack gases.

FORMING AND FABRICATING

Beryllia ceramic shapes are produced using techniques common to other ceramic industries, such as dry pressing in a range of press sizes, extruding, isostatic pressing, hot pressing, and tape casting. More complex shapes require subsequent machining using operations such as grinding, lapping, drilling, or laser cutting. For some configurations, the machining is performed when the body is in the "green" condition, before firing.

Beryllia is commonly metallized with refractory systems such as molybdenum-manganese, or tungsten-based processes, nickel plated for solder and brazing applications, and gold plated for die and wire bond applications. Thick film conductors, resistors, and dielectrics for beryllia are available from a number of thick film ink vendors for hybrid circuit applications. Thin film metallization can be applied to beryllia using processes similar to those for other commonly used thin film substrates.



Process Flow Diagram for Beryllium Oxide Powder Production
(SOURCE: "Producing Defect Free Beryllium and Beryllium Oxide", Brush Wellman Incorporated)

DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA ★