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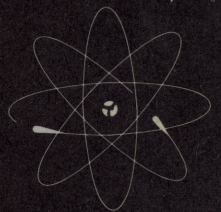
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HEALTH PROTECTION IN BERYLLIUM FACILITIES  
SUMMARY OF TEN YEARS OF EXPERIENCE

A.J. BRESLIN AND W.B. HARRIS

MAY 1, 1958



UNITED STATES ATOMIC ENERGY COMMISSION  
NEW YORK OPERATIONS OFFICE







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## ABSTRACT

Beryllium materials have been manufactured and processed safely by USAEC contractors over a period of ten years at a variety of operations ranging from small experimental projects to large production plants. The application of basically conventional engineering controls to restrict airborne contamination and personal contact has successfully reduced injury to an acceptable level.

The potential hazard increases with greater quantities of in-process material. In small-scale operations the hazard is usually confined to employees directly involved. At larger enterprises such as the beryllium refinery, neighborhood air contamination and stream contamination can present problems, although it should be noted that any present restriction of water concentration is based on administrative policy rather than on known hazard.

The control criteria have been a set of recommendations issued in 1948 by the Beryllium Medical Advisory Committee to the AEC. This committee proposed air concentration maxima for occupational and neighborhood exposures. These values have been re-examined periodically and have remained essentially unaltered, although there has been some liberalization of interpretation to permit greater flexibility in larger plants so that reasonably uninterrupted production could be achieved. The liberalization has been based on the experience described in this report.

Certain key factors in process design and operation common to both large and small operations are essential to satisfactory control. These include close attention to procedural details, restriction of manual process steps, careful application of local exhaust ventilation to most process steps, frequent air sampling to discover incipient control deficiencies, routine thorough housekeeping, and the candid indoctrination of employees to secure genuine cooperation. The importance of these control measures and the techniques of application are discussed along with pertinent exposure data.

A comprehensive medical program is of basic importance. Preplacement screening and periodic re-examination are recommended for any operation of significant magnitude.

Optimum design for the control of neighborhood air contamination has been achieved through the application of stack diffusion theory and careful choice of air cleaning equipment. Continuous offsite air sampling is used at larger installations to monitor the dispersion of stack effluents. Data are presented to demonstrate the degree to which the designs were successful in achieving the basic objective.



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# HEALTH PROTECTION IN BERYLLIUM FACILITIES

## SUMMARY OF TEN YEARS OF EXPERIENCE

### INTRODUCTION

The extraction of beryllium from its ore, beryl, and the production and fabrication of beryllium metal and its compounds and alloys constitute a relatively small yet significant industry in the United States. The beryllium industry began in this country in 1931 and grew slowly for the next ten years. The use of beryllium was given a substantial impetus during and after World War II when beryllium-copper emerged as a highly useful alloy for nonsparking tools and for parts in electronic and mechanical instruments and aircraft engines, and beryllium metal was found to possess properties uniquely suited for certain nuclear reactor components. During this period the federal government was the major consumer of the national output. Since the war the commercial beryllium-copper market has continued to expand, and the demand for metal has also increased with the growing interest in nuclear power reactors. The high temperature characteristics of both the metal and the oxide are also assuming more importance in the field of high-speed flight.

An unfortunate development in the beryllium industry was the discovery of illness in and around plants where beryllium materials were refined and processed. The first reports of occupational illness,<sup>1</sup> which appeared as early as 1936, did not receive wide attention in the United States or were, in some instances, discredited. However, the cases grew in number and were carefully documented. In the early 1940's the seriousness of the hazard was recognized, although agreement was not yet complete as to the cause of the occupational disease. During this period nonoccupational cases also came to light.<sup>2</sup> Many held the view that the anions in the beryllium compounds were the responsible agents<sup>3</sup> rather than beryllium itself. Today concurrence is unanimous among investigators that beryllium *per se* is the causative agent of the occupational illness which is unique to the industry. On the other hand, it has been clearly demonstrated that the application of suitable engineering control measures can make the handling of beryllium and its compounds no more

hazardous than that of other more common toxic industrial materials such as mercury and lead. Experience gained over a period of about ten years in the operation of beryllium facilities under contract to the Atomic Energy Commission has resulted in practical, proven control measures that can serve as guides in the engineering design and safe operation of new or modified installations. The facilities represent a wide spectrum of types of operation from small laboratories to full-scale production plants with processing rates from grams to tons per month.

Among the specific processes with which the AEC has had contact are 1) production of oxide and hydroxide from beryl ore, 2) reduction of metal from salt, 3) oxide fusion, 4) vacuum casting of metal ingots from "pebbles," 5) production of metal flake by chlorination and electrolysis starting with oxide, 6) fabrication of beryllia ceramics, 7) sublimation of beryllium fluoride from a mixture of magnesium fluoride and beryllium fluoride, 8) powder metallurgy operations, and 9) metal machining and fabrication. These processes are described more fully in Appendix I.

The purpose of this report is to summarize the information gathered during the design and operation of these facilities so that it may be used in providing for the safe handling of beryllium materials.

### OCCURRENCE OF BERYLLIUM DISEASE AND CRITERIA FOR ITS CONTROL

Two forms of disease are known to be associated with the production and processing of beryllium materials, respiratory illness and certain kinds of skin reactions.<sup>4</sup> Respiratory illness develops from the inhalation of excessive quantities of airborne beryllium dust, fume, or mist, whereas the skin reactions occur from direct contact of some compounds with the skin or implantation under the skin. Of the two types of exposure inhalation is certainly the more serious, and respiratory illness may terminate fatally; however both kinds of exposure may result in serious loss of working time.

Respiratory illness has been found among residents near beryllium plants as well as among in-

dustrial workers. The dermal effects have been largely occupational in origin, although individual cases have been reported of nonoccupational skin ulceration due to handling broken fluorescent tubes in which the phosphor contained beryllium. Such phosphors have not been used in the United States for many years.

### Respiratory Disease

Respiratory illness appears in both an acute and a chronic form. The former has occurred among industrial workers only, the latter among both workers and nearby residents. Illness is apparently caused by extremely small concentrations. Beryllium fluoride in amounts estimated at 400 to 650 micrograms per cubic meter of air, persisting for only a matter of minutes, caused acute illness in three of eight persons exposed.<sup>5</sup> Concentrations estimated to be no greater than  $0.1 \mu\text{g}/\text{m}^3$  resulted in cases of chronic illness among residents living near an extraction plant.<sup>2</sup>

Nearly every beryllium compound of industrial importance has been known to cause acute illness, beryl being the only known exception. There is some reason to believe that the chronic disease is caused only by beryllia, but existing evidence is inconclusive. For the present it is safest to regard beryllium metal and all its compounds as potentially toxic.

Both occupational and nonoccupational respiratory disease have been avoided at facilities operated under contract to the USAEC by adhering to exposure criteria, originated about ten years ago, which set upper limits on concentrations of beryllium in air. A few mild occupational respiratory cases (chemical tracheitis) have occurred where the limits were temporarily exceeded.

In 1948 the following concentration limitations were proposed by the Atomic Energy Commission Advisory Committee on Beryllium Intoxication:

1) The in-plant atmospheric concentration of beryllium should not exceed  $2 \mu\text{g}/\text{m}^3$  average concentration throughout an 8-hr day.

2) Even though the daily average might be within the above limit, no person should be exposed to a concentration  $>25 \mu\text{g}/\text{m}^3$  for any period of time, however short.

3) In the neighborhood of an AEC plant handling beryllium compounds, the average monthly concentration at the breathing zone level should not exceed  $0.01 \mu\text{g}/\text{m}^3$ .

To place these values in a frame of reference, they may be compared with maximum allowable concentration values for other more common industrial toxic dusts and fumes.

MATERIAL	MAXIMUM ALLOWABLE CONCENTRATION, <sup>6</sup> $\mu\text{g}/\text{m}^3$
Arsenic	500
Fluorides	2500
Lead	150
Mercury	100

Compared to those for other materials, the exposure criteria for beryllium were admittedly stringent but, nevertheless, were thought to be achievable through the application of proper engineering controls. (This evaluation has since proven to be entirely correct.) After a significant period of experience it was recognized that at production plants processing tonnage quantities of beryllium these limits were difficult to maintain without at least occasional exceptions. Since temporary exceptions within designated limits were not found to cause illness, certain liberalizations in the application of the basic criteria were introduced at the major plants under AEC contract. For instance, temporary concentrations (with designated limits) in excess of the stated maxima were permitted, provided that corrective action was immediately begun. Time limits were placed on the duration of the temporary excesses, and, if these were exceeded, operational shutdown was imposed. It was reasoned that small excesses could be accepted safely for limited periods of time because of safety factors in the basic exposure criteria. After several years had elapsed with no evidence of overt illness, the liberalization of interpretation was integrated with the original recommendations. The modified recommendations follow.

**In-Plant Recommendations.** The average in-plant atmospheric beryllium concentration should not exceed  $2 \mu\text{g}/\text{m}^3$ . If the result of the daily weighted average concentration computed on a quarterly basis for any occupation is  $>2$  but  $<5 \mu\text{g}/\text{m}^3$ , the contractor will submit plans for necessary corrections for AEC approval and provide all personnel exposed in this area with approved personal respiratory protective equipment. If the daily average concentration exceeds  $5 \mu\text{g}/\text{m}^3$ , the operation in question will be halted until the necessary improvements can be accomplished. A

daily average concentration  $>2 \mu\text{g}/\text{m}^3$  will not be permitted to exist for a period exceeding 60 days except with the specific approval of the Commission, which will be granted only in the event that satisfactory procedures for reducing the concentration to  $<2 \mu\text{g}/\text{m}^3$  have been accepted by the Commission.

In the event that a single air sample shows a concentration  $>25 \mu\text{g}/\text{m}^3$  within the operating area but  $<100 \mu\text{g}/\text{m}^3$  (and this is to be confirmed within 10 days of the time at which such a sample was obtained), all exposed individuals will be provided with personal respiratory protection approved by the Commission, and the Commission will be notified of steps being taken to eliminate the high concentration. If the concentration exceeds  $100 \mu\text{g}/\text{m}^3$  in a single sample (and this is to be confirmed within the above time limit), operations will be halted and the necessary corrections made to reduce the airborne concentrations at this single point to  $<25 \mu\text{g}/\text{m}^3$ . In no case will concentrations  $>25 \mu\text{g}/\text{m}^3$  be permitted to exist for a period exceeding 60 days without the specific approval of the Commission, which will be granted only if steps have been undertaken that can be expected to provide a satisfactory reduction in air concentration.

***Out-of-Plant Recommendations.*** In the neighborhood of an AEC plant handling beryllium compounds, the average concentration at the breathing zone level should not exceed  $0.01 \mu\text{g}/\text{m}^3$ .

In the event that the maximum average neighborhood concentration at the ground during any calendar month, as determined on a monthly basis, is  $>0.01 \mu\text{g}/\text{m}^3$  but  $<0.05 \mu\text{g}/\text{m}^3$ , the plant will be expected to inform the AEC of specific procedures which will be undertaken to reduce the airborne concentration. In the event that the concentration exceeds  $0.05 \mu\text{g}/\text{m}^3$ , operations will be immediately halted and the necessary corrections made to reduce the average concentration to  $<0.01 \mu\text{g}/\text{m}^3$ . In any event, concentrations  $>0.01 \mu\text{g}/\text{m}^3$  will be permitted to exist for not more than 60 days without specific authorization by the Commission, which will be forthcoming only if steps are being taken to bring about a satisfactory reduction in effluent material.

It is to be noted that no distinction is made with regard to the form of the beryllium contamination. The concentration maxima apply to beryllium itself regardless of its compound.

It should be mentioned that the exposure criteria, although adopted by a large number of beryllium processing installations, have not been recognized in any of the national codes which list maximum permissible concentrations of toxic substances. Ten years of satisfactory experience in several installations, as documented in this report, is thought to be reasonable evidence that the stated exposure criteria are conservative. It may be anticipated that these criteria will be revised eventually. It would appear, however, that any revisions are more likely to be toward relaxation rather than greater restriction.

### **Skin Manifestations**

Cases of ulceration and benign tumors resulting from beryllium fragments imbedded in the skin have been reported, but dermatitis is the only important skin reaction in processing operations. It is associated with the soluble salts, beryllium fluoride and ammonium beryllium fluoride being the most troublesome.

Although dermatitis results only from direct contact, the amount of beryllium dust deposited on the skin from a heavy suspension in air will cause the skin reaction. Material accumulated in work clothes and at the contact surfaces of dust respirators is another source of contact. However, although dermatitis can be severe, it will disappear after an individual is removed from exposure.

Avoidance of direct handling of beryllium materials and personal cleanliness are the two important factors in minimizing skin disease. At operations where gross body contamination is possible, end-of-shift showers and the daily issuance of clean work clothes are necessary. Dust respirators should be decontaminated daily. Needless to say, if the working atmosphere is limited to the beryllium concentrations stated above, the possibility of gross contamination is relatively slight.

### **Summary**

At present the only proven way to prevent sickness at a plant processing beryllium or its compounds is to maintain rigid control of the concentrations of beryllium in environmental air. For beryllium workers the average daily exposure should not exceed  $2 \mu\text{g}/\text{m}^3$ , and transient peak concentrations should not exceed  $25 \mu\text{g}/\text{m}^3$ . For out-of-plant air (neighborhood exposure) the concentration averaged over a month should not ex-



ceed  $0.01 \mu\text{g}/\text{m}^3$ . Excursions above these concentration values may be permitted, but only for limited periods as defined in the AEC control recommendations.

The stated concentration maxima are admittedly stringent, but they can be achieved through the application of engineering controls. However, the control of environmental air contamination alone is not enough. It must be coupled with a sound medical program. Beryllium workers should be under the supervision of an industrial physician.

The following sections describe in detail the components of a control program and cover process design and operations including both in-plant and out-of-plant considerations, supervisory and medical controls, and experience gained by HASL at a variety of beryllium installations.

#### IN-PLANT DESIGN AND OPERATION

Plant design and operation must be geared to eliminate direct contact with beryllium materials and to maintain air concentrations within the limits previously specified. In areas where either of these conditions cannot be met, suitable secondary means must be provided to prevent excessive exposure. Among these are protective gloves and clothing, protective skin creams, and personal respiratory protection. Wherever a choice exists, however, primary control should be selected.

The attainment of an average air concentration of  $2 \mu\text{g}/\text{m}^3$  or less imposes considerably greater restriction on operating techniques and entails far more extensive control equipment than that required for more common toxic substances. Therefore, it has been found generally advisable to segregate beryllium activities if other kinds of work are also being performed at the same installation. This restricts exposure to a limited number of individuals and permits the exercise of greater control over work procedures and the movement of beryllium materials.

The engineering tools required to control atmospheric contamination within the beryllium process areas consist of

- 1) The selection of process components that will release the smallest possible quantities of contamination.
- 2) Application of local exhaust ventilation at all points of potential contamination release.

- 3) Careful operating procedures.
- 4) Thorough housekeeping.
- 5) Provision for suitable personal protective measures.

Each of the components deserves equal emphasis. It would be a mistake to neglect any of them in setting up controls for a beryllium facility.

The responsibility for effecting safe plant operation rests with the engineer who must design equipment for good dust control, stipulate operating procedures consistent with minimal dusting, and monitor the air on a routine basis to be assured that adequate control is continually in effect. It is advisable that this work be delegated to a competent industrial hygiene engineer. Although the individual control methods are not uncommon in industrial practice, an industrial engineer inexperienced with toxic dusts generally will not be aware of the high order of control that must be built into, and maintained at, a beryllium process.

Adequate control is generally more easily accomplished where proper measures are integral with new plant design. The modification of an operating facility where overexposures exist may be more formidable in terms of cost and engineering skill than the proper design of a facility at its inception. Frequently problems are encountered in a modification program which result from existing equipment that is inherently difficult to control. However, modification has been accomplished satisfactorily in several installations where unfavorable conditions had existed.

#### Process Design

Air contaminants are controlled by ventilation, and it is evident that required air capacities and the complexity of hood design are functions of the type of process and the details of its operation. Thus the establishment of good control must begin with the process itself. When undertaking to design a new facility or to install controls in an existing one, the first step should be to investigate the process with an eye to eliminating inherently dusty equipment and operations to the greatest possible extent. This will tend to simplify the designing of the ventilation, which is the next step.

It is quite obvious that the processing of dry, finely divided material will create far more dust than that of wet material. But the complexity of control required for the dry process will be directly

related to the handling methods used. For instance, there might be a choice between a manual and an automatic transfer system. Each may be controlled, but the ventilation necessary for the former method would generally be more complex and less effective than for the latter.

In the layout of a process every effort should be made to minimize the number of operations that present potential escape routes for dust. A few basic principles should be borne in mind.

1) Manual handling should be reduced to an absolute minimum. This recommendation cannot be overemphasized. Experience has repeatedly shown the majority of high dust concentrations in beryllium plants to be associated with manual tasks. This finding is certainly not unique to beryllium operations, but these specific dust sources are particularly manifest at beryllium facilities because of the generally low air dust concentrations. Where manual operations are necessary, they should be properly ventilated.

2) It should be assumed that every implement which has been in contact with beryllium is contaminated and therefore a potential dust source. Contaminated implements should not be removed from the hoods in which they have been employed until thoroughly cleaned. Frequently there are several locations in which one particular implement is needed. In this case it is preferable to provide a duplicate at each location rather than to transfer one implement back and forth. It is also possible in some cases to group operations so that they can all be controlled by a single ventilated enclosure and thereby obviate the need for tool transfer.

3) Each process step should be examined critically to determine whether by rearrangement or substitution it can be made less dusty. For instance, wet classifying is inherently less dusty than dry classifying.

4) The manual transfer of process materials must be expected to be dusty and, consequently, should receive careful attention. Where transfer containers are used, suitable exhaust must be provided for filling and emptying the containers. In transit they must be sealed and externally clean. Continued dusting from recently emptied containers is often troublesome; containers must not be taken outside the exhaust hood before residual dusting has abated or the container is thoroughly cleaned.

5) Where economically feasible, the use of automatic conveyors is advantageous. They are relatively easy to ventilate and require no attendance other than maintenance. Pneumatic conveyors are particularly well suited to handling a material such as finely divided beryllia. However, complications do arise when conveyors are dismantled for maintenance. Portable ventilation can be used for infrequent maintenance jobs.

Bearing these general rules in mind, each step of the process must be visualized to the smallest detail of operation to be sure that suitable control exists throughout. In the case of a new facility, specific steps often change in detail or even in concept during the design stage and, not infrequently, after the facility has been activated. Close liaison with engineering and production personnel is required to assure that the control provided will suit the operating techniques finally adopted.

#### Local Exhaust Ventilation

Careful process design and arrangement can minimize and simplify ventilating hoods and minimize the ventilating air capacity; it cannot eliminate the need for local exhaust ventilation. This is because air concentrations in excess of the stipulated maxima can be produced by extremely small quantities of contaminant. Essentially every process step must be provided with some degree of local ventilation. It is sometimes difficult to comprehend the fact that even processes which appear absolutely free of contamination nonetheless may be sources of significant concentrations. To cite an example, an average concentration of  $11 \mu\text{g}/\text{m}^3$  was measured in the close proximity of a man separating steel balls with a hand magnet from a container of soaking wet beryllium pebbles.<sup>7</sup> The operation was not ventilated. The  $11 \mu\text{g}/\text{m}^3$  can be definitely attributed to this specific operation because the average air concentration in the area was  $1.6 \mu\text{g}/\text{m}^3$ . One might wonder by what means the contamination became airborne, yet it was there. General room ventilation cannot be expected to provide satisfactory control for specific dust sources.

Indeed, general ventilation improperly applied can add to the problem of control by dispersing dust which may have settled on floors and work surfaces. Specific data regarding this phenomenon were obtained at a plant where unit heaters were used to warm the production area.<sup>8</sup> Successive

dust samples were collected alternately with the heater blowers on and off. The concentrations were found to be greater by a factor of two with the blowers on.

The basic principle of control is to contain and remove dust at its source. Local exhaust ventilation will do this provided that hoods and air volumes are properly selected. Hood types of a wide variety have been employed successfully in the many facilities observed, ranging from small laboratory apparatus to large production units. Because of the variety of equipment used at beryllium operations and the variation in operating requirements for the same piece of equipment at different facilities, it is impractical to try to design a universally applicable hood. The type used for each operation must be selected by the industrial hygiene engineer on the basis of good dust control plus operating and maintenance requirements. But a consideration which should not be neglected, particularly in larger plants, is the total exhaust air capacity. Recognition of the extent to which ventilation must be applied because of the multiplicity of even small points of exhaust indicates that the efficient use of air capacity can be an important economic factor. Thus, the selection of hoods with optimum performance on an air capacity basis is a desirable objective. Therefore, adequate dust control, ease of operation and maintenance, and optimum utility of exhaust air should all be given proper weight.

Before discussing specific types of local exhaust control applications, a few general observations may be made. Experience with a variety of hoods leads to the following recommendations:

- 1) With rare exceptions, dampers should not be designed to permit adjustment by operators.
- 2) Where frequent access is required, encumbrances should be minimal.
- 3) Simplicity is desirable. The less manipulation by the operators is required, the greater is the prospect of proper hood use.
- 4) Designs should be conservative.

In describing the kinds of hoods and their particular characteristics as applied to specific plant and laboratory equipment, it is convenient to consider four, perhaps arbitrary, categories of operations.

1) *Manual.* Small, purely manual equipment requiring continual access while in use: machine tools, sorting, weighing, metallography, etc.

2) *Batch automatic.* Larger, semiautomatic, generally requiring intermittent access to introduce or withdraw process material and to adjust equipment: blenders, furnaces, filters, batch centrifuges, ball mills, etc.

3) *Automatic unattended.* Essentially self-operating, requiring little or no access except for maintenance: rotating kilns, continuous feed centrifuges, automatic conveyors, storage bins.

4) *Material transfer.* This is involved in the first two categories above, but it is important enough for separate discussion as a fourth category.

**Manual Operations.** Operations involving continual manual manipulation are, with only a few exceptions, most effectively and economically controlled by completely enclosing hoods provided only with those openings necessary for operational access. Hinged or removable panels may be provided for occasional maintenance. A positive inflow of clean air at the hood openings minimizes the escape of dust into the general atmosphere. A few rules have general application to enclosing hoods:

1) The size of the hood openings must be made as small as possible, consistent with reasonable accessibility, to prevent the escape of dust and for most efficient use of ventilating air.

2) Hoods must be designed so that a man need never place his head inside during normal operation.

3) Air velocities at hood openings should be 150 fpm or greater. Where the operation being controlled imparts a high kinetic energy to the dust particle or where external air turbulence is great, correspondingly greater hood face velocities are needed.

With regard to the last item, it may be demonstrated theoretically that particles of a respirable size ( $<5\text{-}\mu$  diam) will reach a terminal velocity within a very short distance (less than a few inches) even though projected with the very high initial velocities imparted by machine tools such as disc sanders and cutoff wheels. The escape of larger particles should not contribute to the inhalation hazard. From this one might conclude that hood velocities in excess of 150 fpm, a value which assures good control for nonenergetic particles, are unnecessary. However, large particles tend to drag smaller ones along and thus to increase the actual as well as the measured hazard; and the projecting operation will frequently be



such as to project a current of air on which small particles will ride. Also, while large-diameter dust particles may not constitute a primary inhalation hazard, the escape of such particles does constitute a net increase in concentration in the immediate vicinity of the operation and will generally be detected by dust measuring equipment. Although equipment is available by which dust sizes can be differentiated, the present standards for beryllium exposures do not include a size factor; all maximum allowable concentrations are derived on a weight basis.

Relatively small pieces of apparatus such as bench grinders, pulverizers, sieves, weighing scales, tampers, and small blenders and mills can usually be conveniently and effectively ventilated with enclosing hoods. Other fully manual (nonmechanical) operations, such as picking and sorting and special jobs, are also best controlled in this manner.

It is often desirable to group several small machines or operations in a single bench booth, such as a chemical hood. This is particularly effective when three or four machines are to be used successively in the process. In this case their physical proximity represents a saving in time, space, and ventilation capacity. A very definite advantage to this arrangement is that the transfer of material from one piece of apparatus to the next may be done within the hood. It is also practical and simple to retain tools under the ventilation. Ventilation is inherent during handling and no special equipment need be devised.

Hoods of this type may be of any size; a width of 10 to 15 ft is not infrequently encountered. Since the rate of exhaust air will vary with the size of the hood openings for a given design velocity, these should be minimized in the interest of economy. An operating opening 6 to 8 in. high along the hood face usually provides ample access. The opening may be diminished by the addition of sliding panels to allow access to only a portion of the hood enclosure at a time. This will reduce ventilation requirements and induce more methodical operation. The upper part of the hood face may be permanently covered with glass or transparent plastic for visibility.

The unique qualities of beryllium extend even to the manner in which it machines. It has several unusual properties, the combination of which causes it to generate potentially dangerous quantities of dust when it is worked. Not the least of

these, of course, is its very low allowable concentration. The material does not cut easily, requiring special, well maintained tools. It is very friable, forming a small broken chip along with considerable fine dust. The use of coolant helps only slightly. It should be noted, however, that these properties are those of the unalloyed metal and do not apply to beryllium-copper or other alloys.

The ventilation of machine tools warrants special consideration. Generally they cannot be properly operated if too much restriction is enforced on the operator. Totally enclosing hoods may often be unnecessarily cumbersome and for many tools they are not needed. A very useful control method is the combination of a high-velocity chip pickup at the cutting tool and a secondary partial enclosure. This has been applied to lathes with particular success. If the pickup can be designed essentially to surround the source of chips without operational interference, as in the case of milling or drilling, the enclosure may be eliminated.

High-speed abrasive tools have generally required complete enclosure. Surface grinders, centerless grinders, and cutoff wheels require this treatment.

**Batch Equipment.** This category may include certain ball mills, blenders, tanks, reactors, furnaces, filters, and some kinds of centrifuges. No firm line of distinction may be drawn between this category and the last, but these items by virtue of their size would not be included in the manual category. The important characteristic of batch equipment with regard to dust control is the necessity to charge and withdraw material for each process cycle, i.e., transfer of material. Many of these devices present no significant contamination problem while in operation because they are effectively sealed.

An obvious way to overcome the transfer difficulty is to devise an automatic charge and/or receiver system. This has been done successfully for a few batch operations. One example was an oxide furnace gravity fed from an overhead hopper, which was in turn fed by a pneumatic conveyor. Withdrawal of the fired oxide was accomplished manually by the ingenious combination of a ventilated transfer cart and pneumatic conveyor system. The pneumatic suction line was manipulated manually from outside the furnace enclosure and was never withdrawn from the hood. The use of hopper feeds is quite common. For use in connec-

tion with rotating batch equipment, the valving arrangement must be carefully designed for minimum leakage and positive cutoff. Almost invariably, ventilation is necessary.

Wet batch reactions pose no difficulties where the process material can be pumped through pipelines in and out of the mixing or reacting tank. The escape of vapor or mist can be prevented by applying a suitable exhaust to the tank. Here again it is interesting to note that exhaust is in fact required: unventilated wet process equipment may normally be expected to produce concentrations above permissible. The air capacity should be sufficient to create an indraft velocity of 50 to 150 fpm through access covers or a slight negative pressure if the vessel is normally sealed. Extra capacity may be required if the reaction is violently exothermic or when access is required during operation.

Usually, however, the batch operation involves filling and dumping. The effectiveness of the control applied will depend on the care with which ventilation and baffling are designed for the dumping and filling operations.

Two approaches to hooding for batch devices have been used successfully. The first, where size permits, is to enclose the unit completely with provision in the enclosure for access to charge and discharge and to make adjustments. Hoods of this type may often be very simple rectangular boxes with access doors or panels suitably placed. The second method is to apply exhaust at each point in the equipment where dust may be emitted. This requires a more skillful design with proper control velocities to insure capture of the escaping dust. Each type offers advantages; their characteristics are listed below:

	BOX	TAILORED FIT
Design:	Simple.	Requires skillful application.
Control:	Reasonably positive.	Depends on design.
Accessibility:	Sometimes inconvenient.	Generally good.
Housekeeping:	Contamination contained; generally accumulates.	Self cleaning if properly designed.
Material transfer:	Containers require cleaning prior to removal.	May be more or less fool-proof depending on design.
Economy:	Usually efficient and inexpensive.	More costly; uses more air.

In many cases a combination of the two is necessary. The large box type of control permits

precipitation of material on the inside, and serious maintenance problems can result. The combination hood which provides reasonably good local pickup at the source of generation, backed up by an enclosure insuring secondary control to cover inefficiencies in the primary, and also to accommodate occasional bursts or failures, is frequently necessary and highly effective.

**Unattended Equipment.** In this category are storage bins and tanks, automatic transfer gear, and automatic, continuous feed process devices. Since frequent access is not required, the equipment can normally remain sealed (or reasonably enclosed) so that contaminant escape can be virtually eliminated. This does not eliminate the requirement for ventilation. An absolute seal is infrequently attainable even on a simple storage bin. Significant leaks can occur at gasketed manhole covers, material inlet pipes, and discharge pipes or hoppers, especially after repeated temporary removal for maintenance or access. These avenues of escape must be carefully watched for incipient deterioration or loosening of fittings. The minimum ventilation requirement for a fixed closed container is the application of negative pressure to prevent exfiltration from the inside portion free of bulk material, under all conditions of feed. To prevent loss of gross amounts of material, it is sometimes desirable to install a filtered vent.

Automatic transfer conveyors should be completely enclosed and should be ventilated at each point of transfer. The same applies to continuous feed devices. Rotary kilns, for instance, should have a ventilated collar around each end to contain the dust which may leak at the material transfer points. A continuous feed centrifuge, although closed and processing wet material, also operates at a slight positive pressure on the housing and can emit significant concentrations of mist. Negative pressure on the casing and ventilated collars around packing glands will successfully contain the mist.

**Transfer of Material.** Material transfer is among the most difficult operations to control. Drum filling and dumping steps are consistently among the most dusty operations. Up until the present time no fully effective hood design for either operation has come to the attention of the authors. Repeatedly, designs which appeared fool-proof at the conceptual stage have shown flaws when put into practice. On the other hand, many

designs are reasonably good and can provide satisfactory control if the operator follows the prescribed procedures.

Automatic conveyors, where applicable, can eliminate the routine dust problem almost completely. This is especially true of the tubular and pneumatic types, although screws, belts, and buckets can be effective if suitably sealed and ventilated enclosures are installed. Maintenance on such equipment can, however, be quite dusty. If the material to be transferred is particularly abrasive or corrosive, so that frequent maintenance of conveying equipment is needed, rubber lining is often effective; but the choice between manual and mechanical transfer should be carefully deliberated. Examples of both manual and automatic transfer operations and their relative utility are described below.

*Laboratory scale.* Where processes are conducted in chemical hoods, transfer to and from the hoods may be accomplished with relatively little hazard and no special auxiliary hooding provided that care is exercised. This applies to relatively small quantities of material which can be easily carried in small containers (e.g., up to one gallon cans.)

The transfer concept is quite simple: a container capable of being tightly sealed is filled manually within the chemical hood and the cover applied and sealed. Before removal from the hood the exterior of the container must be thoroughly cleaned with a damp cloth or a vacuum cleaner, but the cleaning tools should remain within the hood. The container may then be removed without hazard. An obvious precaution is that the operator's hands and sleeves must not be contaminated when withdrawn from the hood. If this is otherwise inevitable, the operator should work through gloves attached to access ports, which may slide along the front of the hood from one operation to the next.

As long as the filling is done within the hood and the container can be adequately cleaned, dusting can be easily controlled. Container dumping should be similarly executed within the hood. When the containers are too large or heavy for convenient handling within the hood, the control progresses to a more elaborate but less positive technique. If a drum is to be filled outside the hood, specific drum ventilation is required. Such an arrangement may be considered in the same class as production drum filling stations.

*Drum filling – production.* A drum filling station must effectively curtail the following: 1) primary dust during filling, 2) dust dislodged from the drum lip when and if a lid is secured, 3) dust settled on the exterior drum surface, 4) dust dislodged from the filling hopper and hood after the drum has been removed, and 5) excessive loss of product into the exhaust system.

The severity of dusting from these causes is dependent upon the dryness and the particle size, but it is rare for a material to be completely non-dusting. A wet material, for instance, can constitute a serious air contamination source. Considerable housekeeping problems have arisen from drums filled with a wet cake when small cake deposits were allowed to remain on the outside of the drums. After a short storage period the exterior deposits dry and later create significant general air contamination when the drums are moved. This is not a hood problem in the strict sense, but such details require attention in the design of dust controls.

The drum filling problem may be most suitably met by the use of both primary and secondary ventilation. The principle of this arrangement is to remove the bulk of the dust at its primary source, around the hopper and the top of the drum, with an exhaust collar, but with the added safeguard of an enclosing hood with separate exhaust. The enclosing hood retains the dust which may escape from the collar during filling, provides control while the drum is being lidded and cleaned, and retains dust which may be dislodged from the hopper after the drum has been withdrawn from the hood. This arrangement, although probably one of the most effective, is not necessarily foolproof and depends for its success largely on the care with which the attendant positions the drum within the hood and closes and cleans it prior to withdrawal. The exhaust volume rate applied to the secondary hood should be sufficient to create an inward air velocity of 150 lfm at the face. The volume rate applicable to the exhaust collar will depend on the design, 150 cfm/ft<sup>2</sup> of panel top being a rule of thumb value valid for many designs. Great care must be taken in design, however, to minimize the evacuation of significant quantities of valuable product.

*Drum dumping.* This aspect of transfer is equally difficult. Dumping arrangements which do not expose the drum exterior to dust have been

most satisfactory. These generally consist of a cradle on which the drum is tipped over to discharge into a hopper with a ventilated inlet. Special provision may be required to control dust emitted while the lid is removed and/or the drum is being turned from the vertical to the dumping position. Dusting during this part of the dumping cycle may be serious if the material is dry or finely divided. A movable hood member mounted on the cradle or actuated by the cradle motion can be arranged to follow the drum and provide ventilation in this case. Dumping is generally more rapid than filling; hence, air displacement within the hopper must be compensated for in the calculation of the proper hopper ventilation rate. It is also important to make provisions for the dusty air remaining within the drum after dumping and for the material sticking to the sides.

Skip hoists have been used successfully for drum dumping. The entire drum travel must be enclosed and ventilated. The drum exterior can become contaminated in this operation, and provision for its decontamination should be made available where the drum is withdrawn. A drum washer within the ventilated enclosure can be designed to insure adequate cleaning.

Pneumatic unloading is an alternative to dumping. A standard drum hood with an opening through which a pneumatic gulper can be inserted provides adequate control. Pneumatic conveying is unfortunately limited to noncaking and relatively noncorrosive materials.

**Duct Design and Application.** Whereas the local exhaust hoods in a beryllium plant usually must be superior to those found in other industries, system design (i.e., layout, transport velocity, and sizing) can follow standard practice. The only exception is that leakage from exhaust ducts is not permissible. This requires more rigid specification of construction materials in terms of fabrication, corrosion resistance, and joint sealing. Specifications for exhaust system design as recommended by the NYOO have been published,<sup>9</sup> which offer guidance in duct installation to minimize leakage, provide adequate transport velocities, etc.

**Collector Selection.** In any facility where substantial quantities of beryllium materials may be carried in the exhaust system, the selection of air cleaning equipment will require careful consideration for two reasons: 1) beryllium admitted to the air outside the plant may create a neighbor-

hood dust hazard, and 2) the beryllium content may be sufficiently valuable to warrant salvage. From the latter point of view a simple comparison of the cost of the collection installation and operation with the anticipated saving of beryllium content will indicate the optimum air cleaning facility. With regard to neighborhood contamination, factors such as stack height and local meteorology enter into the selection of cleaning equipment. This subject will be discussed in a later section which treats out-of-plant design considerations.

**Specific Examples of Ventilation Control.** Following are 27 photographs depicting applications of ventilation in the categories described above: manual (Figures 1 to 9), batch (Figures 10 to 16), unattended (Figures 17 to 19), and drum filling and dumping (Figures 20 to 27.) Each photograph is accompanied by air concentration data and a brief description of any unique features of the operation or control equipment. Except where noted the hoods have performed satisfactorily over several years, but it should not be inferred that they represent the best possible design in each instance. Experience has indicated that improvements could be made in most of the units. On the other hand, by reviewing these illustrations one may comprehend the variety of operations which may be controlled and some of the alternative methods of control.

The air concentration data are averages of replicate samples collected on individual surveys. The highest, the lowest, and the median (average) concentrations are listed. These numbers show that most of the hoods have failed to provide completely effective control at some time during their service, but that by and large the performance has been satisfactory. Failures are attributable to a number of factors, the human element being among the most important. Success of nearly every hood design depends on proper procedures. High dust concentration frequently can be identified with careless operation. Other factors contributory to control failure are temporary deficiencies in air capacities and deterioration in the hood structures. It is not unlikely that over a period of years all these contributory factors will appear at one time or another, and it is only by frequent air monitoring that they can be detected and rectified so that excessive dust concentrations do not continue.



Figure 1.

OPERATION OR EQUIPMENT: Sorting and sieving.  
PROCESS MATERIAL: Beryllium pebbles and chips.  
HOOD CONSTRUCTION: Sheet metal and clear plastic.  
VELOCITIES:  $\approx 150$  fpm.  
AIR VOLUME RATE: 150 cfm.  
BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): No data.

REMARKS: This is typical of useful enclosures for manual, bench-type operations. For this particular application, classified material may be dropped into appropriate containers through circular holes in the bottom of the hood. Flexible tubes are permanently mounted over the openings and may be attached to containers. The hinged slant panel at the front is opened only for maintenance.

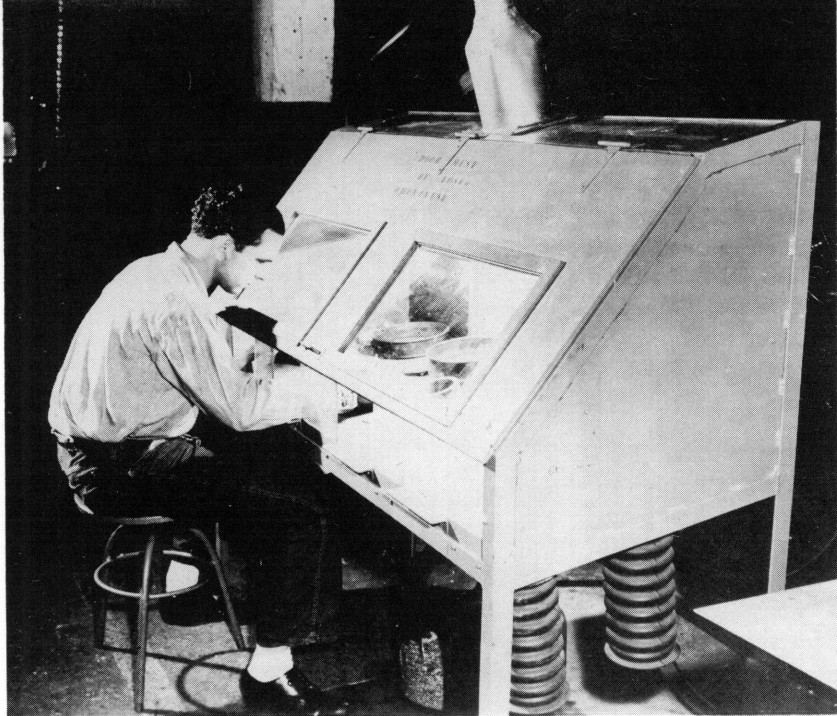


Figure 2.

OPERATION OR EQUIPMENT: Deburring (production).  
PROCESS MATERIAL: Machined beryllium metal parts.  
HOOD CONSTRUCTION: Clear plastic.  
VELOCITIES: 300 to 400 fpm through each hand opening.  
AIR VOLUME RATE: 200 cfm.  
BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): No data.

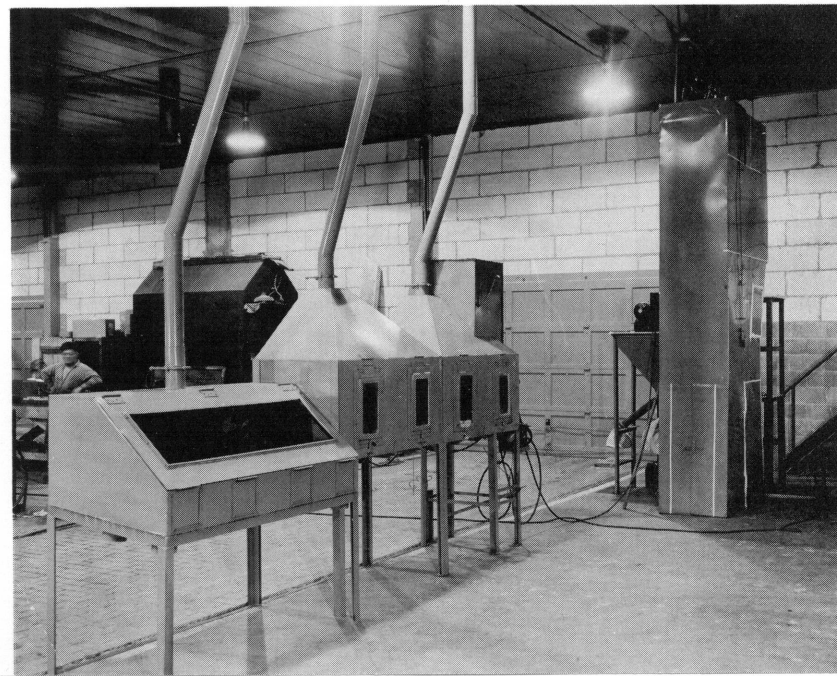
REMARKS: Exhaust from this hood is through a down-draft which may be seen in the center of the bench. Deburring is performed directly over the grate and most of the dust is removed as it is formed.



Figure 3.

OPERATION OR EQUIPMENT: Pneumatic grinding, sorting, and sieving (production sampling).  
PROCESS MATERIAL: Beryllium pebbles and chips.  
HOOD CONSTRUCTION: Sheet metal and Lucite.  
VELOCITIES: Vertical face hoods, 350 to 400 fpm; Slant face hoods, 100 to 200 fpm.  
AIR VOLUME RATE: Vertical face hoods, 500 to 600 cfm; Slant face hood, 600 cfm.  
BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 20, low 0.1, median 1.5.

REMARKS: The two hoods at the right are interconnected. A pneumatic grinder is located in the most remote hood. Ground metal is transferred to the adjacent hood internally for classifying. The doors are closed when the foot-treadle actuated grinder is in use. The hood at the left is similar to that shown in Figure 1 and is similarly used.



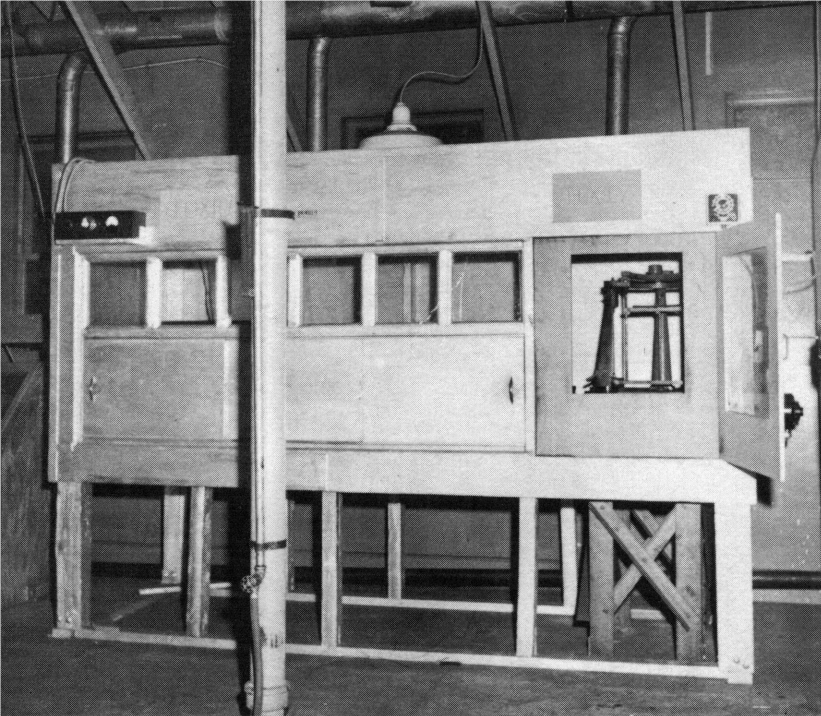


Figure 4.

OPERATION OR EQUIPMENT: General purpose (pilot plant).  
 PROCESS MATERIAL: Beryl, others.  
 HOOD CONSTRUCTION: Plywood and glass.  
 VELOCITIES: 150 fpm.  
 AIR VOLUME RATE: 150 cfm.  
 BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): 0.01.

REMARKS: This is a general purpose hood used for transferring, weighing, sieving, and blending small quantities of finely divided beryllium compounds. A Rotap may be seen at the right end. The sliding panel arrangement on the left offers two advantages: both panels cannot be fully opened simultaneously, thus the total open hood area is limited; and the contaminated surfaces of the inside panels are never exposed to the outside.

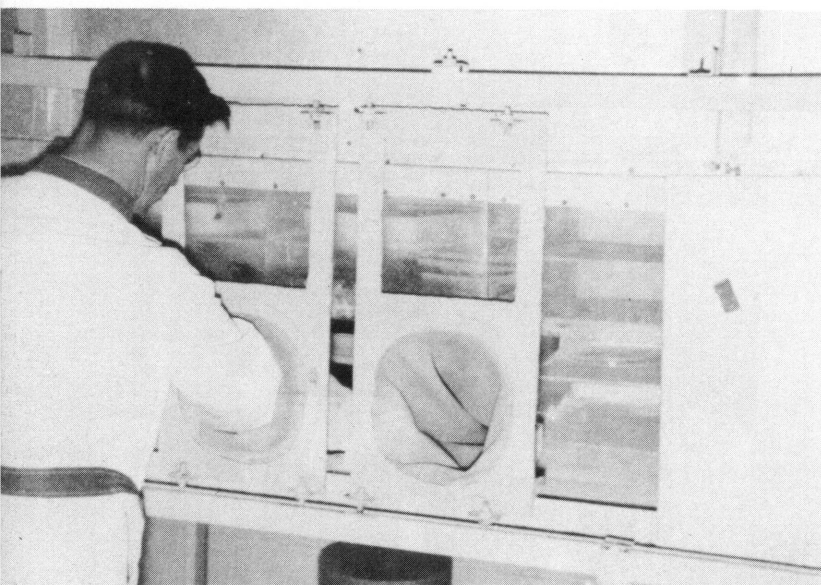


Figure 5.

OPERATION OR EQUIPMENT: Material transfer.  
 PROCESS MATERIAL: BeO.  
 HOOD CONSTRUCTION: Sheet metal and clear plastic.  
 VELOCITIES:  $\approx 200$  fpm.  
 AIR VOLUME RATE: No data.  
 BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 26, low 5.2, median 16.

REMARKS: This hood is employed for the transfer of finely divided beryllia from metal trays to silica trays. Tiers of tray storage racks are mounted within the hood at the rear. The hood is longer than shown here. Glove ports are provided to prevent contamination of the operators' hands and sleeves. A unique feature here is the glove-port mounting which slides on a roller suspension to any position in front of the hood and thus allows the operator to transfer trays within the hood without restriction.

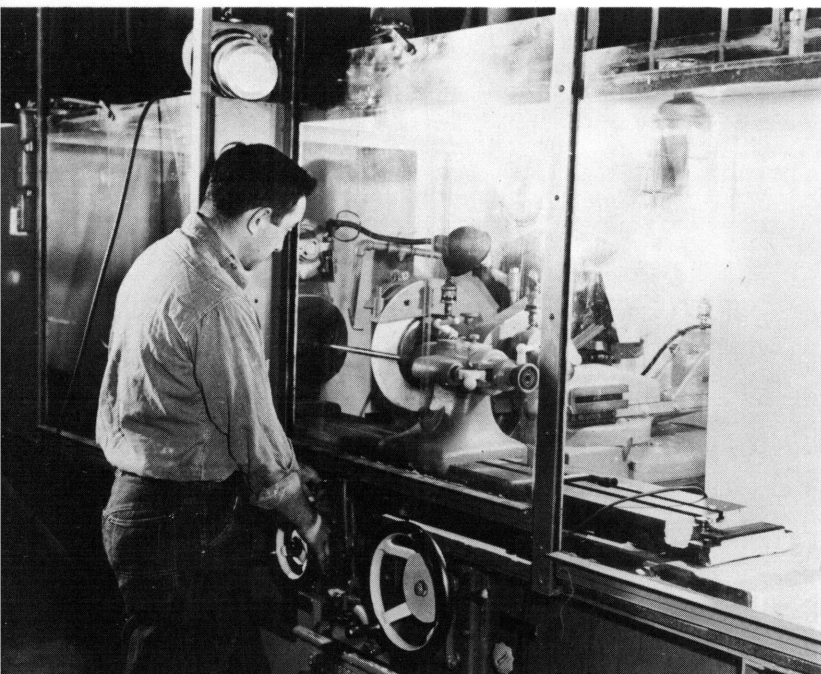


Figure 6.

OPERATION OR EQUIPMENT: Outside cylindrical grinder (production).  
 PROCESS MATERIAL: Metallic beryllium.  
 HOOD CONSTRUCTION: Sheet metal and clear plastic.  
 VELOCITIES: No data.  
 AIR VOLUME RATE: No data.  
 BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 5.3, low 0.2, median 1.1.

REMARKS: This is a simple enclosing hood with a transparent, vertically sliding access panel, which is fully closed during operation to prevent the escape of high-speed dust particles generated by the grinding process.



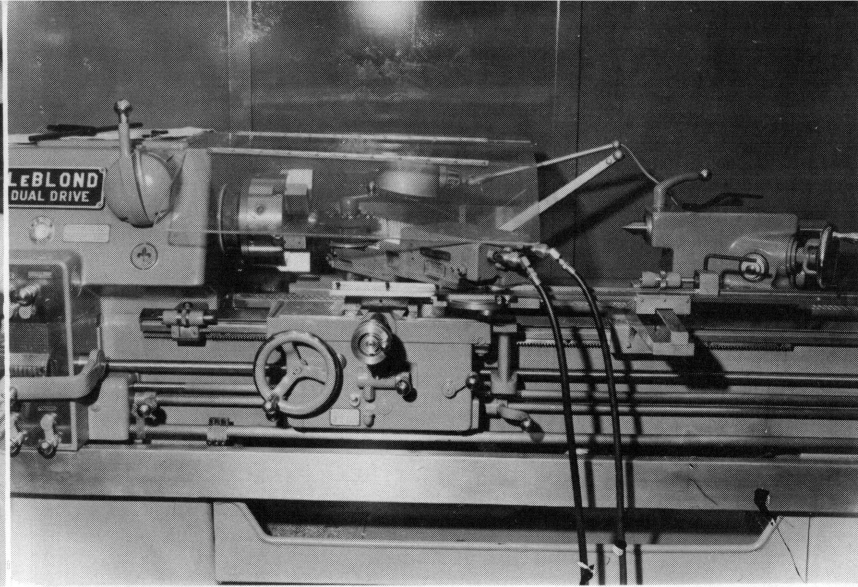
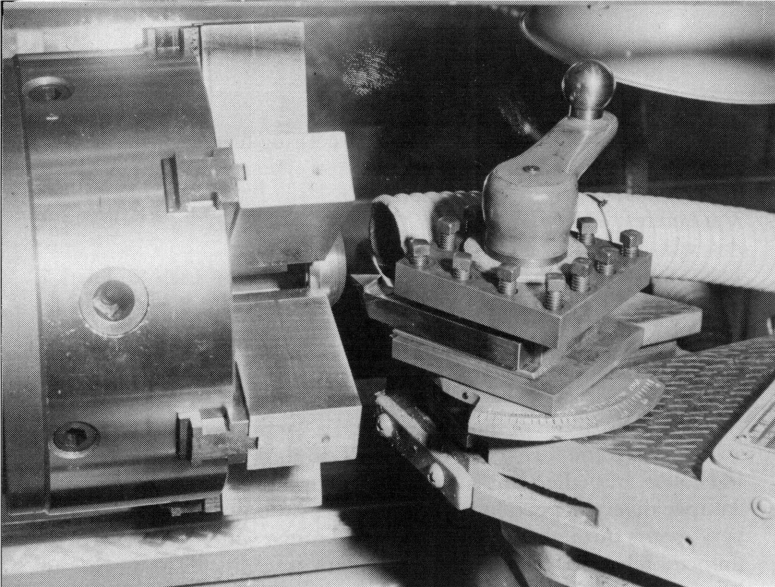


Figure 7.

OPERATION OR EQUIPMENT: Lathe (production).

PROCESS MATERIAL: Beryllium metal.

HOOD CONSTRUCTION: Clear plastic.

VELOCITIES: No data.

AIR VOLUME RATE: 200 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): No data.

REMARKS: The two views show the ventilation arrangement, which consists of a flexible tube chip pickup and a secondary plastic semienclosure. The chip pickup is the only source of suction.

Figure 8.

OPERATION OR EQUIPMENT: Lathe (production).

PROCESS MATERIAL: Beryllium metal.

HOOD CONSTRUCTION: Sheet metal and clear plastic.

VELOCITIES: Chip pickup,  $>5000$  fpm in throat; Hood, 125 to 200 fpm at work.

AIR VOLUME RATE: Chip pickup, 170 cfm; Hood, 330 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 5.8, low 1.0, median 1.2.

REMARKS: This lathe control arrangement consists of two complementary components, a chip collecting suction head mounted on the tool stock and fixed-position enclosing hood with hinged plastic front panels.

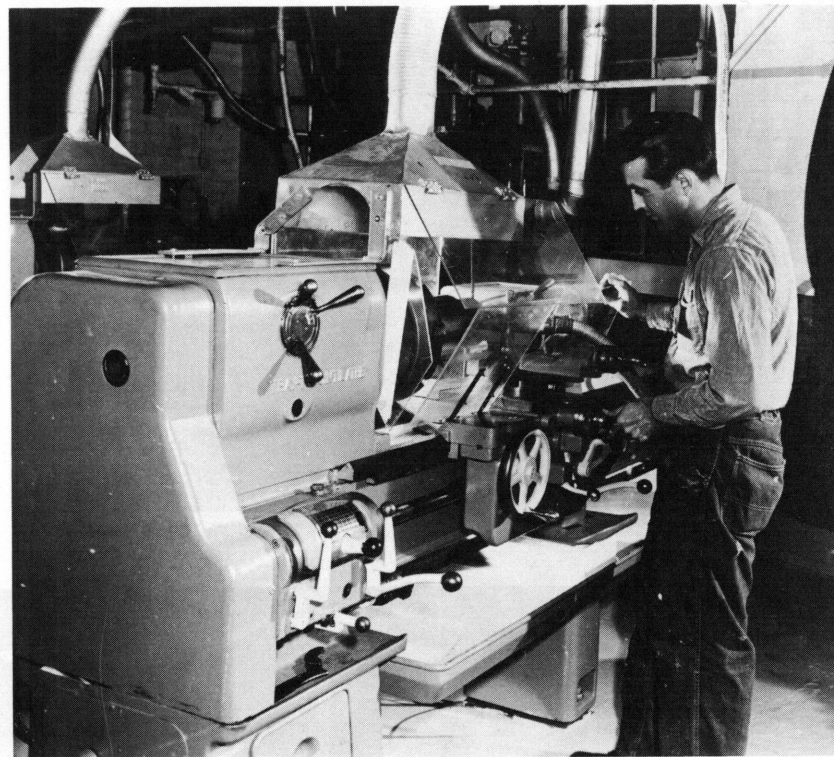


Figure 9.

OPERATION OR EQUIPMENT: Jig boring (production).

PROCESS MATERIAL: Beryllium metal.

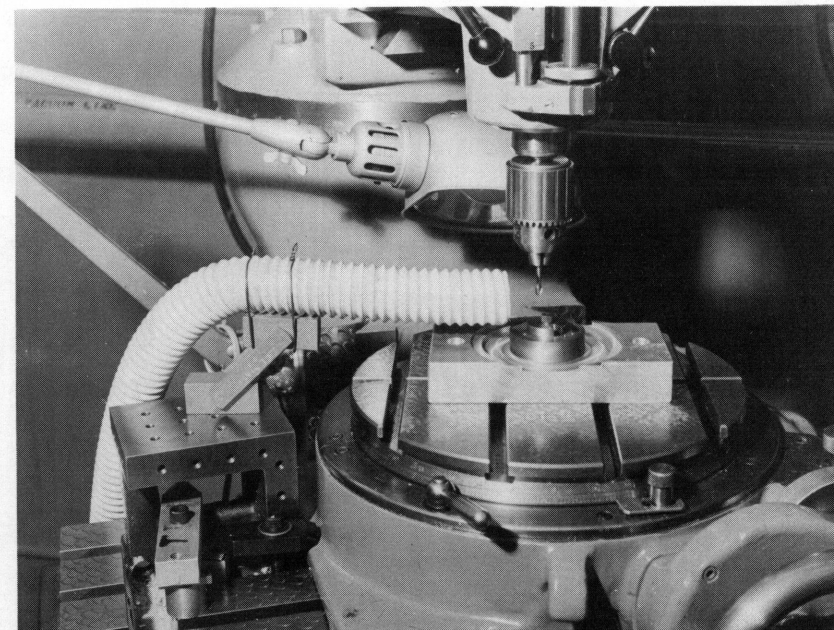
HOOD CONSTRUCTION: Flexible tube.

VELOCITIES: No data.

AIR VOLUME RATE: 200 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): 0.4

REMARKS: Metal dust and chips are swept away as soon as formed in this operation. Control is satisfactory because the particles possess practically no kinetic energy.





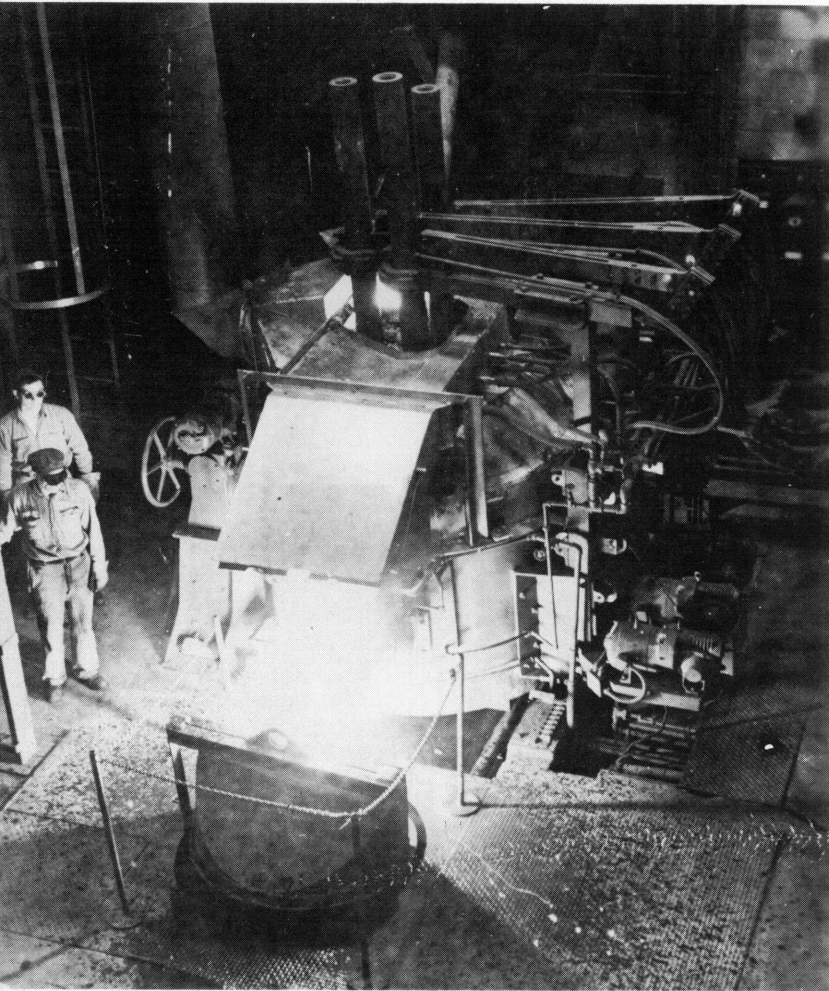


Figure 10.

OPERATION OR EQUIPMENT: Carbon arc tilting furnace (production).

PROCESS MATERIAL: Crushed beryl.

HOOD CONSTRUCTION: Sheet metal.

VELOCITIES: No data.

AIR VOLUME RATE: 5800 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): During pour, high 15, low 1.3, median 7.4; General air, high 4.5, low 0.6, median 1.1.

REMARKS: The furnace is shown in its tilted or pour position. The hood is attached rigidly to the furnace; the connecting branch duct has two rotatable elbow joints. An exhaust collar provides ventilation at the open top of the furnace, and a canopy ventilates the pour spout. When the furnace is upright all exhaust air is drawn through the collar, but when the furnace is tipped to pour a gravity actuated damper diverts a portion of the air to the canopy hood. The molten beryl pours through a water stream and into a water tank where it is immediately quenched. Fumes and steam are collected in the canopy hood.

Figure 11.

OPERATION OR EQUIPMENT: High-frequency reduction furnace (production).

PROCESS MATERIAL: Magnesium and beryllium fluoride.

HOOD CONSTRUCTION: Sheet metal.

VELOCITIES: 1200 to 1500, 800 to 1000, 150 to 200, 150 to 250 fpm.

AIR VOLUME RATE: 4500 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): During pour, high 87, low 1.5, median 8.8; Changing molds, high 56, low 2.7, median 14.

REMARKS: The box-like hood entirely encloses the furnace. It includes an area next to the furnace on the left side where the mold may be placed to cool following each pour while a clean mold is introduced through a door on the right side and fastened to the furnace. Other doors are provided to withdraw the cooled mold and to scrape the furnace crucible during the pour. The furnace is charged by means of a special hood at the top of the main enclosure shown in Figure 22. The drum inside the hood contains beryllium fluoride. It may be tilted to dump into the furnace by means of a crank arrangement (not seen) on the far side of the hood.

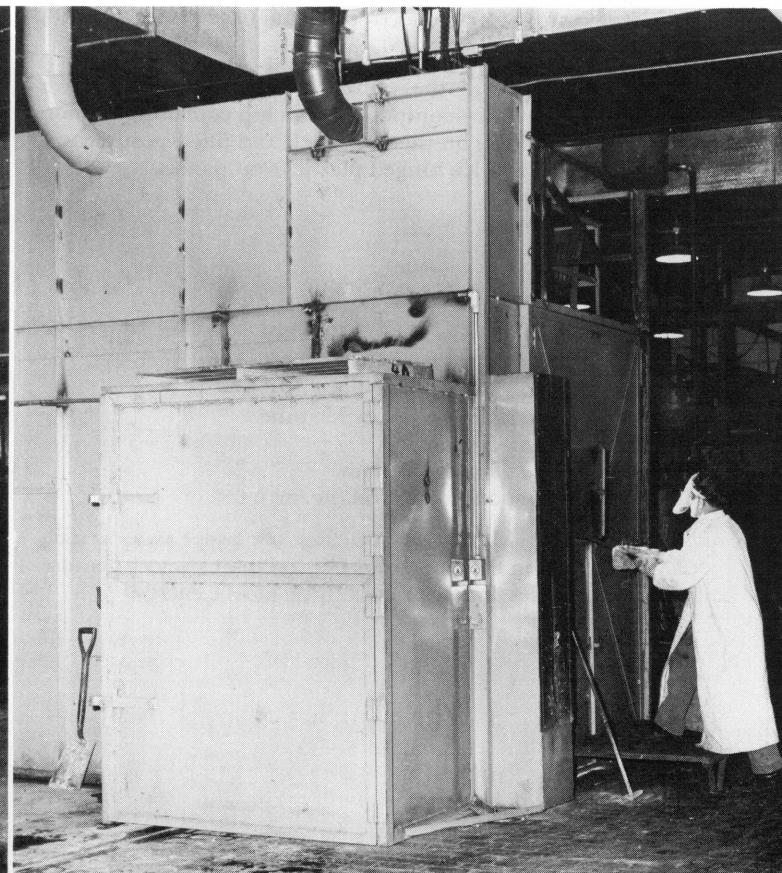
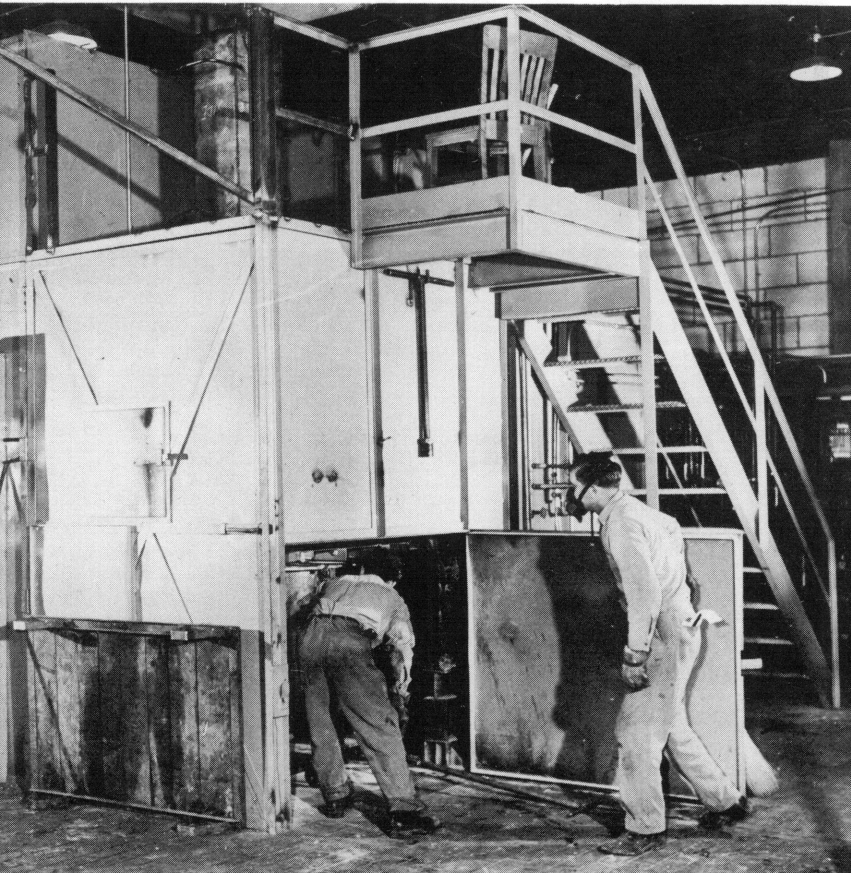




Figure 12.

OPERATION OR EQUIPMENT: Jaw crusher (semiproduction).  
PROCESS MATERIAL: Beryllium oxide.  
HOOD CONSTRUCTION: Sheet metal and glass.  
VELOCITIES:  $>200$  fpm.  
AIR VOLUME RATE: 1500 cfm.  
BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 38, low 0.7, median 19.

REMARKS: This hood ventilates the feed end of a jaw crusher used on fused beryllia. A drum containing chunks of beryllia is introduced horizontally with its lid fastened into the compartment at the left of the operator. The lid is then taken off the drum but left in the drum compartment. The top door to the compartment is left slightly ajar to maintain a positive inflow of air past the drum into the crusher feed compartment from which the ventilating air is exhausted. This air stream minimizes deposition of beryllia fines on the exterior surface of the drum. The operator, working through glove ports, rakes the beryllia chunks from the drum into the crusher.

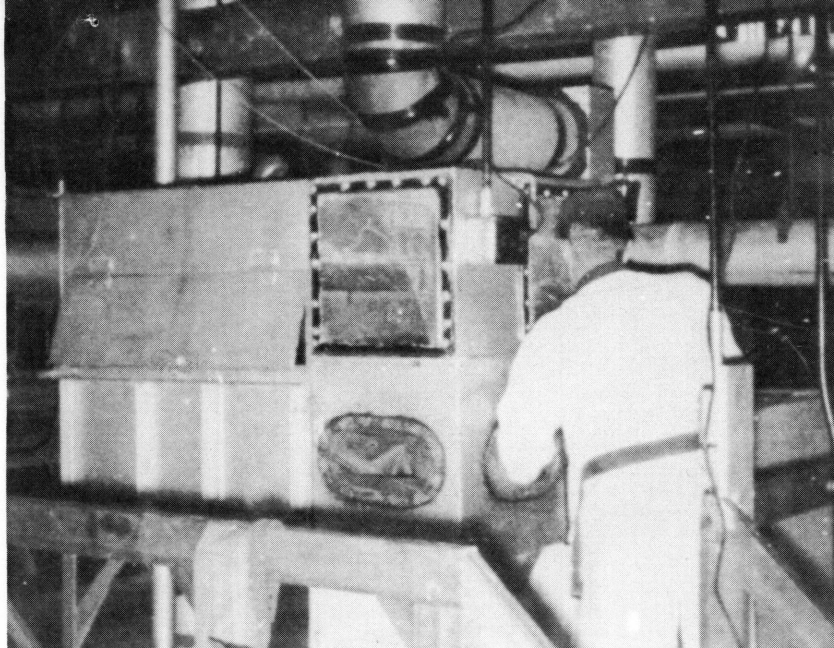


Figure 13.

OPERATION OR EQUIPMENT: Jaw crusher (pilot plant).  
PROCESS MATERIAL: Beryl.  
HOOD CONSTRUCTION: Plywood.  
VELOCITIES: Feed door, 450 fpm; Receiving drum door (one open), 125 fpm.  
AIR VOLUME RATE: 900 cfm.  
BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): 0.01.

REMARKS: Access doors are provided for feeding material to the crusher and for changing the receiving drum. Only one of the large doors need be opened to effect the latter operation. The double width door is provided for maintenance access.

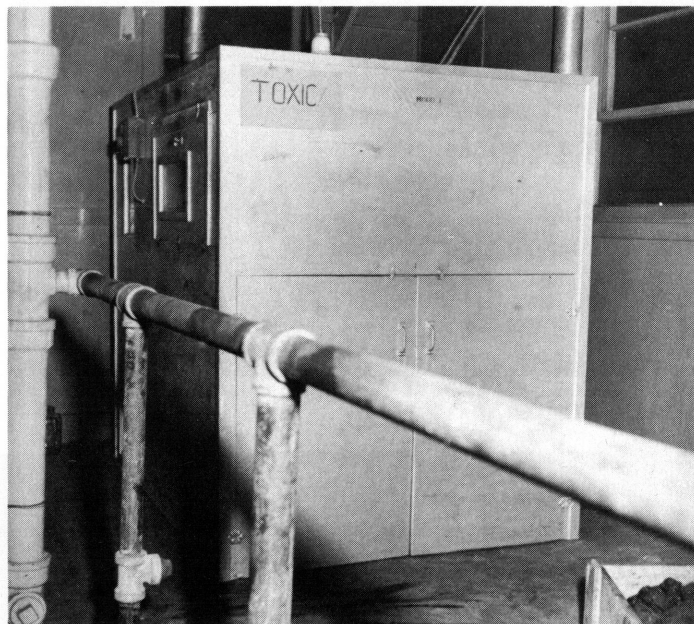
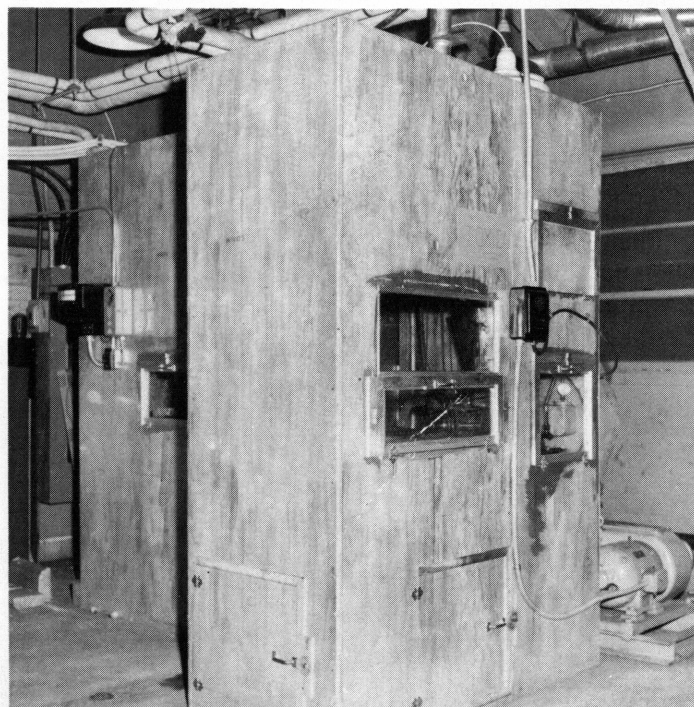


Figure 14.

OPERATION OR EQUIPMENT: Extruder and electric furnace (pilot plant).  
PROCESS MATERIAL: Beryl and graphite.  
HOOD CONSTRUCTION: Plywood and glass.  
VELOCITIES:  $\approx 200$  fpm.  
AIR VOLUME RATE:  $\approx 350$  cfm.  
BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): 0.01.

REMARKS: No internal hooding. Access doors suitably located to install and withdraw process material.





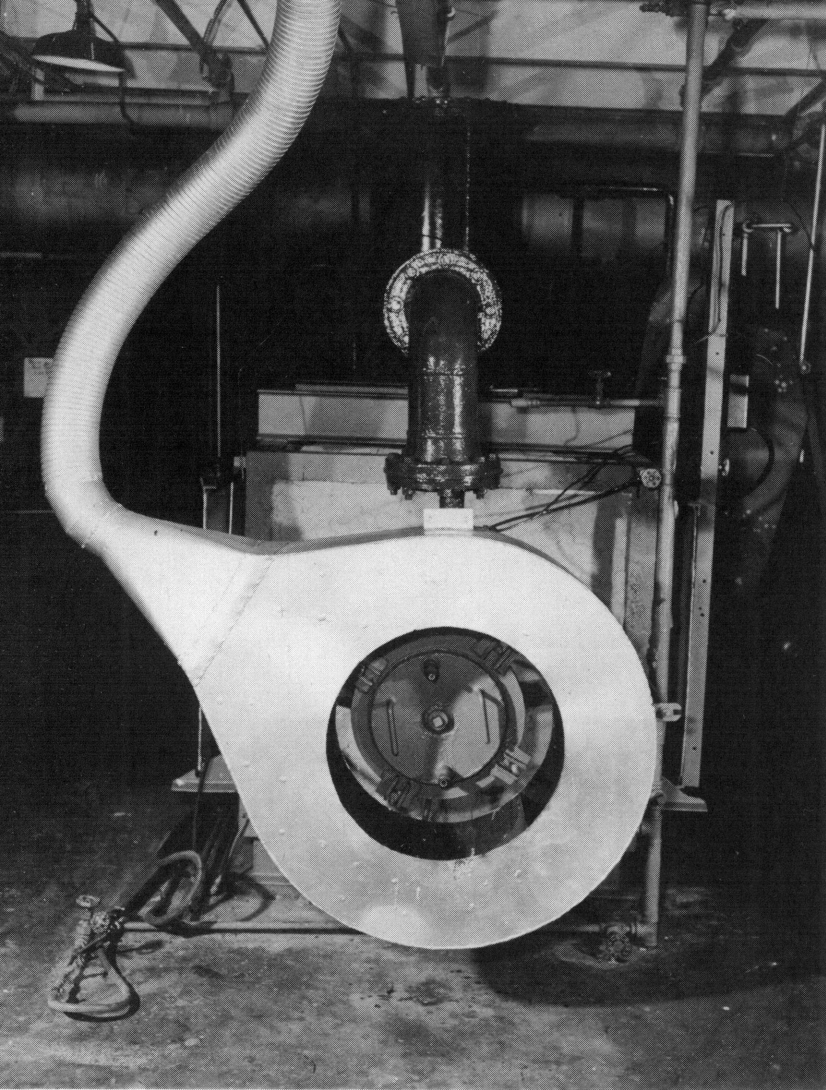


Figure 15.

OPERATION OR EQUIPMENT: Horizontal sintering furnace (production).

PROCESS MATERIAL: Beryllium metal powder.

HOOD CONSTRUCTION: Sheet metal.

VELOCITIES:  $\approx 150$  fpm.

AIR VOLUME RATE: 450 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): Load, high 3.0, low 0.8, median 1.6; Unload, high 5.7, low 0.5, median 2.3.

REMARKS: In another hood, not shown, beryllium powder is loaded into a die and the die sealed with tape. The die is inserted in the sintering furnace through the circular end plate shown in the photograph. The die seal is broken under pressure from a hydraulic ram during the sintering process. When the die is withdrawn, the exhaust collar captures dust which may have escaped from the die in the furnace.

Figure 16.

OPERATION OR EQUIPMENT: Filter press (production).

PROCESS MATERIAL: Filter cake is principally  $\text{FeOH}$  with traces of  $\text{BeOH}$ .

HOOD CONSTRUCTION: Sheet metal.

VELOCITIES: 75 to 100 fpm at filter press leaves.

CAPACITY: 800 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 21, low 1.3, median 6.9.

REMARKS: These two photographs illustrate an unsuitable hood and the reason for its unsuitability. The operator in the photograph on the left is afforded reasonable protection, but the operator in the right-hand picture is within the stream of contaminated exhaust air. By the nature of the filter press cleaning process, operators could not avoid leaning under the canopy. Another bad feature is that the canopy installation is an inefficient method of exerting ventilation control in this instance because the source of contamination is too remote from the hood. This operation was abandoned in favor of a process which required no manual contact with beryllium materials. Note that the adjustable damper is another undesirable feature.

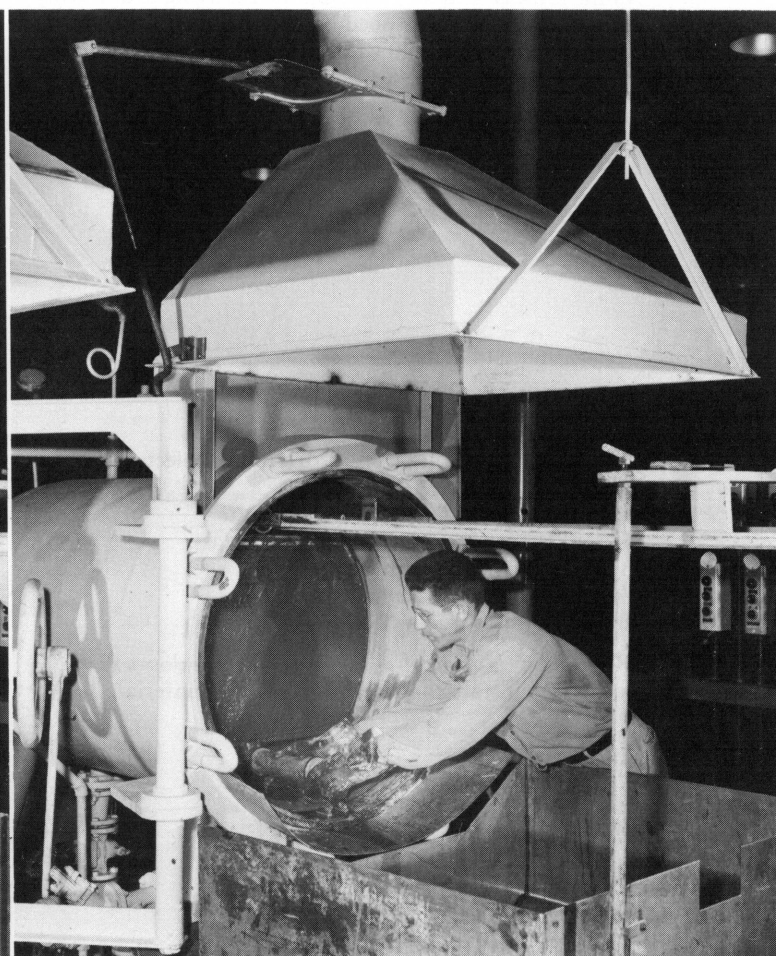


Figure 17.

OPERATION OR EQUIPMENT: Mixing tank (production).  
PROCESS MATERIAL: Principally beryllium hydroxide.  
HOOD CONSTRUCTION: No hood (exhaust connection for negative pressure).

VELOCITIES:  $\approx 150$  fpm.

AIR VOLUME RATE: 300 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 4.2, low 1.1, median 2.1.

REMARKS: Air capacity is designed for 150 fpm indraft when access door is open.

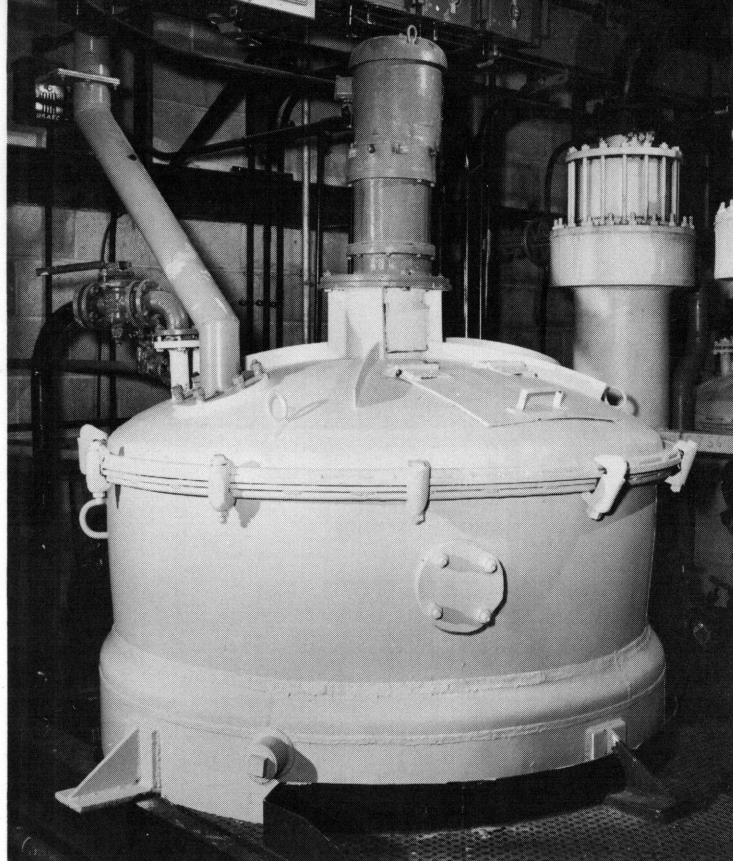


Figure 18.

OPERATION OR EQUIPMENT: Centrifugal separator.  
PROCESS MATERIAL: Ammonium beryllium fluoride (crystals).

HOOD CONSTRUCTION: No hood (negative pressure).

VELOCITIES: Not applicable.

AIR VOLUME RATE: 250 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 0.9, low 0.2, median 0.6.

REMARKS: The ventilation maintains a negative pressure inside the centrifuge casing. A guard over the drive shaft prevents leakage from being sprayed into the air.

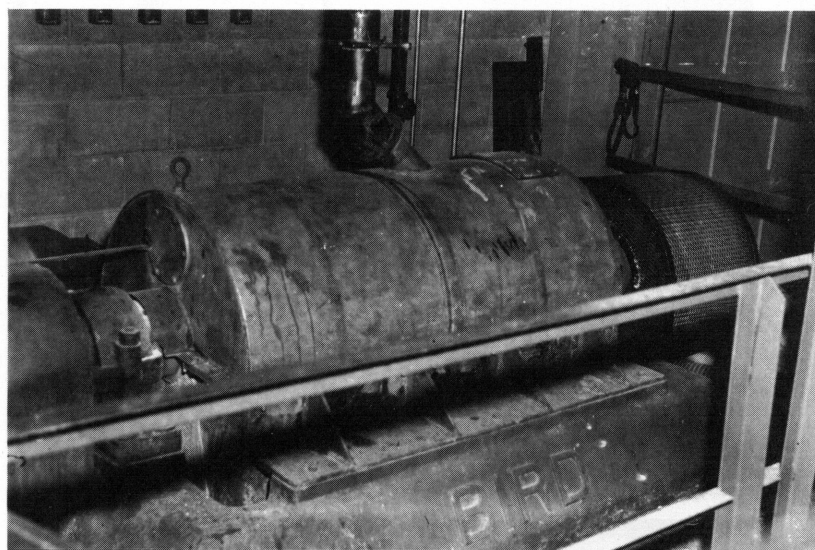


Figure 19.

OPERATION OR EQUIPMENT: Rotating kiln (production).

PROCESS MATERIAL: Fused beryl.

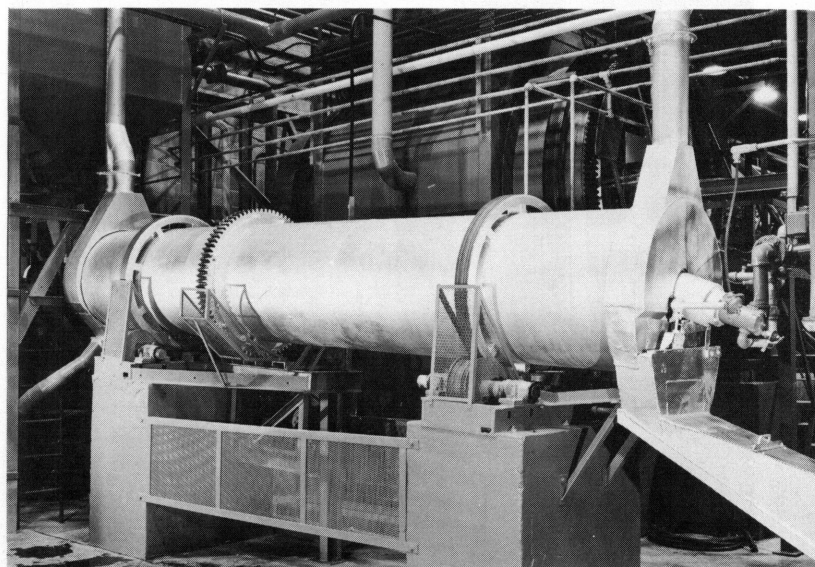
HOOD CONSTRUCTION: Sheet metal.

VELOCITIES: Not applicable.

AIR VOLUME RATE: Feed end, 320 cfm; Dish end, 375 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 2.6, low 0.4, median 1.4.

REMARKS: Both ends of the kiln are ventilated. The chute under the near end of the kiln terminates at the boot of a bucket elevator which is also ventilated.





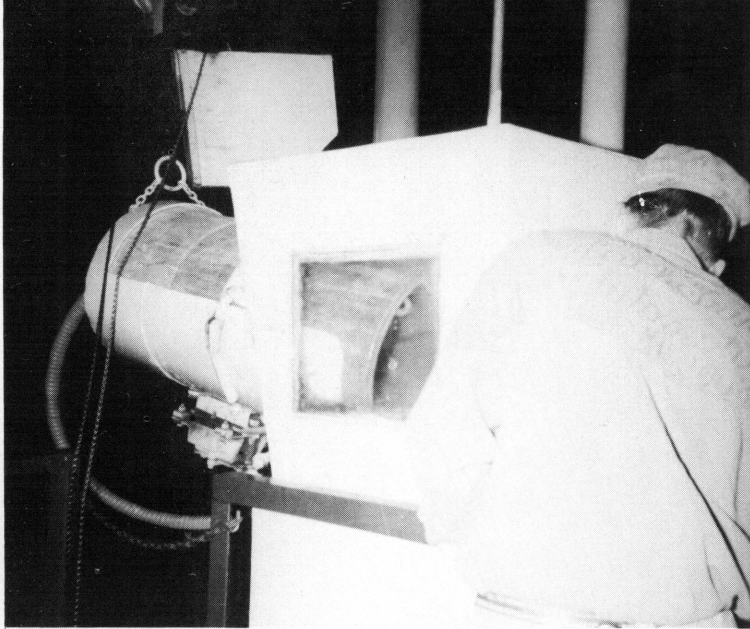


Figure 20.

OPERATION OR EQUIPMENT: Magnetic separator (production).

PROCESS MATERIAL: Beryllium pebbles.

HOOD CONSTRUCTION: Sheet metal and clear plastic.

VELOCITIES: 250 fpm.

AIR VOLUME RATE: 375 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 7.9, low 1.0, median 3.6.

REMARKS: The drum lid is removed after the drum is tipped into the hood. The pebbles flow from the drum by gravity with the help of a vibrator. The operator regulates the flow with a hoe projecting through the side of the hood and by adjusting the drum cradle elevation with an electric winch.



Figure 21.

OPERATION OR EQUIPMENT: Magnetic separator (production).

PROCESS MATERIAL: Beryllium pebbles.

HOOD CONSTRUCTION: Sheet metal and Lucite.

VELOCITIES: 200 fpm.

AIR VOLUME RATE: 1200 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 6.7, low 1.1, median 1.4.

REMARKS: The drum is lifted into position on the cradle and the lid is removed and left inside the enclosure. The door is closed and further operations are conducted through an access window on the other side of the housing. The cradle is lifted with a hand-turned windlass.



Figure 22.

OPERATION OR EQUIPMENT: Furnace charging (production).

PROCESS MATERIAL: Beryllium fluoride.

HOOD CONSTRUCTION: Sheet metal and clear plastic.

VELOCITIES: No data.

AIR VOLUME RATE: No data.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 16, low 0.6, median 1.8.

REMARKS: This castored enclosure moves on a track to a position over a reduction furnace charge opening. The drum is tipped on a hand-cranked cradle and dumps through a chute in the far end of the enclosure. The door is closed during dumping. A flexible exhaust connection (not visible) ventilates the cabinet.

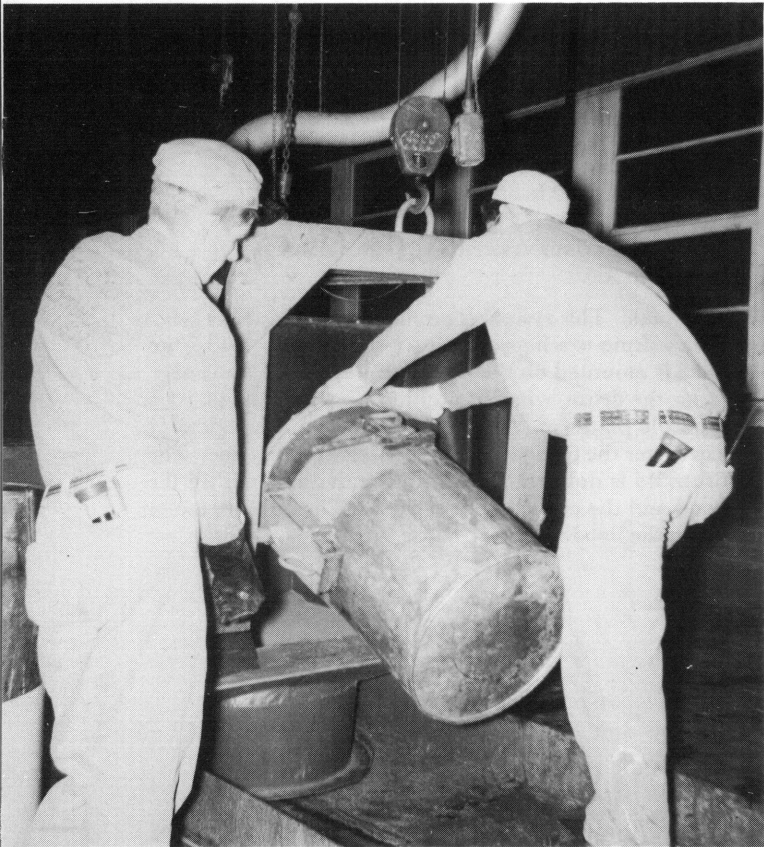


Figure 23.

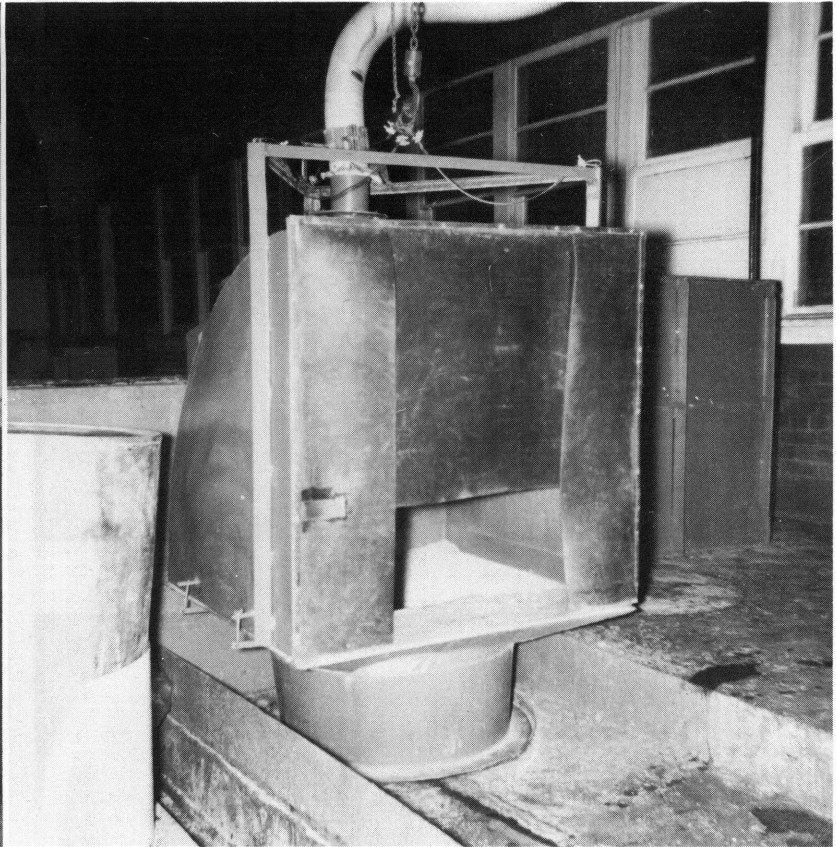
OPERATION OR EQUIPMENT: Wet ball mill (production).  
 PROCESS MATERIAL: Beryllium pebbles, beryllium fluoride,  
 and magnesium fluoride.  
 HOOD CONSTRUCTION: Sheet metal and rubber.  
 VELOCITIES: 300 fpm.  
 AIR VOLUME RATE: 450 cfm.  
 BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): Charging and  
 dumping, high 22, low 8.7, median 15.

REMARKS: The two views explain this operation. The hood is over a chute which discharges to a ball mill below. The rubber flaps are intended to conserve air capacity by producing maximum velocity around the drum when it is in the dumping position.

Figure 24.

OPERATION OR EQUIPMENT: Vezin sampler (production).  
 PROCESS MATERIAL: Beryllium pebbles.  
 HOOD CONSTRUCTION: Sheet metal.  
 VELOCITIES: 100 to 125 fpm.  
 AIR VOLUME RATE: 650 cfm.  
 BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): 13.5.

REMARKS: This is a skip hoist by which drums of pebbles are dumped into the sampler unit hopper. The lid is placed on or removed from the drum at a position directly in front of the hood in the indraft air stream.





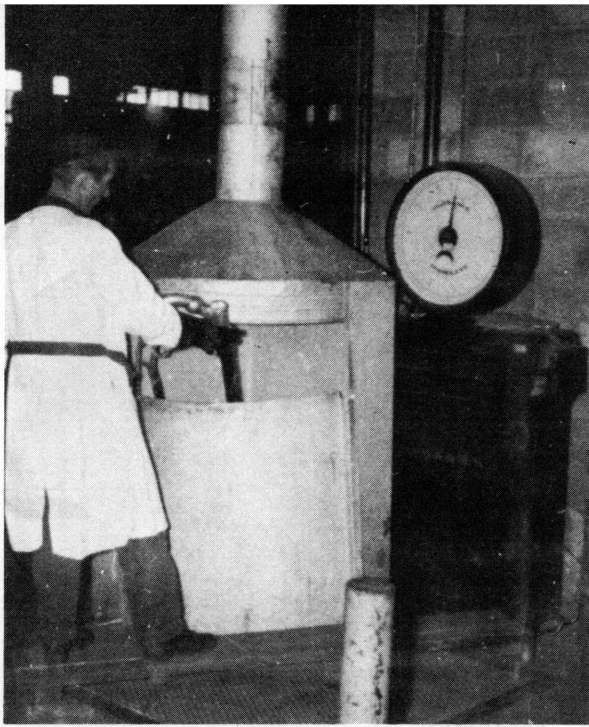


Figure 25.

OPERATION OR EQUIPMENT: Pneumatic unloader.

PROCESS MATERIAL: Beryllium oxide fines.

HOOD CONSTRUCTION: Sheet metal.

VELOCITIES: 250 to 350 fpm with front door closed.

AIR VOLUME RATE: 1500 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 4.6, low 1.6, median 3.1.

REMARKS: This system is employed to transfer beryllia from a drum to a hopper over a fusion furnace. The drum hood is mounted on the floor at the edge of a scale platform; the drum, when in position within the hood, is on the scale platform. With this arrangement the operator can meter the furnace charge by weight differences. The drum lid is not removed until the drum is within the hood and the curved door is closed. The gulping tool is left in the hood when not in use.



Figure 26.

OPERATION OR EQUIPMENT: Beryllium fluoride casting furnace discharge (production).

PROCESS MATERIAL: Molded beryllium fluoride pieces.

HOOD CONSTRUCTION: Sheet metal and rubber.

VELOCITIES: 100 to 275 fpm.

AIR VOLUME RATE: 2000 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 12.4, low 4.2, median 8.3.

REMARKS: The drum enclosure has doors at two ends; the empty drums are introduced at the end opposite that shown. The molded pieces of fluoride drop into the drum positioned below the discharge chute. The level of material in the drum can be viewed through a small window at one side of the enclosure. The drum lids are placed and removed inside the enclosure.

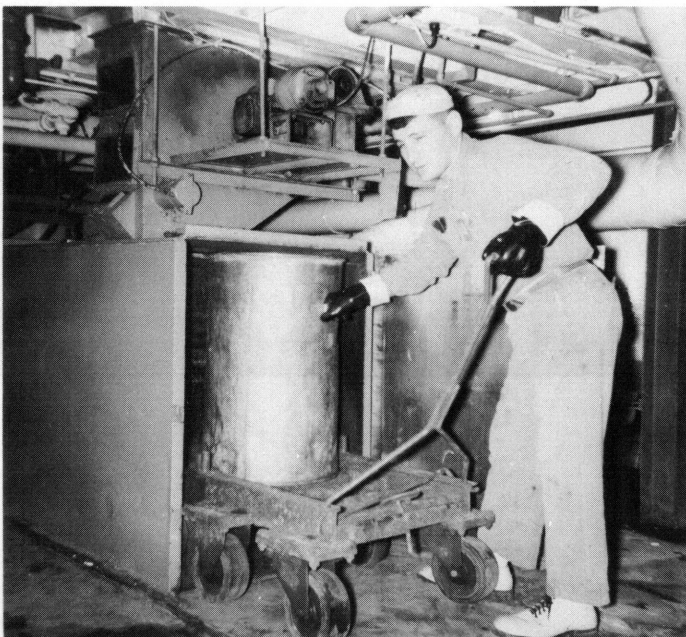


Figure 27.

OPERATION OR EQUIPMENT: Beryllium fluoride casting furnace discharge.

PROCESS MATERIAL: Beryllium fluoride.

HOOD CONSTRUCTION: Sheet metal.

VELOCITIES: 50 to 100 fpm.

AIR VOLUME RATE: 700 cfm.

BERYLLIUM CONCENTRATION ( $\mu\text{g}/\text{m}^3$ ): High 24, low 2.2, median 7.6.

REMARKS: The operation of this hood is similar to that described under Figure 26.

## Personal Protection and Hygiene

**Respiratory Protection.** Respirators have a definite but limited place in the general control program. Their use should be held to a minimum and carefully regulated.

The authors have taken the position that respirators should not be used as a control measure unless a job cannot be practically controlled by ventilation or some other primary method. This view is not unique – the pitfalls of respirator use are generally recognized. Most engineers are aware of the universal tendency among workers to avoid wearing respirators because of discomfort and inconvenience. The likelihood of imperfect fit with resultant failure of protection may not be as commonly understood. In any event, the stated position is particularly justified in beryllium processing, where it has been demonstrated that illness can develop from a single high exposure of short duration.<sup>5</sup>

However, there are dusty tasks which cannot be otherwise controlled. Maintenance and repair jobs commonly are in this category, e.g., disassembling equipment and changing split dust collector bags. These are occasional tasks performed by a relatively small number of persons over whom careful supervision is possible. It is best to perform maintenance and repair operations in a manner which prevents exposure of persons other than those directly involved by transferring equipment, if movable, to a special ventilated maintenance room or by restricting major repair jobs to off-hours. Careful cleanup after maintenance should be a part of the operation.

Within the cited limitations, dust or fume respirators of the filtration type may be used with reasonable confidence for concentrations up to about 100  $\mu\text{g}/\text{m}^3$ . At higher values the use of air-supplied respirators is recommended. For this purpose some contractors have installed a compressed breathing-air system with connections distributed at dusty job locations. Others prefer the greater flexibility obtained with compressed air cylinders mounted on a cart that can be wheeled to any desired location.

With regard to filtration respirators, there is at present no firm basis for recommending any specific model or manufacturer because there is no authoritative source of information about respirator effectiveness against contaminants as toxic as

beryllium. The Bureau of Mines employs a testing schedule to qualify respirators for toxic materials "not significantly more toxic than lead." Since beryllium is significantly more toxic than lead, this testing schedule is probably not stringent enough. On the other hand, the Bureau of Mines is the only agency which routinely tests respirators and publishes lists of approved equipment. It is therefore suggested that devices approved for lead dusts be used for beryllium operations but with caution and with the understanding that they are not guaranteed to be adequate for the application.

**Personal Hygiene.** Personal cleanliness will reduce the incidence of dermatitis. Direct skin contact with beryllium materials should be avoided, but accidental exposure is apt to occur. Cleanliness should be maintained by local washing whenever portions of the skin have been exposed to beryllium materials, and by a shower at the end of each shift for production or maintenance personnel who deal with gross quantities of beryllium compounds. Several protective creams have been found to reduce the incidence of dermatitis even among sensitive persons. Selection may be made by the industrial physician.

Dirty work clothes may be conducive to dermatitis. Dust tends to localize in various portions of work clothes, which causes direct skin exposure. Work clothes should be restricted to use only in the plant and should be cleaned several times a week.

Occasional visitors to the process areas should be provided with protective clothing to be worn over their street clothes.

**Clothing and Showers.** In large installations or in any installation where the likelihood of gross contamination on the clothes and the body is great, clean work clothes should be issued daily and showers taken daily. To insure this, the locker and shower rooms should be placed so that they cannot be bypassed and provided with one-way entrances and exits.

It is of interest to note that excessive dust concentrations may be generated in locker rooms. These apparently stem from the rough handling of contaminated work clothes and can be corrected by sufficient dilution ventilation, careful clothes handling, or both.

There are no special specifications for work clothes other than that they be readily cleanable. A one-piece coverall does have the advantage that



contamination will not localize around the midriff to the same degree as when a belt must be worn.

Work shoes should also be issued by plant management. These should be restricted to use in the plant. They may be stored in clothes lockers or special shoe lockers. It has not been found necessary to decontaminate work shoes.

Laboratory coats for visitors, or for regular employees (in the case of smaller installations), should be kept near the entrance to the contaminated work area. Shoe covers are not necessary.

**Lunch Room.** In the interest of general cleanliness, a lunch room has usually been made available for beryllium workers. However, there is no known beryllium ingestion hazard, and no aspect of beryllium toxicity suggests that eating in work areas is harmful.

It is not necessary to segregate beryllium workers from other personnel in the lunch room. Conceivably, clothing contamination could be great enough to generate high dust concentrations in the lunch room air, but this would not occur unless control in the plant were substandard.

**Laundry.** At least one instance of chronic illness, in the wife of a beryllium worker, has been reported which was attributable to an exposure to beryllium while washing contaminated work clothes. Routine air samples in a beryllium plant laundry show that concentrations of  $40 \mu\text{g}/\text{m}^3$  may occur from placing batches of dirty work clothes in a washing machine.<sup>10</sup> This is convincing evidence that clothes contaminated with beryllium should not be sent indiscriminately to commercial laundries. The practice at beryllium facilities under AEC contracts has been to operate a laundry on the premises; these range from a single domestic washing machine to a full complement of commercial washer, extractor, and dryer units.

Handling contaminated work clothes prior to placing them in the washer should be done with some care to minimize dusting. Serious air contamination has not been found in subsequent steps. One successful method of curtailing dust generation is to direct a fine water spray on the clothes as they are initially collected in the dressing room. Reduction of dust concentration by a significant factor has been achieved by this technique.

Under certain circumstances clothes can be sent to a commercial laundry. For example, in a

small installation (perhaps a laboratory) in which only gram quantities of beryllium are in process, with proper handling procedures the magnitude of clothing contamination would be quite small or more probably nil, and there would be no hazard in laundering the garments. However, it is difficult to establish quantitatively the line of demarcation between this situation and that previously described. Before deciding whether or not to use a commercial laundry, it is advisable to conduct tests to determine the potential dust hazard.

### Housekeeping

The accumulation of even minor unnoticed quantities of contaminant spilled over a period of time will become a generalized hazard. Continual policing by the operators is required to maintain low general air concentrations. Therefore, housekeeping should be a part of the regular work habit. Spills should be immediately cleaned by the employees who cause them.

Efficient housekeeping in large installations is best accomplished by a special janitorial staff which spends full time on area decontamination in addition to the local policing by production workers. Dust deposits on floors, walls, process equipment, ducts, and rafters must be continuously removed.

The selection of suitable cleaning methods is of great importance because many common janitorial practices disperse dust and therefore cannot be tolerated in a beryllium plant. Cleaning with brooms or compressed air will generate intolerable dust concentrations. Even on a wet floor, stiff brooms can raise significant mist concentrations. High velocity nozzles are likewise unsuitable. Mops or squeegees are more satisfactory in wet areas. An inherently non-dust-producing device such as a vacuum cleaner is preferable for dry areas. It may be either a portable unit or a permanent system; the latter may be justified in large beryllium installations. If a portable cleaner is selected, the exhaust should be connected to the ventilation system to prevent the reintroduction of dust to the working atmosphere. A permanent system should contain a generous distribution of vacuum taps so that all work areas may be serviced. Even the operation of a vacuum cleaner, however, can be dusty unless moderate care is exercised. Concentrations as great as  $6 \mu\text{g}/\text{m}^3$

have been measured where a vacuum cleaner was being used too energetically.

Ease of housekeeping is related to the type of interior construction: smooth surfaces and concealed structural framework will reduce the effort required to maintain a clean work area. However, this is not essential, and the choice is primarily economic.

Normal industrial housekeeping techniques will clean surfaces well enough, the objective being to remove loose surface contamination.

For dust control, there is no value in analyzing smear samples for surface contamination, since no correlation has been found between surface dust and air dust concentration. To mention an analogous case, several years ago a special effort was made to learn whether a correlation exists between radioactive surface contamination and air dust concentration, and none was found.<sup>11</sup>

#### OUT-OF-PLANT

There is evidence that an unusually small concentration of beryllium in air can produce illness among residents in the neighborhood of a beryllium plant.

In 1948 an intensive epidemiological study was conducted in the neighborhood of an extraction plant where nonoccupational illness had appeared. Ten cases were recorded, all within a radius of  $\frac{3}{4}$  mile from the plant. Reconstruction of neighborhood exposures in effect during the period when the illnesses were thought to have developed indicated that concentrations at the  $\frac{3}{4}$ -mile radius may have averaged as low as  $0.1 \mu\text{g}/\text{m}^3$ .

Based on the findings of that study,<sup>2</sup> the upper limit of average monthly exposure in the neighborhood of beryllium plants was set at  $0.01 \mu\text{g}/\text{m}^3$ .

The principal source of neighborhood air contamination is the stack (or stacks) from which process effluents are emitted. Secondary sources may be contamination on the plant roof and exposed stockpiles of ore or other materials; however, these can be neutralized by obvious methods and need not be discussed further. The control of contamination emitted from a stack is somewhat subtle and requires an understanding of the mechanics of diffusion. Theoretical and empirical expressions have been developed which relate the ground level concentrations to source height and strength. These relationships are only approxi-

mate, but they may be used as engineering guides to regulate the plant effluent so that neighborhood residents will not be exposed to hazardous beryllium concentrations.

The concentration at the ground is a function of the rate of effluent emission, source height, wind speed and direction, lapse rate, topography, effluent particle size (if a solid), and distance from the source. For the purpose of rough estimation, most particulate effluents behave sufficiently like gases so that no correction is required in using the diffusion formulas.

Among the several factors governing ground level concentration, the source height and strength may be selected by the engineer. If a site for a beryllium plant is open to selection, the local topography and prevailing meteorological conditions should be evaluated in terms of their effect on the plant effluent behavior. A favorable situation for a plant would be in an area of low population density. Maximum concentrations most frequently occur at distances of from 5 to 30 stack heights. In a location clear of neighbors to a distance beyond this span, the restriction on the plant effluent necessary to keep nonoccupational exposures within the prescribed limit would be less stringent. However, regardless of the existing physical situation, ultimate control of nonoccupational exposure reduces to a proper selection of source strength and elevation. If the plant is to operate continuously, these must be designed so that the monthly average ground level concentration at any inhabited location does not exceed  $0.01 \mu\text{g}/\text{m}^3$  under any foreseeable climatic conditions.

#### Permissible Stack Discharge Rate

The subject of the diffusion of stack effluents has received considerable attention from investigators and continues to develop as new information comes to light. Many theoretical and empirical treatments have been advanced; although basically similar, each possesses specific differences, and none is universally applicable to all practical situations. Individual theories may be more or less suited to individual problems. In view of the existence of several detailed discussions<sup>12,13</sup> of stack theories and their application, a similar discussion will not be included here. However, an example of a practical application of the theories will be presented to demonstrate their utility.

In 1949 the Commission undertook the construction of a beryllium refinery in western Ohio. A site was chosen in a sparsely populated farming area characterized by very flat and unobstructed terrain. In spite of the low population density, the question of potential air pollution received careful consideration, and the inescapable conclusion was that ground level concentrations must meet established criteria. The combination of a tall stack for good contaminant diffusion and carefully limited contaminant discharge was the method selected for restricting the out-of-plant beryllium concentration. All process ventilation was to be discharged through a single stack. The selection of stack height was based primarily on construction cost, bearing in mind the advantage of height with regard to diffusion; 185 ft was the value adopted.

The next design step was the computation of a permissible effluent discharge rate. The expressions of Bossanquet and Pearson<sup>14</sup> were used to calculate both the discharge rate at which the maximum ground level concentration would equal  $0.01 \mu\text{g}/\text{m}^3$  and the distance at which the maximum concentration would occur. These calculations were done by using diffusion parameters both for moderate turbulence (which simulated conditions in the original plant which the new one was to replace) and for conditions of low turbulence (which were expected at the new plant site.) A maximum permissible discharge rate of 150 g/day was selected as reasonably close to satisfying both turbulence conditions. Actually, this is very conservative in view of the exposure criterion that the concentration at any location averaged over a month should not exceed  $0.01 \mu\text{g}/\text{m}^3$ . Theoretically this average concentration would be realized at the calculated discharge rate only if the wind blew continuously in one direction and at one velocity for the full month and if the concentration were measured in the center of the smoke plume. It is known that a plume characteristically shakes back and forth even during conditions of reasonably uniform wind direction; thus, the downwind concentration measured at a fixed geographical location will always be less than that predicted by the diffusion expression used in this instance.

With a permissible discharge rate of 150 g/day as a starting point, a table was prepared listing the several plant processes and their estimated con-

tributions to the total effluent. This could be done quite accurately because effluent measurements were available from the older plant which the new one was to replace. Further, the efficiency of individual air cleaning units used in the earlier plant was known, and that of other types could be predicted from experience. The sum of all the process effluents was about 10 kg/day. With the type and extent of air cleaning equipment in the original plant, this rate was reduced to about 3 kg/day. On the basis of the composition of the effluents and the inlet loading of each collector, air cleaning equipment was chosen which would provide the necessary degree of decontamination to meet the total effluent limitation of 150 g/day.

The plant was constructed and the necessary exhaust systems installed to maintain the concentration in the working atmosphere within the plant below the permissible occupational level of  $2 \mu\text{g}/\text{m}^3$ . Each exhaust system was filtered through the equipment specified, and the discharge of all collectors and all systems was brought together in the single stack.

The performance of the control system was very carefully observed during the first two years of plant operation. An out-of-plant sampling network was established and operated continuously (and is still in operation at the time of this writing). Sampling stations were placed at distances of 1000, 2500, and 5000 ft from the stack. Stack

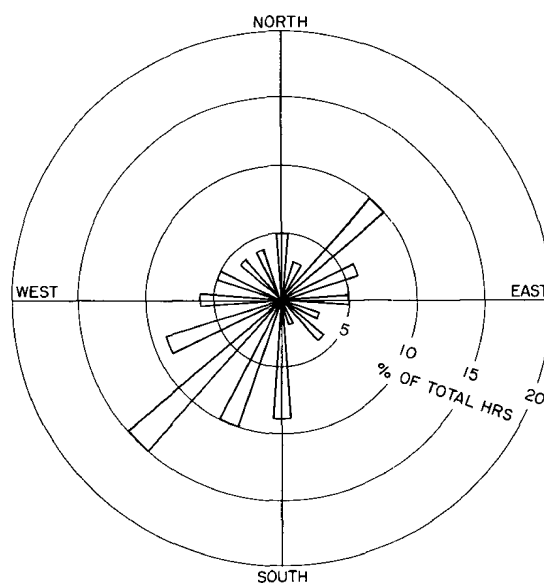
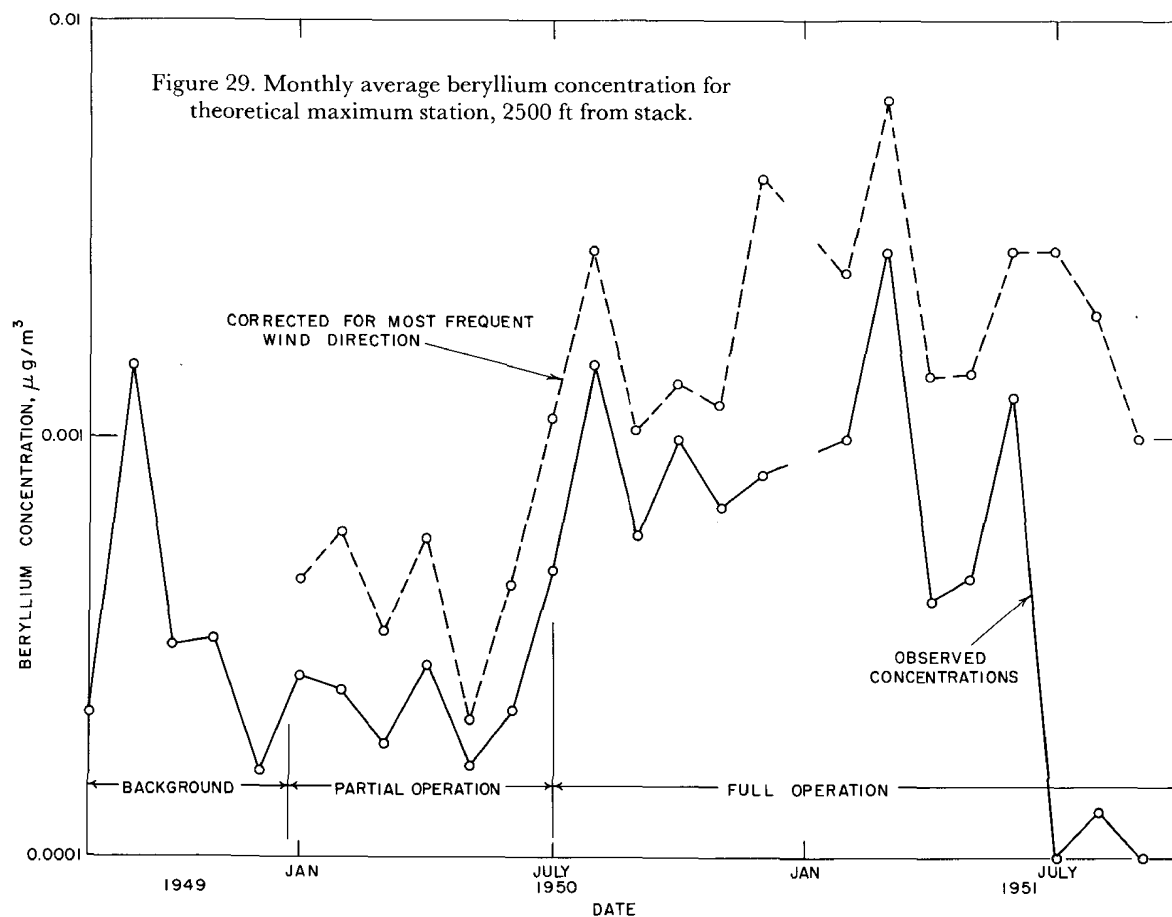


Figure 28. Typical monthly distribution of wind directions.



samples were taken to check the design efficiency of the collection equipment. Over the first two-year period, the effluent varied between 80 and 140 g/day. In order to determine the maximum downwind concentrations, the concentrations observed at the sampling stations were corrected for most frequent wind direction. In Figure 28 is a wind rose showing the method of normalizing the data.

Figure 29 shows a plot of the data. The first portion of the curve indicates background showing the results of samples taken prior to plant operation. Next an interim period is shown during which the operation was partial. The rest of the data represent maximum plant operation. The adjusted curve is in all cases below 0.01 and in most cases above 0.001.

As a matter of interest, the average beryllium concentrations at the three sampling stations may be compared with the theoretical diffusion curve relating concentration to distance from the source (Figure 30.) The actual concentration values are

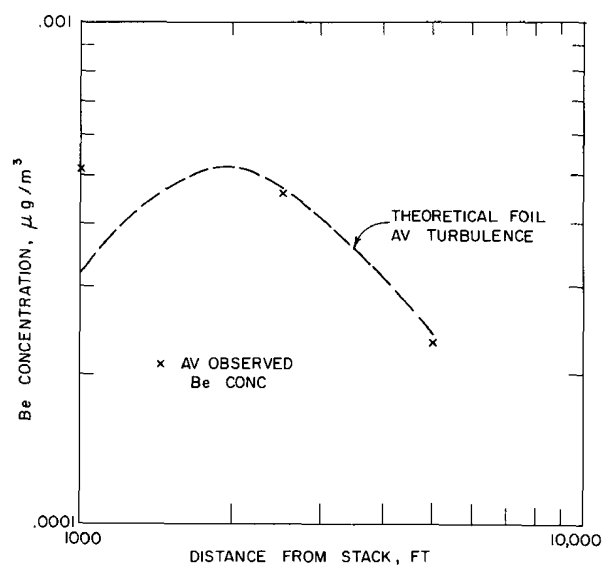


Figure 30. Comparison of observed offsite beryllium concentration vs distance from stack with theoretical diffusion curve [Bossanquet and Pearson<sup>14</sup> formula,  $C_0 = (10^6 M / \sqrt{2\pi pqux^2})e^{-H/px}$ ].

taken from a period when consecutive data for all these stations were available. The theoretical curve, from the Bossanquet and Pearson<sup>14</sup> expression, is based on an arbitrary discharge rate, so that only the slope of the curve may be validly compared with the empirical data. If one works back through the Bossanquet and Pearson situation up to the source strength from these concentration data, the value is in the neighborhood of 3 to 5 g/day. It must be remembered, however, that the concentration data on this graph have not been corrected for frequency of wind direction. Other out-of-plant sampling data have been published previously by this laboratory. These were shown to correlate remarkably well with diffusion theory.

### Selection of Air Cleaning Equipment

It has been shown that a prescribed ground level concentration can be related to a specific rate of contaminant discharge at a known elevation above the ground. Thus, a rate of emission can be calculated which will produce ground level concentration not in excess of the limit established for nonoccupational berylliosis. Obviously, for safe operation, means must be available by which the discharge rate can be maintained below the calculated value.

The first step is to determine what discharge rate might be expected. In an existing installation the total rate of emission can be measured by conventional stack sampling techniques. Care must be exercised to sample each point of discharge if there are more than one. It is also important that samples be representative of all the material in the stack and of complete operating cycles, so that transient peaks or lulls in emission rate do not bias the measurements. The rate of emission should be calculated as an average over a 24-hr period.

For example, an emission rate exceeding the calculated permissible value by a factor of three but persisting for only 8 hr per day will result in the desired ground level concentration over a full day. Ground level concentration fluctuations over short periods are not significant. This is implicit in the neighborhood exposure criteria.

For new plant design, direct measurements cannot be obtained barring the pre-existence of an old plant; however, estimates of the dust dispersed from various operations may be made by several methods. These include extrapolation from pilot plant data, testing of specific pieces of equipment,

or extrapolation from data obtained with machinery similar to that to be used while processing materials having physical and/or chemical properties similar to those of beryllium containing materials.

The stack discharge rate determined by any of these methods can be compared with the rate specified as safe with respect to neighborhood pollution. Conceivably the estimated emission rate may be so low that no air cleaning will be required; possibly there may even be no need for a stack.

If the estimated discharge exceeds the calculated safe rate, the ratio of the difference between the two values to the estimated emission represents the cleaning efficiency required to produce the desired emission rate for a one-collector system. If the nature of the process is such that several ventilation systems, carrying different kinds of contamination, terminate at the stack or discharge point, several collectors, possibly of different types, may be indicated. The efficiency of each need not be identical; however, the weighted average efficiency must equal the prescribed value, i.e., the net discharge of all the collectors must not exceed the calculated safe value.

From this point the problem consists of proper selection of air cleaning equipment, which will depend on the chemical and physical character of the contaminant(s) and the necessary cleaning efficiency. Collectors which have been used at beryllium installations are listed below according to the kind of contaminant and measured efficiencies.

Cottrell	BeO, BeSO <sub>4</sub> , SO <sub>2</sub> , SO <sub>3</sub>	96-98.5
	Frit reacted with H <sub>2</sub> SO <sub>4</sub>	83
Scrubber	NH <sub>4</sub> F	54-93
Cloth bag	Ground ore	95
	Frit	93
Cyclone	Frit reacted with H <sub>2</sub> SO <sub>4</sub>	87
Scrubber	Be, NH <sub>4</sub> , BeF, NH <sub>4</sub> F	61
Scrubber	Beryl, frit	20
Reverse jet	BeO	99.99+
	Ground ore	96+
Electrostatic precipitator	Metal	65-99+

It should not be construed that beryllium has any significant effect on air cleaning equipment performance. The above efficiencies might be

found in many different kinds of installations. Individual collectors will have performances depending upon the characteristics of the material to be separated from the air, and must be selected on an individual basis in accordance with good industrial practice.

In addition to air cleaning efficiency, two important factors to be considered are the variation in resistance to air flow between individual collector units, and the frequency and complexity of repair and maintenance. Where bag-type collectors or scrubbers are used, ventilation systems should be designed to provide sufficient capacities in dust control hoods at maximum collector loadings. Collector maintenance usually involves seriously high transient dust exposures. It is virtually impossible to provide primary control for these operations.

### Waste Disposal

The responsibility of management at a beryllium facility must include the fate of solid and liquid wastes as well as gaseous wastes beyond the facility perimeter. Some of the factors which have led to the present Commission policy relating to waste disposal are discussed below.

Whereas gaseous beryllium bearing wastes are known to have caused nonoccupational illness, solid and liquid wastes have not. However, relatively high concentrations of beryllium have been measured in the vicinity of beryl ore stockpiles on the open ground, and it might be conjectured that dust could be similarly dispersed from dry waste. (Such sources may possibly contribute to the neighborhood concentrations under special circumstances and becloud the interpretation of off-site monitoring samples.) The concentration of beryllium in waste materials would doubtless be considerably less than that found in beryl. But even though the likelihood of creating an actual hazard through the release of waste materials is exceedingly small, it behooves management to take some precautions. This has been evident from the inception of Commission activity in beryllium work and is made necessary by the ever present problem of public relations. Beginning with the publicity which occurred in 1949-1950 concerning the various aspects of beryllium toxicity, the public has become generally aware of its dangers, and in the vicinity of beryllium facilities people are prone to be overly sensitive to real and imagined dangers. This suspicious and sometimes

hostile attitude of neighbors has presented problems in the form of liability proceedings and undeserved criticism in the press.

In view of the public attitude, the treatment of wastes in some cases requires greater care than indicated by the potential hazards. The Commission has come to agreements with local and state health authorities where large production facilities exist that the beryllium content of bodies of water into which liquid wastes are introduced will be maintained below 1 ppm. Recent range finding tests by the U.S. Public Health Service<sup>15</sup> indicate that under certain specialized test conditions, death was produced in fish by  $\text{Be}^{++}$  concentrations as low as 0.1 ppm. Although this work has not been repeated, it is mentioned as an indication that the value 1 ppm may require downward revision.

Where large quantities of solid wastes have been generated, they have been stored in a manner to minimize leaching to surface water run-off or into ground water strata.

The degree of the solid and liquid waste disposal problem depends on the quantity of beryllium materials processed. In laboratory or other small operations, liquid wastes can be dumped down a sink drain with no hazard. Small quantities of solids may be discarded with other rubbish, but it is advisable to wrap them to eliminate contamination during handling. Where the systematic generation of wastes is of the order of pounds or more per week, the effects of disposal should be more carefully scrutinized. At full-scale production facilities, where wastes amount to tonnage quantities, precautions should be taken as described below.

The three major sources of solid waste materials in transforming beryl to metallic beryllium are:

- 1) *Alum.* This is a fine crystalline material, generally containing <0.1% beryllium, which is produced from the aluminum fraction of the beryl. Assuming a production rate of 100,000 lb beryllium metal per year, the alum production would be of the order of 1500 tons. This is not a large amount of waste material, but its small beryllium content introduces a disposal problem. Some of the solid waste materials have commercial by-product value, but it is difficult to sell them: although harmless in the envisioned uses, the beryllium content, small as it is, has generally made the material psychologically unacceptable to potential consumers.

2) *Magnesium fluoride*. This material is produced in about the same quantities as the alum, and contains possibly as high as 0.5% beryllium.

3) *Miscellaneous sludges*. These are largely fluorides and sulfates from the refining of the metal and may contain as much as 0.5% beryllium.

At a production rate of 100,000 lb/year of metal, it can be expected that sludges of the type described above will be produced at a rate of about 5000 tons. Whereas this material may be stored on the ground as is usual with industrial chemical solid wastes, the presence of small concentrations of beryllium and relatively high quantities of fluoride requires supervision of storm water run-off and reflation by the wind. If the storage area can be on impervious ground and the rate of surface evaporation exceeds the rainfall, the storage should present no problem. If these conditions do not pertain, other means of disposal should be considered.

The wet processing of beryllium generates fairly large volumes of liquid waste materials which usually contain common chemicals such as sulfate and aluminate, contaminated with rela-

tively low beryllium content. Wet scrubbing devices add to the load of liquid effluent. A 100,000-lb/year plant can be expected to produce about five million gal waste. In the vicinity of a large river this should present no great problem; but if no such large volume of water is available, other disposal means must be considered. It has sometimes been found necessary to use a rather complex system of controlled discharge into relatively small streams at periods of high run-off. In the past the controlling factor in liquid waste disposal has been the sulfate content, which has been limited to not more than 100 ppm above the normal background of the river.

## SUPERVISORY CONTROLS

### Training and Supervision

The manner in which employees operate plant equipment is as much a part of dust control as is local exhaust ventilation. Of particular importance are specific procedural details for manual tasks. Examples of jobs which can be dusty if improperly executed are placing and removing lids from con-

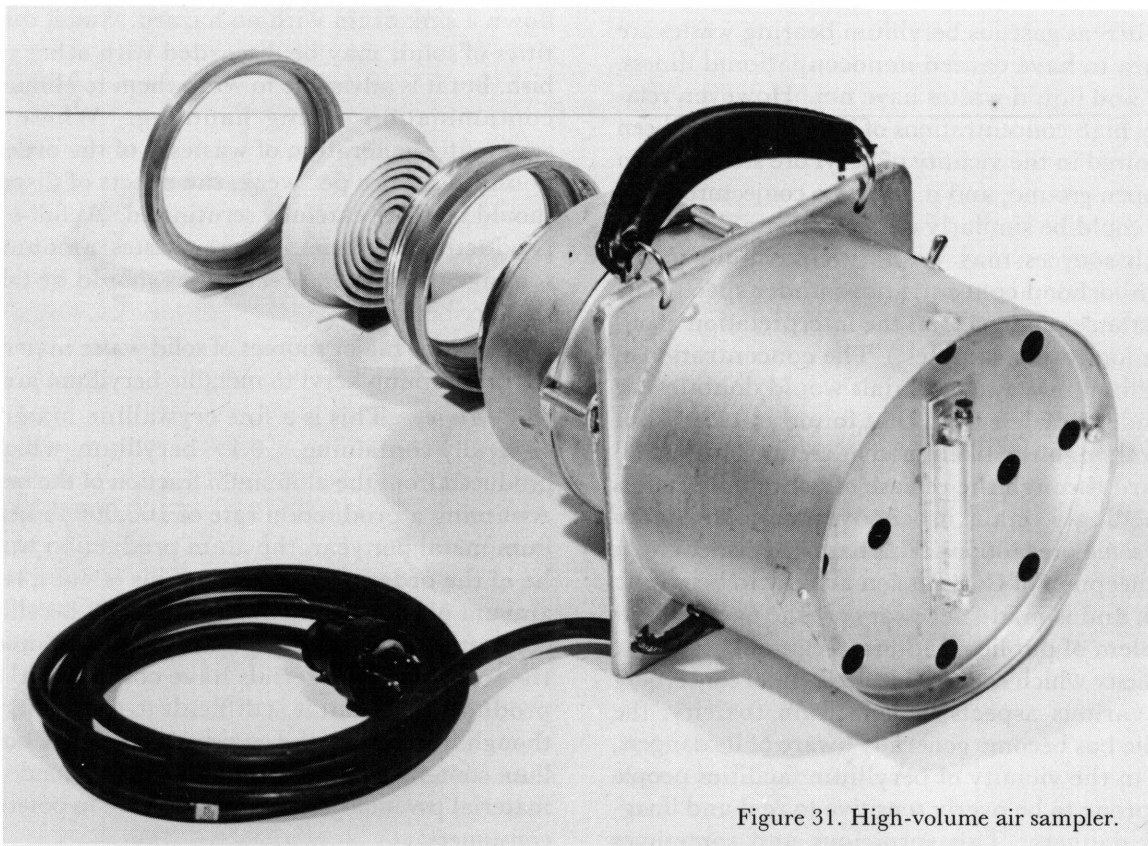


Figure 31. High-volume air sampler.



tainers, handling tools in and out of hoods, transfer of in-process material, furnace charging, etc.

There are ways to do jobs of this nature with a minimum of dusting. It is important that each worker be acquainted with the best procedures and apply them consistently; rules of good operating practice must be rigidly enforced. Frequently the safest practices are tedious or require special effort. (Needless to say, best results occur where control design adds minimal operating inconvenience.) Workers will be more willing to comply with such rules if they understand the reasons for them; therefore, a program of education about known beryllium hazards is beneficial to both supervisors and workers. It should create a feeling of respect rather than fear for beryllium materials.

There is a marked tendency even for persons acquainted with the toxic aspects of materials to lose sight of their potential hazard as time passes because of familiarity, and therefore to become less careful in handling procedures. To counteract this tendency, supervisory personnel must be continuously on the lookout for deviations from good practice and must immediately censure employees who commit infractions.

### **In-Plant Air Monitoring**

Except for waiting for evidence of overt disease, the only means of determining whether satisfactory control is being maintained is to measure the beryllium dust concentration in the environmental air. A bioanalytical method has not yet been found which correlates with beryllium exposure or illness, although bioanalysis has been found useful in the case of other toxic substances.

The survey of dust exposures is an integral part of dust control and may be considered as the proof testing of engineering controls. It often constitutes a basis for redesign or modifications toward better control. Basically, it serves two important purposes: it provides an evaluation of the exposures of employees to beryllium, and it enables the engineer to detect sources of contamination. Monitoring must be performed on a repetitive basis in view of the changeability of dust concentrations in a plant. Deterioration of equipment, employee turnover, relaxation of clean work habits, process changes, and seasonal effects are factors which tend to change control effectiveness. This variability may be more or less pronounced according to the nature and size of the beryllium process. In any case, the air sampling technician should be in

frequent contact with all phases of the operation so that the effects of process changes on air contamination can be quickly identified.

In addition to spot checks at new or modified processes, an in-plant dust monitoring program should include complete plant surveys about every quarter year, designed so that each employee's exposure may be evaluated. From this information, significant trends in exposure can be examined with a view to finding possible trouble areas.

The time required to complete a complete plant survey is quite variable depending on the number of employees and the number and complexity of the jobs. The most effective, reproducible, and useful type of plant survey involves obtaining sufficient samples suitably located to permit calculation of a time-weighted average exposure. This takes considerable effort, but has been productive. A production extraction or fabrication plant employing  $\approx 150$  to 250 persons can be adequately sampled and studied in 7 to 10 man-days, with the collection of 300 to 500 samples. A small laboratory or shop employing up to 12 persons may take 1 to 4 man-days, depending on the repetitiveness of the operations.

The first phase of an exposure survey consists of the collection of air samples throughout the plant. To evaluate an average daily exposure properly, the dust concentration at each job performed by an employee throughout the day must be known; obviously a great many samples must be collected even for a plant of moderate size. The number of samples necessary for full exposure evaluation is quite variable, the number of samples per employee diminishing with an increasing number of employees. For fewer than 10 persons, from 10 to 25 samples per person may be required; for 50 to 250 persons, from 1 to 3.5 samples per person may be sufficient.

**Equipment.** Any air sampling device that separates the air contaminant in a manner suitable for chemical analysis can be used for beryllium monitoring provided the sampling rate is great enough. A high sampling rate is necessary because of the normally low beryllium concentration at an adequately controlled facility. A minimum rate of 1 cfm is recommended and higher rates are desirable. A high-volume filtration-type sampling unit (Figure 31) originally conceived by Silverman and later modified at HASL possesses several characteristics particularly favorable for beryllium sampling. A high volume rate

(20 cfm through a 4-in. Whatman #41 filter disc) provides good sampling sensitivity in a short time in atmospheres where concentrations are normally expected to be low. The unit is compact, weighing about 11 lb, and may be supported in the hand while taking samples for short periods. Sampling heads in which the filters are held can be interchanged readily, so that heads may be prepared in a clean area in advance of sample collection to prevent contamination in the plant. The Whatman #41 filter paper normally used in this instrument is ashless, which simplifies the analytical procedure.

At a sampling rate of 20 cfm the linear velocity through the filter paper is approximately 200 fpm. Collection efficiencies at this velocity have been reported to be 85% for uniform liquid droplets<sup>16</sup> 0.3  $\mu$  in diameter and better than 90% for dust distribution<sup>17</sup> with a mean size (by weight) of 0.5 $\mu$ .

Great care must be exercised in handling the filter discs to prevent contamination; they should be manipulated by forceps. After sample collection the discs should be placed in individual glassene or cellophane envelopes and remain untouched until analysis.

**Survey Procedure for Obtaining Time Weighted Exposures.** Samples should be collected at all potentially contaminating operations and in all areas occupied by employees for significant periods. The selection of areas and operations to be sampled is based on a careful observation of each employee's work procedure. The time during which he is exposed to each concentration must also be known and can be obtained while samples are being collected.

Upon completion of a survey, the collected sample and time data are used to compute the exposures of individual employees. The organization of the data for these computations may be greatly simplified by the use of a standard form (Figure 32) completed for each job in the plant. The form is designed for efficient data tabulation and simple, direct interpretation. The following explanations may clarify its use.

*Column 1.* The samples listed are designated as BZ or GA, abbreviations for "breathing zone" and "general air" which refer to the manner in which the samples are collected. Breathing zone samples are collected where a worker may be exposed to contamination from a specific source at which he is performing an operation. The intake to the sampling instrument is held near the worker's

nose for the duration of the operation. General air samples are collected to measure concentrations in areas occupied by employees when they are not engaged in specific dusty operations, such as process areas, lunchrooms, locker rooms, and rest areas. For these samples, the instrument is fixed in one location for the sampling period, usually 30 to 60 min.

*Column 5.* Replicate samples are collected at each operation and in each area. Generally a minimum of 3 breathing zone samples is collected at each operation. From 3 to 20 or more general air samples may be required from an occupied area depending upon size, number of occupants, and complexity of operations performed within it.

*Column 9.* The summation of the product of average concentration (column 5) and time per shift (column 4) is divided by the total time in the shift to yield an average weighted exposure. This relationship may be expressed

$$\text{Average Concentration} = \frac{\sum(T \times C)}{\sum(T)}$$

This value must be 2  $\mu\text{g}/\text{m}^3$  or less to satisfy the basic criterion of safe exposure.

*Column 8.* The second item of the exposure criteria stipulates that no single concentration should exceed 25  $\mu\text{g}/\text{m}^3$ . This column provides the data as to whether or not this criterion is met.

The above example illustrates the method of evaluating the exposure of each employee in terms of the criteria currently accepted. If an exposure is found to exceed the stated limits, the analysis sheet provides a direct guide to the operations or areas involved, so that controls may be corrected or added as needed. If average exposures exceed specified criteria, column 9 will reveal which exposures contribute most to the shift total, and improvements may be made in appropriate locations.

### Out-of-Plant Air Monitoring

The ultimate effectiveness of any control of airborne effluents is determined by the resultant average ground level concentration, which is best determined by direct, continuous measurement. It is also useful in some instances to measure the quantity of material leaving the stack, particularly early in the operation of new pollution control equipment as a check on performance compared to design predictions. Stack sampling is a well-known procedure and can often be easily accomplished. On the other hand, difficulties can

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(11-4-52)

**JOB ANALYSIS SHEET**

OPERATOR: Sulfate Mill Operator      1 MEN/SHIFT:      2 SHIFTS/DAY:      2 MEN/DAY

#1 OPERATION OR OPERATING AREA	#2 TIME PER OPERA. (MIN)	#3 OPERA. PER SHIFT	#4 TIME PER SHIFT (MIN) (T)	#5 NO. OF SAMPLES	#6 #7 #8 CONCENTRATION, μg/m <sup>3</sup> (C)			#9 AVG. CONC.* TIMES TOTAL TIME (T × C)
					LOW	HIGH	AVG.	
					1. BZ Lighting Burner	1.4	1.5	
2. BZ Feeding Sulfate Mill			60	6	0.2	9.8	4.5	270
3. BZ Removing Cover Plates	6.4	1.5	9.6	4	2.9	5.8	4.3	41
4. BZ Sampling Sulfate	1.0	1.5	1.5	4	2.5	13	6.4	10
5. BZ Measuring Specific Gravity	0.7	3	2.1	5	5.2	8.6	6.5	14
6. BZ Replacing Cover Plates	7.2	1.5	11	4	3.6	5.7	5.0	55
7. BZ Cleaning Burner End	1.8	1.5	2.7	4	1.3	16	6.0	16
8. GA Sulfate Mill Area			351	10	0.6	2.1	1.4	490
9. GA Leaching Area			20	7	0.6	12	2.8	56
10. GA Lunch Room - Lunch Period			20	7	0.04	2.7	0.8	15
11. GA Lunch Room - Rest Period			10	4	0.06	3.1	1.0	10
12. GA Locker Room			28	6	0.3	1.4	0.8	22

\*Adjusted to two significant figures

Σ T 508

Σ (T × C) 1007

$$\frac{\Sigma (T \times C)}{\Sigma (T)} = \frac{1007}{508} = 2.0$$

$$\mu\text{g}/\text{m}^3 = 1.0$$

TIMES THE MAXIMUM  
ALLOWABLE CONCENTRATION

Figure 32.

arise from large duct or stack cross sections with sharp velocity gradients and/or marked turbulence, or from the presence of entrained moisture, corrosive acids, heavy loadings, or combinations of these.

In an installation where the effluent beryllium rate may be capable of producing average ground level concentrations exceeding or even approaching  $0.01 \mu\text{g}/\text{m}^3$ , a constant check on the existing concentrations should be obtained. A properly designed monitoring system will provide data which can be evaluated as long-term averages; instantaneous peak values are generally not considered significant. The out-of-plant exposure criterion is an average monthly concentration at the breathing zone level (3 to 6 ft above the ground) not  $>0.01 \mu\text{g}/\text{m}^3$ , in all directions from the plant. The average concentration in any direction will vary with the frequency with which the wind blows in that direction and with the time variation of beryllium discharge rate from the stack. In order to know whether the criterion is being met, only the highest average concentration each month need be known, regardless of its direction. If this value is  $<0.01 \mu\text{g}/\text{m}^3$ , it follows that the averages in all other directions are within the allowable limit.

To obtain a valid monthly average concentration, continuously operating samplers must be employed. Experience has shown that a permanent system of samplers can be serviced with relatively little trouble and can provide dependable service. The basic problem is to select sampler locations which will yield reliable and meaningful information.

The maximum ground level concentration occurs at a distance which is predictable, as previously shown, on a theoretical basis but highly variable, changing with wind speed, lapse rate, and other factors. The distance is most frequently from 5 to 30 stack heights, and 3 sampling units located at suitable intervals along this span can be expected to pick up the most severe concentrations.

For a constant rate of contaminant emission, the maximum monthly average concentration would be expected to occur in the direction toward which the wind blows most frequently; therefore it is desirable to place samplers along a line in the prevailing downwind direction. If the prevailing winds were invariable, one line of samplers so placed would provide all the required information; however, prevailing wind directions

change seasonably in many locations. Availability of power to the units and ease of access to the units are also important factors in their placement. An array of sampler lines distributed in many directions would insure the detection of the maximum monthly average regardless of wind direction, but experience has proved the efficiency of setting the samplers in a single convenient line and correcting the concentrations obtained by the ratio of wind frequency in the direction where it is maximum to wind frequency in the chosen direction during each monthly sampling period. Although some error is introduced, the values are sufficiently accurate for the purpose. For this procedure cumulative wind frequency and direction data are needed. They may be obtained from a recording wind vane and anemometer at the plant site or from a U.S. Weather Bureau station if nearby.

From the cumulative wind data a wind rose may be plotted for each month showing the percentile frequency of the winds in each compass point direction. The ratio of the frequency in the monthly prevailing direction to the frequency in the sampler direction may be multiplied by the maximum average concentration detected to obtain an estimate of the maximum average for the month, if it is assumed that the rate of contaminant emission does not vary substantially and that no significant bias in any direction is brought about by meteorological conditions.

Sampler location must depend somewhat on available sites. The most desirable locations from the standpoint of prevailing wind direction may be inaccessible because of topography or buildings or for other reasons. The local area where the sampler is to be placed should be relatively free of tall obstructions. The samplers must be sheltered from the weather; for this purpose a small "dog-house" type of hut with louvered openings to permit good air circulation is suitable.

The high-volume sampler described previously as an in-plant survey instrument is equally suitable for outside air sampling. These units may be operated continuously for periods up to several days without filter change. Experience indicates that with monthly brush replacement the pumps may be expected to operate for years without servicing. For this purpose an MSA type S filter has been used rather than the Whatman #41 because it has less resistance to air flow and a greater surface area. Thus, the sampler operates at a higher flow rate, which is desirable for out-

door air sampling. This paper contains considerable ash, which makes analysis for small quantities of beryllium difficult, but the large air volume filtered in out-of-plant monitoring tends to counteract this difficulty.

#### MEDICAL CONTROL PROCEDURES\*

Medical control must be an integral part of the occupational hygiene program for two reasons. 1) Despite the relatively long period of operation without significant overt illness under the exposure limitations discussed above, it cannot yet be stated with certainty that the maximum allowable concentration values are safe under all conditions. Experience suggests that, if anything, the in-plant values may be somewhat conservative, but it is possible that chronic illness may still appear after longer intervals. The apparent discrepancy between permissible occupational and nonoccupational exposure levels is yet to be resolved. Hence, a medical examination program is needed to detect symptoms of illness. 2) In almost any conceivable operation, accidental exposures in excess of target levels are likely to occur, the probability increasing with larger quantities of in-process material and with operational modifications. Occasional failures occur in the most carefully designed controls and these may be undetected, particularly if only transitory.

The medical program is designed to screen prospective employees for persons who may be predisposed to respiratory illness, to discover incipient illness by periodic examinations, to prescribe treatment for overt illness, to determine preventive measures including therapeutic layoff, to differentiate beryllium disease from other illness, to maintain medical records, and to perform examinations at termination of employment.

The recommendations which follow are based on data gathered at plants producing beryllium salts from ore and are conservative in that they are designed for conditions involving massive quantities of beryllium materials with consequent possibilities of gross contamination on work clothes, direct dermal contact with any of a variety of compounds, and occasionally severe exposures to dusts or fumes. They are subject to modification in the case of lower potential exposures, e.g., at a laboratory project where comparatively small

quantities are used, frequency of examinations might be reduced or other relaxations might be permissible, but these should be approved by a physician.

The control program is based on the following premises:

1) Beryllium and its salts are toxic and produce in man acute pulmonary, chronic pulmonary, dermal, and systemic manifestations.

2) Beryllium poisoning appears to occur in association with industrial processes in which beryllium and/or its salts contaminate the atmosphere.

3) The disease is not limited to workers but may occur in those living in the immediate vicinity of a plant or in the families of workers who come in contact with the beryllium brought home on soiled work clothes.

4) Certain pre-existing physical conditions may predispose to the disease or be adversely affected by exposure to beryllium.

5) Inhalation of beryllium compounds may produce acute or chronic pneumonitis. Dermatitis occurs when the skin comes in contact with soluble beryllium salts, and ulceration frequently after a soluble particle has penetrated the skin. Chronic granuloma may develop at the site of implantation when an insoluble beryllium salt or beryllium metal has been introduced under the skin.

6) The respiratory tract is the chief site of beryllium poisoning. In both the acute and chronic type severe dyspnea and pulmonary changes are outstanding. The gravity of the condition is directly related to the status of the respiratory and cardiovascular systems, and both must be evaluated completely for prevention as well as treatment of the condition.

#### Physical Examinations

*Schedule. Preplacement.* All employees – office, shop, service, maintenance, and yard workers – should be examined prior to entry.

*Periodic.* Employees routinely occupied in areas in which acute pulmonary or cutaneous manifestations are possible should be examined every week.

Employees routinely occupied in areas in which only chronic pulmonary manifestations are possible should be examined every month and have a 14×17-in. (35.5×43 cm) roentgenogram of the chest made every six months.

For those employees intermittently occupied in areas of possible exposure, the frequency of exami-

\*We gratefully acknowledge the assistance of Dr. Irving Tabershaw in the preparation of this section. See also reference 18.

nations should be determined by the plant physician.

All employees with possible exposure should receive a yearly examination.

Employees who have had previous acute manifestations should have an examination at least every three months.

All previously exposed persons who have had any prolonged physical stress such as serious illness, surgical operation, or childbirth should have at least monthly examinations for a minimum of six months after returning to work in any area.

*Terminal.* Employees should be examined at termination of employment unless a routine complete physical examination and chest x-ray has been done within one month.

*Scope. Preplacement.* This examination should include complete medical and occupational history; complete physical examination; special attention to weight, vital capacity, pulse rate before and after exercise, and skin; and the following laboratory procedures: standard 14×17-in. roentgenogram of chest, urinalysis, and complete blood count.

*Periodic: weekly and monthly.* This examination is to cover symptoms review, weight, vital capacity, condition of skin, nose, and throat, plus further examinations if any positive symptoms are found.

*Periodic: yearly and termination.* This should be the same as the preplacement examination.

*Recording.* Results of examinations are to be recorded on standard forms. All records are to be kept in a locked file to which only authorized personnel have access. One person, preferably a member of the plant medical department, shall be charged with the responsibility of completing and maintaining records.

### Physical Standards for Employment

Subject to the final judgement of the examining physician, the following abnormalities may be considered as disqualifying.

1) A history of repeated infections of the respiratory tract, chronic cough, unstable tuberculosis, any acute diseases of the liver with sequelae, acute disease of kidney with sequelae, asthma, or other respiratory tract allergy, or prior occupational disease, especially of the respiratory tract.

2) Evidence on physical examination of any chronic pulmonary disease, organic heart disease, enlarged liver, or deficient vital capacity.

3) Results of laboratory tests showing roentgenographic evidence of any form of pulmonary fibrosis, except apical pleural cap, or of active or unstable tuberculosis, except calcified primary complex; abnormal heart shadow associated with diminished cardiac reserve; persistent proteinuria (other than postural), casts, red cells, or pus in abnormal amount in urine; or abnormal hematologic findings.

4) Other special factors described below under "Procedure for Medical Examination."

### Medical Personnel and Facilities

Fixed standards cannot be established. The program must be under the supervision of a physician, and the personnel and the facilities shall be adequate to permit proper execution of the program outlined.

A separate room, affording complete privacy, is considered essential for carrying out examinations and for housing records.

Laboratory examinations may be performed outside the plant if facilities are not available within the plant.

Appropriate medical consultants should be used when indicated.

### Prophylactic and Therapeutic Regimen

The decision as to the treatment of persons with accidental significant exposure or with suspected or overt illness due to beryllium compounds must be left to the attending physician. The following points are given as a general guide.

In any case of suspected significant exposure that may produce acute manifestations, examination should be done daily for one week and weekly for two weeks thereafter.

Any employee who develops a cough, pain or tightness of the chest, anorexia or loss of weight, shortness of breath, or related symptoms should be kept under medical surveillance until the symptoms have disappeared or until the cause has been definitely established as other than beryllium.

An employee presenting any of the above symptoms subsequent to known massive exposure should have a prophylactic layoff with satisfactory compensation and rest at home and should be visited daily by a physician, the duration of the layoff being determined by the latter. Satisfactory compensation is suggested to encourage employees with symptoms to report early, since early detec-

tion of acute beryllium poisoning is of prime importance.

Symptoms plus any abnormal physical finding should entail a prophylactic layoff and strict rest in bed at home with daily visits of the physician, depending on severity.

Symptoms plus roentgenographic evidence of pneumonitis and/or evidence of oxygen deficiency call for hospitalization.

Rest in bed, oxygen, symptomatic treatment, and possibly the refined steroids are the only therapeutic measures recognized at present.

The use of aminophylline, antihistamine drugs such as diphenhydramine hydrochloride N.N.R. (Benadryl hydrochloride<sup>(R)</sup>) and tripeleminamine hydrochloride N.N.R. (Pyribenzamine<sup>(R)</sup>), and positive pressure oxygen breathing may be tried at the judgement of the physician. There appear to be no contraindications to the use of these drugs, but neither is there conclusive evidence of any therapeutic value. The early and judicious use of the refined steroids, e.g., Meticorten, Aristocort, etc., has indicated these to be of value.

All persons having occupational contact with beryllium should be warned of the potential dangers and instructed in methods of protecting their health.

Foremen and supervisors should be instructed to be on the alert for suspicious symptoms in any of their men.

#### Procedure for Medical Examination

**Preplacement.** In addition to the general and medical history, an occupational history should be taken containing full details of all previous employment with special emphasis on exposure to dusts, fumes, gases, etc. It should be noted whether or not accidents were industrial and compensable, and when and where operations were performed.

Temperature, pulse rate, respiratory rate, and weight may be taken and vision and hearing tested by a nurse.

**Special Tests and Standards.** Recent loss of weight should be scrutinized by the examining physician as possible evidence of associated disease. Loss of weight is generally one of the outstanding manifestations of pulmonary disease in beryllium workers.

A pulse rate consistently above 96/min should be cause for further study and possible exclusion from employment. Failure of the pulse rate to return to not more than 10 beats above the resting

rate 2 min after exercise (hopping on each foot 20 times) may indicate poor circulatory function. The cardiac status should be evaluated on the basis of all pertinent findings including physical and roentgenologic examinations.

Vital capacity measurements are to be made with standard apparatus and subject erect. Values more than 15% below normal standards may be cause for exclusion. Diminishing function may indicate incipient pulmonary damage.

## EXPOSURE EXPERIENCE

### In-Plant Concentrations

In the design and installation of equipment for toxic materials, it is useful to know the extent of previous control measures. Many years of experience with the handling of beryllium under a wide variety of operations and conditions, representing normal plant practice under engineering control specifically designed to provide adequate protection to the employees, have resulted in a large mass of data. These are presented in several tables, organized according to classes of processes. Dust concentrations and methods of control used are listed for specific operations. Each concentration value is an average from two or more replicate air samples collected during a given survey. In most cases operations were sampled on several surveys, and the highest, the lowest, and the median of the average concentrations are presented. Where only one value (median) or two values (highest and lowest) are listed, the operation was sampled in only one or two surveys. Most of the data given are breathing zone concentrations, but some general air concentrations are included to give an indication of background and over-all employee exposures.

It should not be concluded that the listed concentrations are invariably associated with the listed operations. Control equipment of greater or less effectiveness would yield correspondingly higher or lower concentrations. The wide spread between the high and low concentration values for some of the operations is in part a reflection of improvement in control design effected during the operational period; however, it also reflects normally experienced fluctuations in control effectiveness resulting from changes in procedure and personnel and other aspects of plant operation such as housekeeping and ventilation system performance.



Table 1

## Metal Fabrication

		Be concentration, $\mu\text{g}/\text{m}^3$		
		Max	Min	Median
Metal cutting, lathe operations				
Chipping	Enclosure, hi-velocity pickup	2.4	0.4	1.1
Turning	" " "	5.8	1.0	1.2
Drilling	Ventilated collar	10	4.9	8.9
Jig boring	Hi-velocity pickup	4.6	0.5	3.0
Sawing (band)	Hi-velocity chip pickup, water coolant	5.2	0.4	1.3
Milling	Hi-velocity chip pickup	7.2	0.5	0.9
Metal grinding				
Surface grinder	Enclosure, water coolant	5.3	0.2	1.1
Cutoff wheel	" " "	5.9	0.1	1.0
Centerless grinder	" " "			29*
Miscellaneous impact†				
Forge (cold)	Ventilated enclosure	30	1.7	
Shear	" "			32*
Extrusion (cold)				
Load end	Open end steel jacket	1.7	1.0	1.3
Discharge	" " " "	2.0	1.8	1.9
Discharge	Unjacketed	2.3	0.3	0.4
General machine shop air		20.0	0.1	0.6

Note: Each value represents the average of replicates collected on a single survey.

\*At least three surveys except as noted.

†Dust created by manual handling rather than operation. This was a crushing operation.

Table 1 presents the values obtained during fabrication of beryllium metal from sintered powder. Some of the operations described were carried out only once, on an experimental basis. In some cases adequate control was found too difficult and the operation was discontinued.

Table 2 presents data collected during the handling of beryllium powders. These are prepared by chipping vacuum cast ingots on a chipping lathe (see Table 1) and charging the chips into an attrition mill for grinding to a fine sieve size. The powder from the mill normally discharges into a glass container screwed to the discharge spout. Powders of various analyses are blended and charged into a steel compact die, which is then welded, loaded into a sintering furnace, and sintered under heat and pressure. The steel die is later stripped from the final compact. Again it should be pointed out that the data presented show BZ concentrations under a particular set of circumstances. Some of the values represent

actual exposure to the employee; others do not, because the employee was protected by a dust respirator.

Table 3 lists operations involving the handling of beryllium pebbles and casting pebbles into ingots.

Table 4 presents data gathered during operations involving beryllia. It is important to note that the operations specified in the table vary greatly in magnitude, in some cases being on a small laboratory scale and in others involving large quantities of material.

Table 5 includes miscellaneous chemical and furnace operations. Most of these derive from work performed in a single metallurgical plant, but certain other data are given. In the case of manual handling, the samples represent the averages of breathing zone levels. Where no breathing zone sample is shown, it was possible to gather data only from the general atmosphere because of the automatic nature of the operation.

Table 2  
Powder Handling Operations

		Be concentration, $\mu\text{g}/\text{m}^3$		
		Max	Min	Median
Powder preparation (changing containers)	Ventilated enclosure	18	1.8	7.1
Blending (small)	Hood-hand ports			4.3
Blending (large)	Booth	32	1.5	9.7
Compacting	Ventilated enclosure			0.8
Vertical sintering face	Ventilated collar			
Load		3.0	0.8	*
Unload		8.8	0.5	3.4
Die stripping	Isolated, ventilated room (respirators)	128	6.1	63
General air, furnace area		0.6	0.2	0.3
General air, powder preparation area		2.2	0.3	0.6
Chip handling				
Change receiver		12	6.3	9.1
Pneumatic transfer to drum		57	2.3	14

\*Only two values.

Table 3  
Metal Handling Operations

		Be concentration, $\mu\text{g}/\text{m}^3$		
		Max	Min	Median
Pebble sampling (Vezin)	Ventilated enclosure			13.5
Pebble (bead) weighing	Inadequate ventilation	66	21	
Vertical-pour vacuum face				
Charging pebbles	Ventilated semienclosure	23	4.6	15
Remove billet and mold	" " "	41	19	24
Clean billet and mold	Ventilated table with backdraft	42	1.5	29
Clean crucible	" " " "	3.8	3.6	3.7
General air, vacuum casting area		4.8	3.6	2.9
Tilt-pour furnace				
Charge pebbles	Flexible exhaust duct	11	8.8	10
Pour	Ventilated collar	20	3.5	12
Remove billet and mold	Exhausted buggy	49	5.3	6.0
Remove billet from mold	Exhausted cabinet	6.2	0.5	0.9
General air, vacuum casting area		9.8	8.6	4.2
Sand blasting ingot	Commercial sandblast booth	27	2.0	2.2

Table 4  
Beryllia Operations

		Be concentration, $\mu\text{g}/\text{m}^3$			
		Max	Min	Median	
Calcining $\text{BeSO}_4$ to $\text{BeO}$ , beehive furnace	Slot hood				
	Charge	14	0.5		
	Unload	336	4.7		
	General air	0.9	0.2	0.5	
Fused $\text{BeO}$ , fusion furnace	Ventilated enclosure				
	Manual charge			3.6	
	Pneumatic charge	4.6	1.6	3.1	
	Clinker break-up			3.5	
Crushing $\text{BeO}$					
	Jaw crusher	Ventilated feed	38	0.7	19
	Roll crusher	Ventilated enclosure	5.3	2.7	4.0
Ceramic operations	Chemical hood				
	Mixing slip			0.5	
	Shaping form			0.6	
Tamping powder	Downdraft hood			2.3	

Table 5  
Miscellaneous Chemical Operations

		Be concentration, $\mu\text{g}/\text{m}^3$		
		Max	Min	Median
Filtration				
Clean large Sparkler	None	8.8	2.5	
Clean large Sparkler	None	21	0.3	2.3
Clean Hercules	Canopy hood	21	1.3	6.9
Clean basket centrifuge	Ring slot	6.7	3.9	5.3
Continuous centrifuge	Negative pressure on casing			
Change discharge drum		15	4.9	5.1
General air		0.9	0.2	0.6
Crushing				
Beryl jaw crusher	Ventilated enclosure			0.01
Beryl ball mill, charge	" "			0.02
Frit ball mill, general air	Unit under negative pressure	2.6	0.5	0.7
Ball mill, wet				
Charge	Booth	22	8.7	15
Dump	No ventilation, wet material	5.9	0.9	2.7
Electrolysis				
Sampling salt	Local exhaust			9.5
Hoe product				13.6
Dump product				10.4
General air				6.8

Table 6  
Beryllium Production, Miscellaneous Furnace Operations

		Be concentration, $\mu\text{g}/\text{m}^3$		
		Max	Min	Median
BeF sublimation	Ventilated enclosure			
Charge retort				39
Insert liner				3.8
Remove liner	Ventilated buggy			1.0
Remove condenser	" "			2.8
General air				0.02
Sulfating furnace	Ventilated enclosure and local exhaust			
Ignite burner		15,000	3.8	22
Remove coverplate		85	2.1	4.0
Replace coverplate		13	0.8	5.0
General air		5.9	0.2	1.2
Beryl fusion	Ventilated, horizontal collar			
Pour	Canopy hood	15	1.3	7.4
General air		4.5	0.6	1.1
$\text{NH}_3\text{BeF}_2$ decomposition	Ventilated enclosure and local exhaust			
Change feed drum		19	1.9	3.5
Change discharge drum		24	2.2	7.6
General air		3.6	0.7	1.2
BeF reduction	Ventilated enclosure and local exhaust			
Charge		16	0.6	1.8
Pour		87	1.5	8.8
Change molds		56	2.7	14
General air		2.9	0.6	1.8
Beryl frit heat treatment	Rotary kiln, local exhaust at ends			
General air		2.6	0.4	1.4

In Table 6 are the data from miscellaneous operations encountered in beryllium processing. It should be noted that these do not represent ideal conditions but are the actual results obtained.

Table 7 is a list of auxiliary operations related to plant services.

All the dust concentration data given so far represent specific types of equipment and operations. All the data of this type obtained from two operating plants are combined and presented graphically in Figures 33 to 36, which show composites of dust concentrations and personal exposure histories from the two plants, one being a refinery producing recast metal from beryl and the other a powder metal plant producing finished sintered shapes

from recast ingots. All the data resulted either from approximately annual surveys conducted by the HASL or from routine daily dust samples collected by the industrial hygiene staffs of the two plants. The HASL data were collected in each case over a relatively short period of very intensive sampling; therefore, although presumably typical, they do not represent average conditions throughout the year. The purpose of these surveys was to check the data obtained by the plant staff members. It is not unlikely that marked deviations occurred within the year.

Figures 33 and 34 show the breakdown by concentration range of all dust samples collected by HASL during each survey over an 8-year period.



	Be concentration, $\mu\text{g}/\text{m}^3$		
	Max	Min	Median
Housekeeping			
Wash floor (hose)	30	2.7	
Sweep floor			2.9
Vacuum floor			6.1
Laundry			
Load dry clothes			40
Remove wet clothes			1.1
General air	1.3	0.3	0.7
Lunch room	2.5	0.2	0.8
Locker room	3.9	0.2	0.8
Maintenance shop	0.7	0.2	0.5

The number of samples in each survey is given, and cumulative percent greater than stated concentration is plotted against concentration of beryllium in air for each survey. In Figures 35 and 36 the same air concentration data have been weighted with time for each individual operation to yield daily average exposures for employees, and against this is again plotted cumulative percent greater than stated concentration. The procedure used for converting the data is shown in Figure 32.

This type of data leads to speculation about the meaning of the patterns it exhibits; however, in doing so, many factors must be kept in mind. For example, in Figures 33 and 34 a trend is apparent towards a reduction in concentration from survey 1 to survey 4 at each plant. This is undoubtedly real to some extent, and can be explained on the basis of improving operational methods as per-

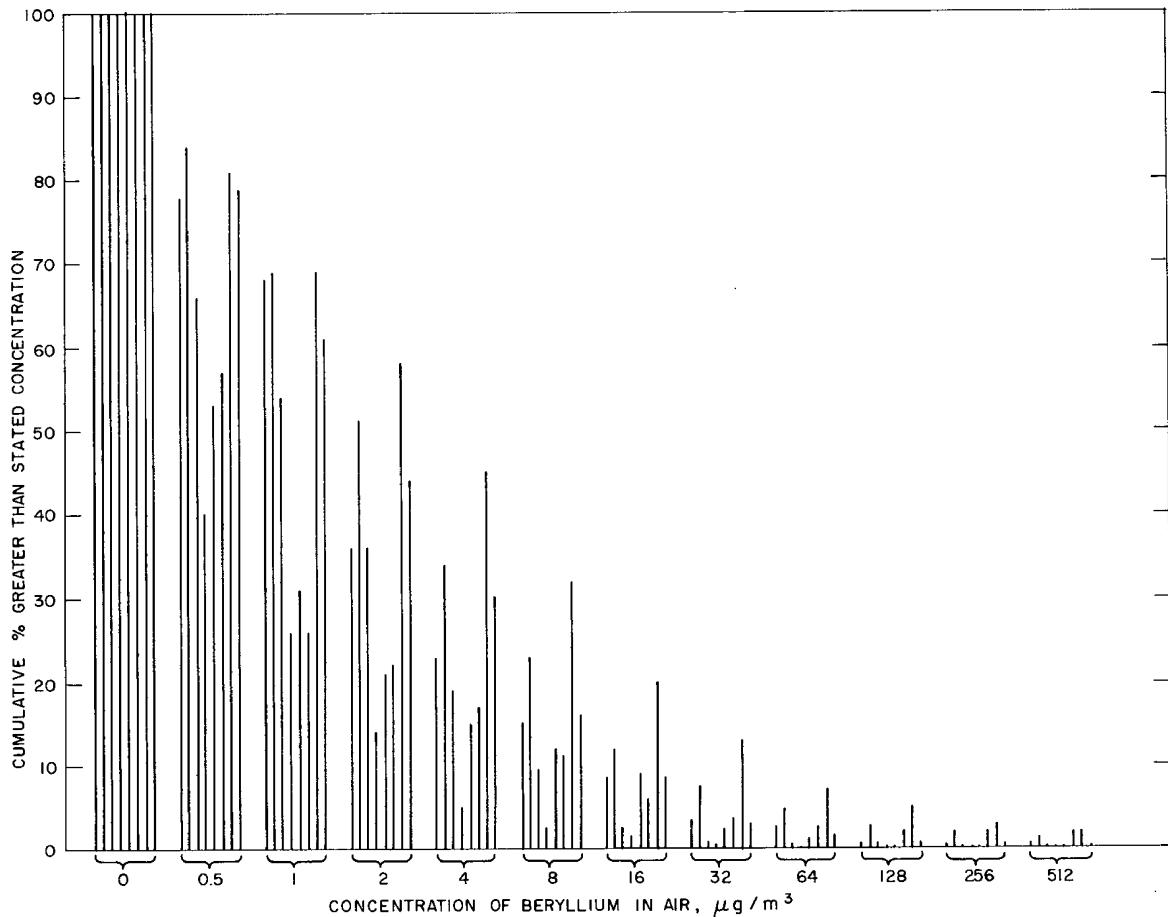


Figure 33. All samples at refinery 1950 to 1957, by survey. In each group of vertical lines the first represents the survey of Feb. 1950 (283 samples), the second that of Sept. 1950 (221), the third Jan. 1953 (487), the fourth Aug. 1953 (282), the fifth April 1954 (182), the sixth March 1955 (150), the seventh June 1956 (493), and the eighth Jan. 1957 (529).

sonnel gain experience and equipment is perfected so that manual handling and maintenance decrease; however, it must be remembered that certain seasonal variations also occur, and these cannot be neglected.

In each case survey 4 was performed during midsummer and the first three during other seasons. Airborne concentrations within an operating plant quite commonly show a marked decrease in the warm season when doors and windows are more likely to be open, which provides a great deal of natural ventilation plus a significant improvement in the operation of mechanical exhaust.

Another point is brought out by comparing the results of survey 7 at each plant. Although both were conducted during the summer, at the refinery (Figure 33) a significant increase is seen, but at the powder metal plant (Figure 34) concentrations remain reasonably low. Examination

of the operating record suggests an explanation. At the refinery survey 7 was made immediately after resumption of full production after a 2-year period of substantially reduced throughput. This sudden increase in production rate created many problems, such as a newly trained production force, inadequately maintained dust control equipment, etc., which might be expected to produce more airborne materials.

The above discussion is presented to show the kinds of things that must be considered in interpreting the data and will qualify any conclusions drawn from them.

The primary value of Figures 33 to 38 is that they indicate the magnitude and spread of the data accumulated in the course of operating major industrial beryllium facilities. Figures 33 to 36 show both the number of samples and the average exposure of all plant employees as evaluated dur-

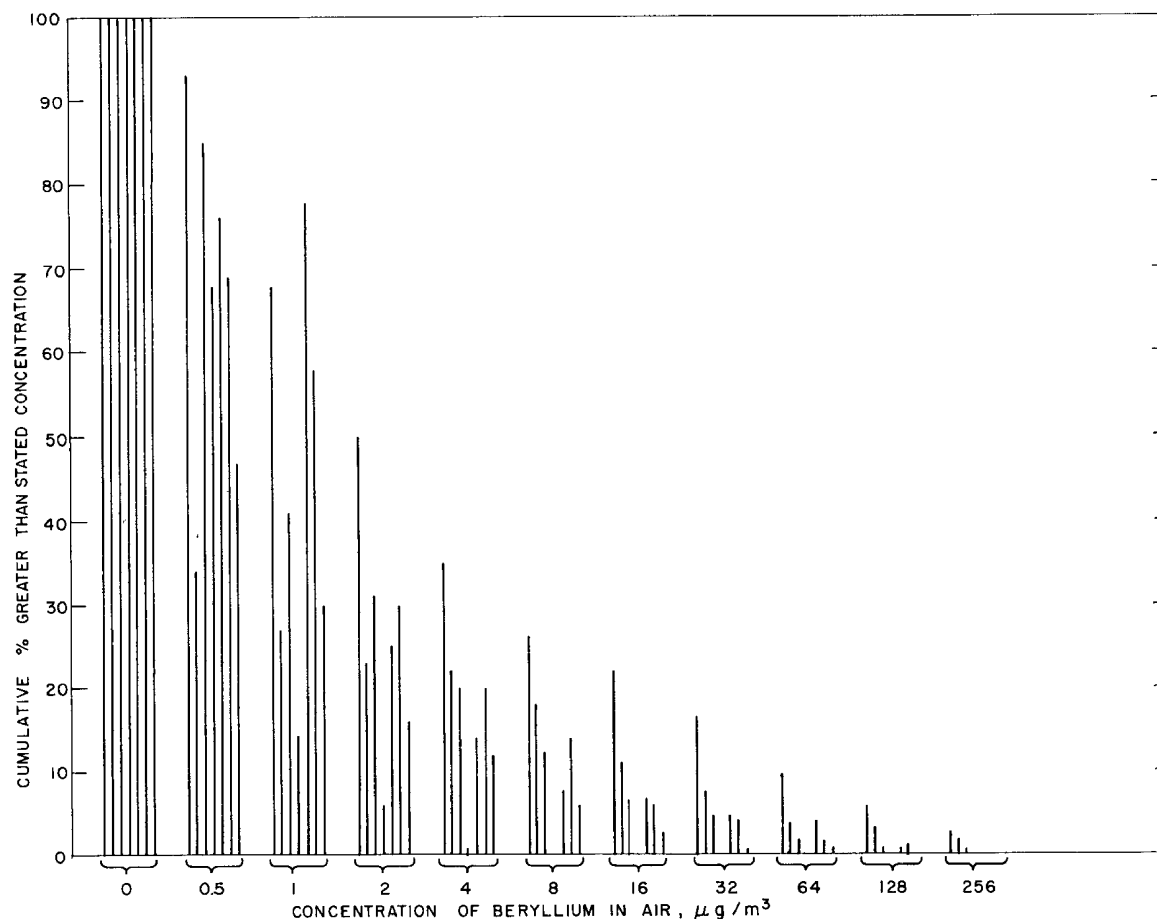


Figure 34. All samples at powder metal plant 1950 to 1957, by survey. In each group of vertical lines the first represents the surveys of 1950 (132 samples), the second that of May 1952 (174), the third Dec. 1952 (299), the fourth July 1953 (227), the fifth April 1955 (219), the sixth March 1956 (120), and the seventh June 1957 (256).

ing the period 1950 through 1957 at two major plants. Attention is drawn to the following points:

1) The number of samples showing concentrations  $>25 \mu\text{g}/\text{m}^3$  includes an appreciable proportion (averaging about 5%) of the total samples taken in each survey. In one refinery survey 13% of all samples showed  $>25 \mu\text{g}/\text{m}^3$ , and in one fabrication plant survey, 17%.

2) With  $100 \mu\text{g}/\text{m}^3$  as a criterion, a considerable number of samples (about 2%) still showed concentrations above this value, with a maximum of about 5% in the refinery and 6% in the fabrication plant. Even if the criterion is raised to  $250 \mu\text{g}/\text{m}^3$ , a significant number of samples from both plants show concentrations exceeding it. It should be noted that in each survey between 100 and 500 samples were taken.

Two  $\mu\text{g}/\text{m}^3$  being the maximum permissible concentration, Figures 35 and 36 indicate that

$\approx 10$  to 15% of the personnel at both plants had average daily exposures greater than this in most surveys.

4) Significant numbers of persons in most surveys, with relatively few exceptions (periods of low industrial activity), had exposures  $>5 \mu\text{g}/\text{m}^3$ ; and average concentrations of  $10 \mu\text{g}/\text{m}^3$  existed in each plant for relatively large numbers of operations. The numbers of employees involved in these surveys were between 12 and 234.

To make the above data meaningful, occupational exposures must be related to occupational illness. It is of little value to state that no cases of chronic beryllium poisoning have arisen from operations at either of these plants, since the time interval is still too short for this to be very significant; but the fact remains that no such cases have as yet been diagnosed. It should not be overlooked that, when the maximum permissible concentra-

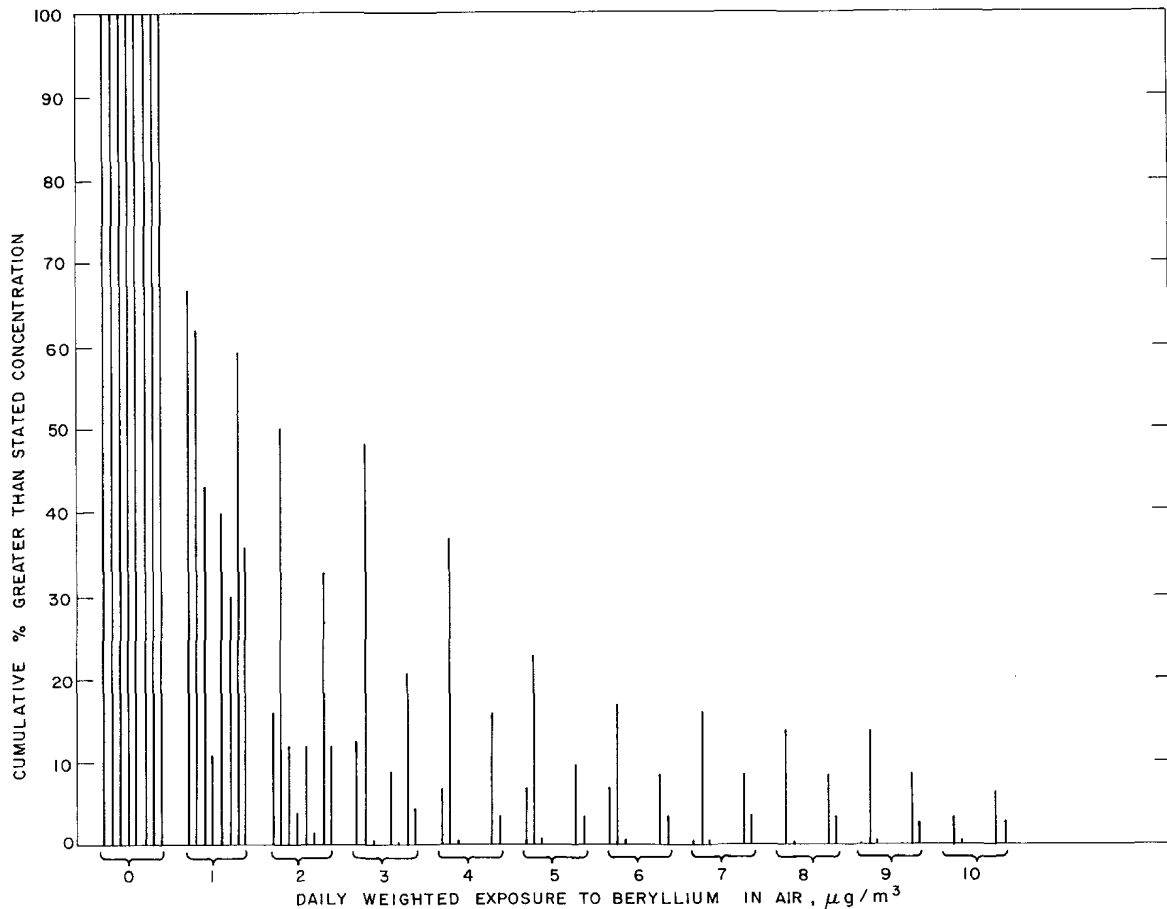


Figure 35. Weighted exposures at refinery 1950 to 1957, by survey. In each group of vertical lines the first represents the survey of Feb. 1950 (169 employees), the second that of Sept. 1950 (173), the third Jan. 1953 (208), the fourth Aug. 1953 (150), the fifth April 1954 (68), the sixth March 1955 (61), the seventh June 1956 (165), and the eighth Jan. 1957 (198).

tions were established, it was not anticipated that an in-plant maximum permissible concentration of  $2 \mu\text{g}/\text{m}^3$  could guarantee complete absence of chronic illness. It was believed that in a small portion of the population cases might develop at this level, and partly for this reason the permissible concentration outside the plant was set much lower. But because of the relatively small numbers of people involved and the relatively low incidence of chronic illness, it was believed that the above in-plant limit would provide an acceptable risk.

In contrast to the chronic disease, the acute illness may develop within 72 hr, and the over-exposure is immediately verified. For this reason, more detailed air sample data are given for the period when occupational illness occurred, namely the 18-month period from January 1950 to July 1951. These data are from the refinery only, be-

cause no cases were diagnosed at the fabrication plant during the entire period of observation. Figure 37 is similar to Figures 33 and 34, showing cumulative percent greater than stated concentration versus beryllium concentration in air, and Figure 38 is similar to Figures 35 and 36, showing cumulative percent greater than stated concentration versus daily average exposure; these figures differ from the earlier ones in that they cover only an 18-month period and include quarterly rather than annual surveys. Figure 39, which is to be studied in conjunction with Figures 37 and 38, shows the total number of cases of occupational respiratory illness resulting in time lost from work diagnosed from 1950 to the present; note that all occurred within the 18-month period specified above. The cases are grouped in the quarters during which they were considered to have been contracted. The total number of cases was 26, and

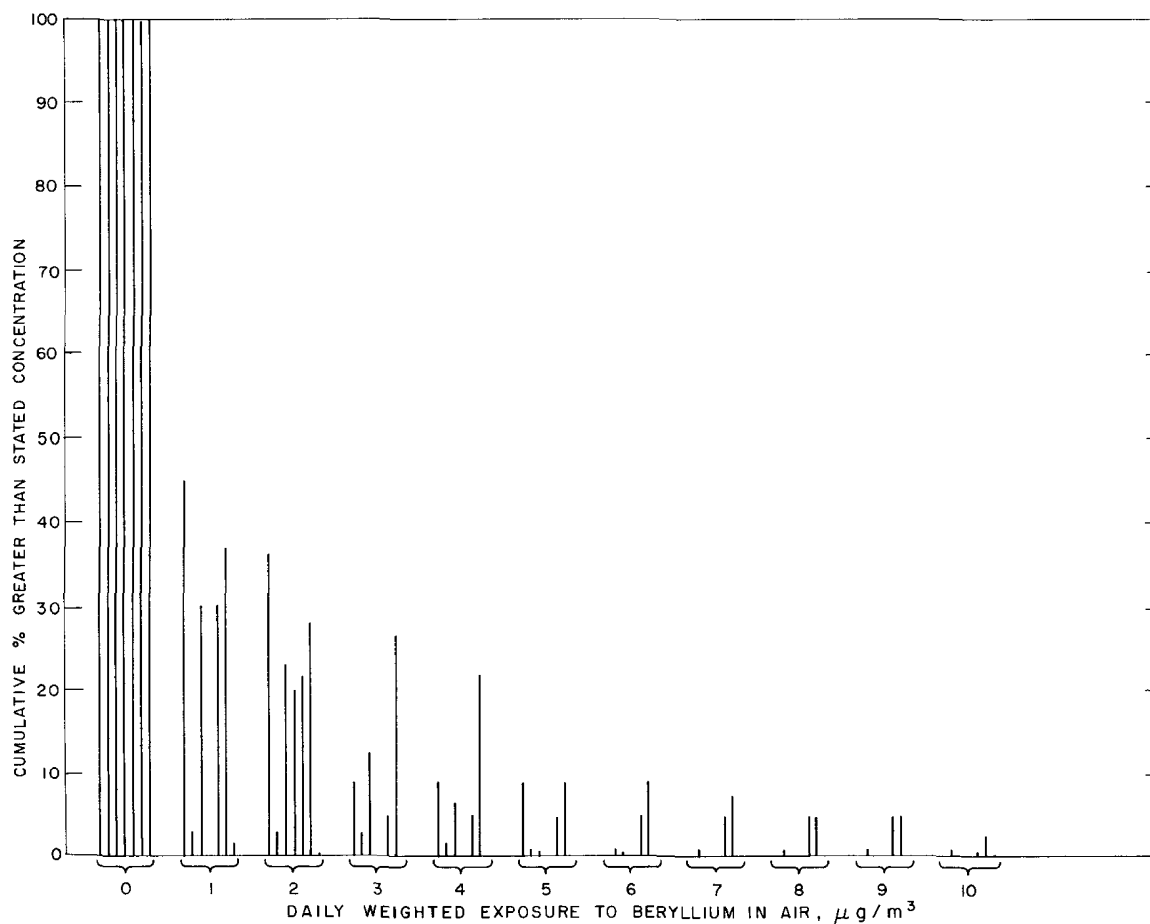


Figure 36. Weighted exposures at powder metal plant 1950 to 1957, by survey. In each group of vertical lines the first represents the surveys of 1950 (12 employees), the second that of May 1952 (105), the third Dec. 1952 (121), the fourth July 1953 (126), the fifth April 1955 (125), the sixth March 1956 (123), and the seventh June 1957 (234).

they ranged in severity from a simple case of tracheitis to one case of chemical pneumonitis, this last being the only one serious enough to require hospitalization.

The following conclusions might be drawn from a consideration of the data in Figures 37 to 39:

1) During this period the number of samples showing  $>25 \mu\text{g}/\text{m}^3$  was, if anything, lower than the 7-year average, and the same is true for any higher concentration level chosen.

2) The number of samples showing high levels increased greatly during the first year and declined thereafter. Excluding the first two surveys, taken when a relatively small proportion of the plant was in operation, these results can be considered seasonal, although they probably do reflect some improvement in plant operation. The curve in Figure 39 has a shape which is similar but

displaced by one quarter. This displacement is very difficult to explain and seems to indicate that there is little if any connection between the cases of illness and the air concentration data collected. The best evaluation of these two sets of information seems to be as follows: a) The air sample data do not in fact reflect the conditions which created the illness. b) The illnesses occurred in almost direct relation to the initial increase in plant activity as new processes were brought on stream. c) The curve of illnesses directly reflects the period of difficulties requiring machine teardown and bypassing of mechanical handling frequently inherent in novel operations. d) Some of the above factors are also reflected in the air sampling data, although the build-up and training of personnel proceeded more rapidly than the sample data appeared to indicate. e) There is probably no way to sample adequately the actual exposure of new

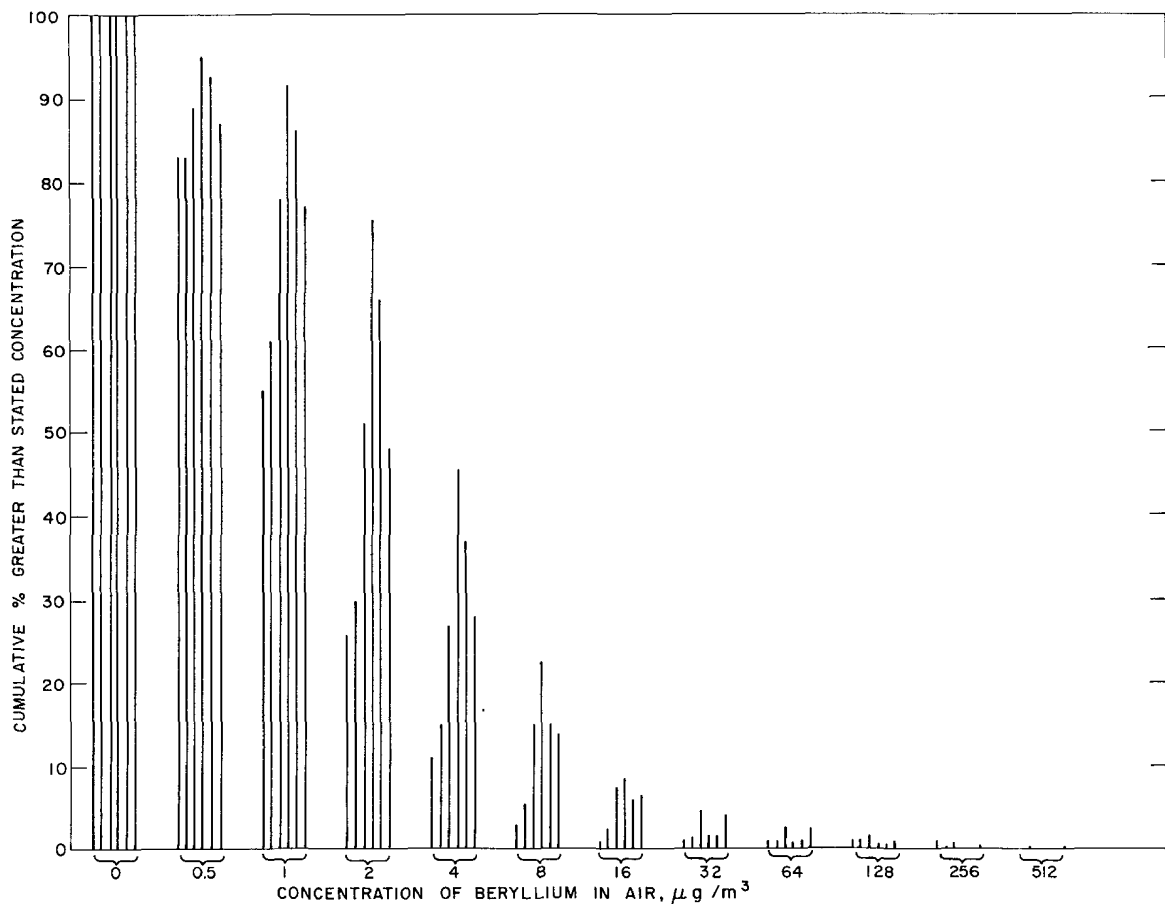


Figure 37. Quarter-yearly dust samples in refinery 1950 through June 1951, by survey. In each group of vertical lines the first represents Jan.-Mar., the second April-June, the third July-Sept., and the fourth Oct.-Dec., 1950; the fifth Jan.-Mar., and the sixth April-June, 1951.



personnel involved in breaking in new, untried equipment.

It is interesting to compare the data in Figure 37 for the period during which the large number of illnesses occurred, where 1.5% of all dust samples show  $>100 \mu\text{g}/\text{m}^3$ , with data in Figure 33 (survey 7), where 5% of all samples show  $>100 \mu\text{g}/\text{m}^3$ . Ten cases of illness occurred in the immediately preceding quarter in 1950, and no cases occurred in 1956.

It must be emphasized that all interpretation of these data must be considered speculative, and the authors do not presume to assign real significance to any of the above conjectures. However, the data in this report, which represent actual measurements, do appear to support the possibility that beryllium illness is caused by short-term massive doses which cannot be adequately meas-

ured by usual dust sampling procedures. The authors believe the data to indicate that, by striving to keep exposures within the specified limits, it is possible to maintain and operate any type of beryllium processing facility with the absence of acute illness, and that time will show whether or not this is also true of the chronic disease. Furthermore, absolute adherence to the target values does not appear to be essential.

#### Offsite Concentrations

The offsite beryllium concentrations have been continually measured at a refinery over a period of several years. Some of these data were presented in an earlier section of this report. On Figure 40 are plotted sample data collected over a two-year period. The data are presented as collected, i.e., not corrected for wind frequency. Two stations

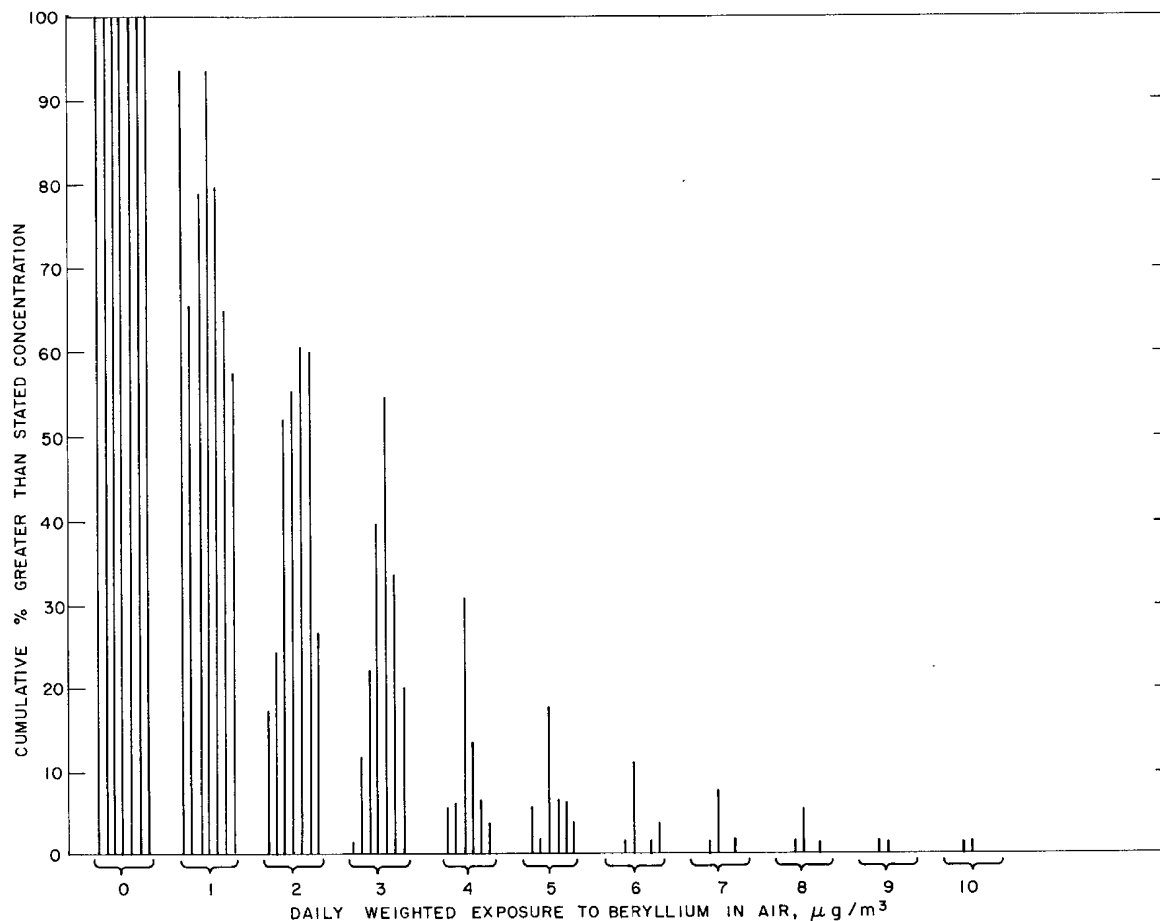


Figure 38. Weighted exposure at refinery 1950 through June 1951, by survey. In each group of vertical lines the first represents Feb.-May, the second June-July, the third Aug.-Sept., the fourth Oct.-Nov., 1950; the fifth Dec. 1950 to Jan. 1951; the sixth Feb.-Mar., and the seventh April-May 1951.

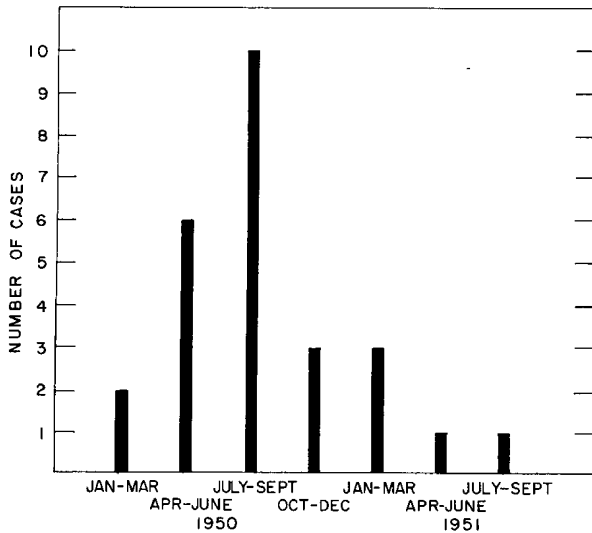


Figure 39. Number of cases of occupational respiratory illness resulting in time lost from work.

were operated for about half this period, three during the other half. The data are typical of values obtained throughout the duration of plant operation.

#### New Plant Operation

The start-up of a new production facility is particularly difficult with respect to the maintenance of health standards. There is necessarily a prolonged period of break-in during which process equipment is tested and adjusted and modifications are effected. Planned operating procedures are frequently suspended or abandoned, and confusion is increased by the presence of construction and maintenance crews working side by side with production personnel.

During this trying period hazardous conditions are very likely to occur, even if only for relatively short intervals, and the continuous attention of an industrial hygienist is required to remedy serious exposures as they occur.

During the start-up of a plant operated under AEC contract, in anticipation of these difficulties a plan was adopted to keep hazardous conditions to a minimum, the basic feature being step-wise inauguration of the process with each step tested in terms of both operation and air hygiene before going on to the next so that trouble spots could be confined to small areas and numbers of people. Although this plan provided an opportunity to rectify many trouble spots, the respiratory cases

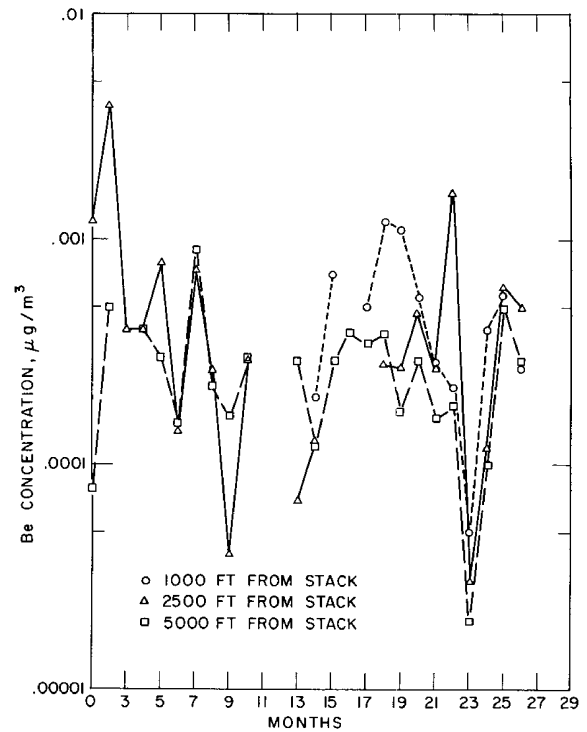


Figure 40. Monthly average offsite beryllium concentration at three sampling stations, two-year record, uncorrected for frequency of wind direction.

previously discussed did occur. Dermatitis also occurred, but with complete recovery. Since that time, a seven-year period, there have been no respiratory cases. Cases of dermatitis, however, have continued at a fairly uniform, low rate, primarily among maintenance personnel as a result of direct contact with beryllium materials. The cases invariably clear up after cessation of exposure.

#### Urinary Beryllium

Urinary beryllium samples were collected routinely at one production plant over a period of several years, and in a substantial number of cases daily weighted exposure values were obtained at the same time. Similar data covering a much shorter period were taken at another production facility. There were about 60 employees in the two groups. The urinalysis values with the corresponding daily weighted exposures are plotted in Figure 41.

The following will clarify the origin of the data and the manner of presentation:

- 1) All urine samples were 24-hr specimens.

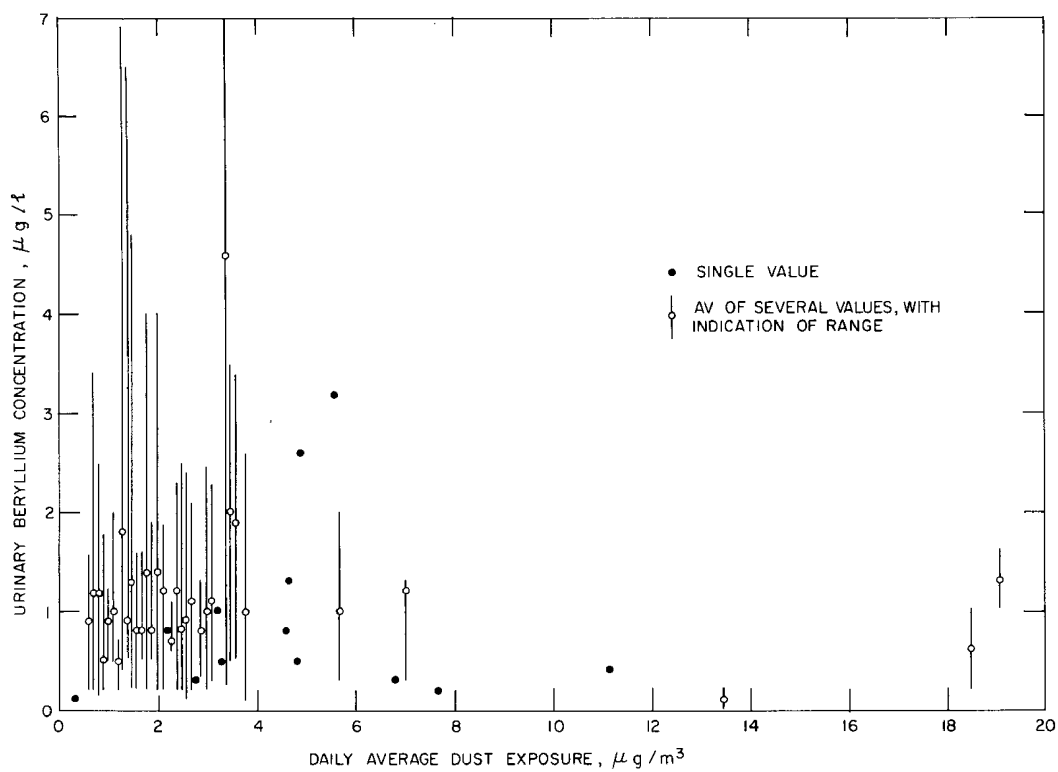


Figure 41. Beryllium concentration in 24-hr urine sample vs daily average dust exposure for 60 workers.

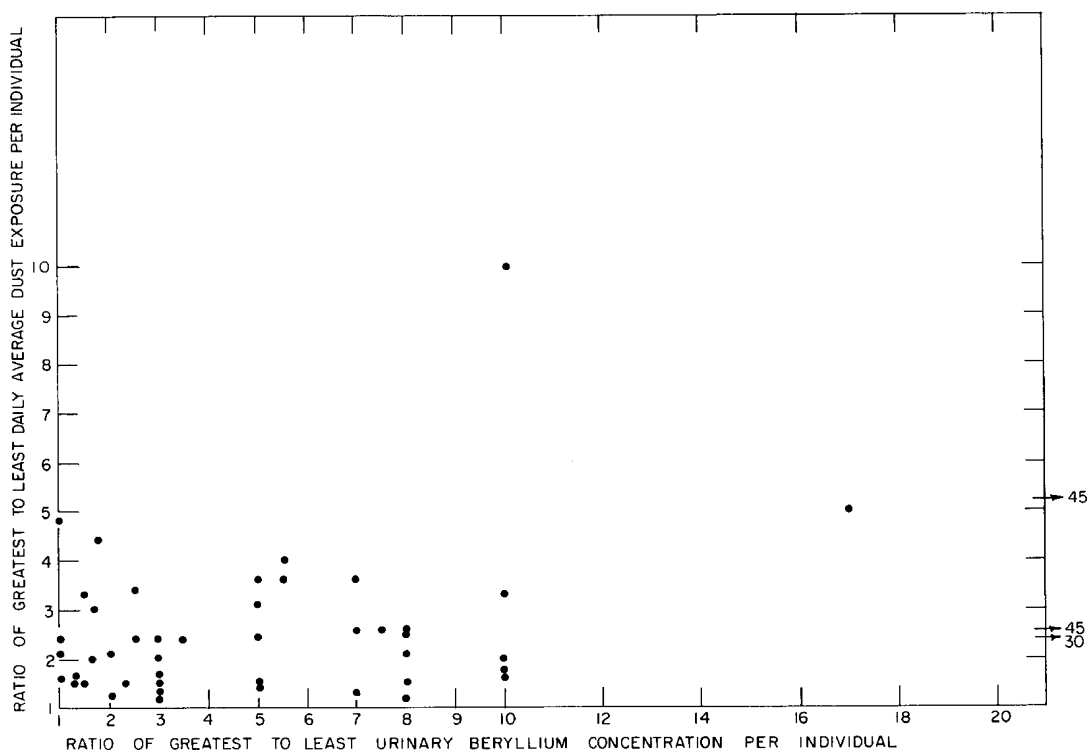


Figure 42. Comparison of range of dust exposures with range of urinary beryllium concentrations for individual employees.

2) The dust exposures are applicable to the time when the urine specimens were collected. The reported exposures are not adjusted for the potential protection afforded by dust respirators. Thus, the reported exposures may tend toward overestimation, and this effect would be more pronounced at the greater exposure values.

3) Many individuals were sampled more than once, but at long intervals. The urinalyses so obtained are treated as separate values if the individual's dust exposures differed for the successive times of sample collection.

4) Most of the plotted values are averages of two or more urinalyses which correspond to a given dust concentration value. These are not necessarily samples from one individual.

With regard to item 3, it is of interest that the urinary beryllium values of the same employee at different times showed a wide spread. The ratio of the highest to the lowest value in any individual ranged from 1 to 45. The range for the corresponding dust exposure ratios was 1.2 to 10. This information is presented in detail in Figure 42.

On the basis of the data presented in Figures 41 and 42, no correlation can be found between urinary beryllium and dust exposure. Analysis of the data by other methods, e.g., segregation according to type of air contaminant, duration of exposure, etc., also failed to indicate any correlation. For the present, urinary beryllium cannot be used as a quantitative indication of degree of exposure.

#### ACKNOWLEDGMENTS

The experience of ten years reported here is by no means that of the authors alone; rather, it is a composite of the contributions from many individuals including members of the staffs of several industrial concerns. We regret that because of memory deficiencies the list of credits may be incomplete.

We wish to thank Merrill Eisenbud for reviewing and commenting on the report. Most of the exposure criteria and safeguards described evolved from his original work in this field.

The reader may recognize a similarity between the discussion on the medical program and one of Dr. Irving Tabershaw's early contributions to the beryllium literature. Dr. Tabershaw not only allowed us to plagiarize his paper but assisted us, in cooperation with Dr. John Zielinski, to bring

it up to date with current concepts. We are indebted to both.

The many thousands of dust samples which were the source of the exposure data presented in this report were collected and evaluated by present members and alumni of this laboratory including Emil Christofano, Harold Glauberman, Richard Heatherton, Paul Klevin, Peter Loysen, Arthur Piccot, Frank A. Thomas, and Martin Weinstein.

Beryllium sample analyses were performed by the HASL Analytical Branch under the direction of Dr. John Harley. Credit is especially due to John Alercio, George Welford and Salvatore Garafalo. Dr. Harley also wrote the description of analytical procedures which appears in Appendix II. Many of the engineering designs and procedures are products of cooperative effort with the engineering and production staffs of several beryllium facilities with which we have worked. Prominent among these are Avco Manufacturing Corporation, Beryllium Corporation of America, Brush Beryllium Company, Burns and Roe, Inc., Clifton Products, Inc., Leemath, Inc., Nuclear Metals, Inc., and Sylvannia-Corning Nuclear Corporation. There are many more.

We do not wish to represent that the listed individuals and organizations necessarily subscribe to all our statements and opinions.

We appreciate the diligent stenographic support provided by Miss Marguerite Lynn, Miss Mildred Sidorsky, Mrs. Judith Sugarman, and Mrs. Gloria Tasho, who patiently typed numerous drafts and revisions.

Finally, with grateful appreciation we thank Mrs. Margaret Dienes of Brookhaven National Laboratory who edited the manuscript for publication.

#### APPENDIX I: MANUFACTURING PROCESSES\*

##### Sulfate Extraction of Beryllium from Beryl

Beryl ore is fused in a carbon-lined three-phase electric furnace, then poured through a high velocity water jet into a water-quench tank. After the quenched beryl (frit) is screened to separate the large pieces, which are recycled to the melting

\*Parts of the following process descriptions were taken from *The Metal Beryllium*, Am. Soc. Metals, 1955.

furnace, it is heat treated in a gas-fired rotary kiln at moderate temperatures, ground to <200 mesh in a dry grinding circuit, weighed into batches, and mixed with concentrated sulfuric acid to form a smooth slurry which is pumped through a small jet into a gas-fired sulfating reactor preheated to 250° to 300°C. Exhaust gases from the sulfating reaction are passed first through a cyclone separator, where entrained ore fines are recovered, and then into a packed scrubbing tower for absorption of SO<sub>2</sub> and SO<sub>3</sub> in spent caustic from the later beryllium hydroxide operation.

Silica is water leached from the sulfated ore in a counter-current Bird solid-bowl continuous centrifugal, and reslurried and centrifuged twice before it is discarded to waste. Ammonium hydroxide is blended continuously and automatically with the pregnant liquor (containing BeSO<sub>4</sub>) from the leaching plant, and the mixture is fed continuously into a crystallizer held at 20°C where ammonium alum is crystallized out. After the alum crystals are separated from the ammonium alum slurry in a Bird solid-bowl centrifugal, the filtrate is fed continuously into a water-cooled beryllating reactor together with a chelating agent (ethylenediaminetetraacetic acid) and dilute sodium hydroxide solution. Sodium beryllate solution is transferred continuously from the beryllator into a hydrolyzer held at boiling to precipitate granular α-beryllium hydroxide, which is subsequently separated and water washed in a Bird solid-bowl centrifugal. Filtrate from the beryllium hydroxide centrifugal is polished by filtration through a Sparkler filter, and the cake so collected is recycled to the alum crystallization step.

At this point, a bifurcation occurs in the process. Part of the hydroxide may be converted back to sulfate for reduction to oxide, and the remainder fluorinated for subsequent conversion to metal.

Beryllium hydroxide for conversion to oxide is redissolved in sulfuric acid; the resulting soluble beryllium sulfate is crystallized out and then separated in a continuous Bird centrifugal. After the salt is dissolved in (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> solution, the resulting solution is filtered to remove impurities, evaporated to a predetermined gravity, and centrifuged. The salt is then fired in batch furnaces to drive off SO<sub>3</sub>, leaving BeO, which is subsequently drummed.

Beryllium hydroxide for fluorination is dissolved in ammonium bifluoride solution in a repulper,

and the resulting ammonium beryllium fluoride solution is transferred to Haveg tanks and heated to boiling. After calcium carbonate is added to remove aluminum, heating is discontinued and lead dioxide is added for removal of manganese and chromium. The resultant slurry is filtered through Hercules vertical-leaf pressure filters; the filtrate is treated with ammonium polysulfide to precipitate lead, nickel, and copper sulfides, filtered and polished in Sparkler filters, and transferred into a continuous salting vacuum evaporator for simultaneous evaporation and crystallization. During these operations the slurry is continuously pumped from the evaporator body to a continuous solid-bowl Bird centrifugal, where the ammonium beryllium fluoride salt is removed from the slurry and the filtrate is returned to the evaporator for further concentration.

Ammonium beryllium fluoride salt is fed continuously into the top of a high-frequency electrically heated furnace; liquid beryllium fluoride goes to the bottom of the crucible from which it is continuously drained through an overflow weir onto a casting wheel located below the furnace. Ammonium fluoride gas evolved during the decomposition reaction is collected in a packed scrubbing tower followed by a Cottrell electrostatic precipitator and is treated in batches in Haveg tanks with hydrofluoric acid to provide a solution of ammonium bifluoride which is recycled to the dissolving operation.

Beryllium fluoride pellets produced in the continuous fluoride furnace together with small lumps of magnesium are loaded into a graphite crucible in a high-frequency electric furnace provided with a close-fitting ventilation system, and reduction is carried out as a batch operation with a cycle time of ≈3½ hr. After the molten charge is poured into a graphite receiving crucible and allowed to cool, the solidified block of metal and slag is crushed and dumped (along with steel balls) into a ball mill for wet milling to separate the beryllium metal pebbles from the magnesium fluoride slag. Solution is pumped continuously through the mill and slurried with added hydrofluoric acid to remove the magnesium fluoride, which is filtered off, washed, and discarded. The combined filtrate and washings are recycled to the purification step.

After the mill charge is dried and the steel balls magnetically removed, the beryllium pebbles are gravity separated in a mixture of ethylene di-



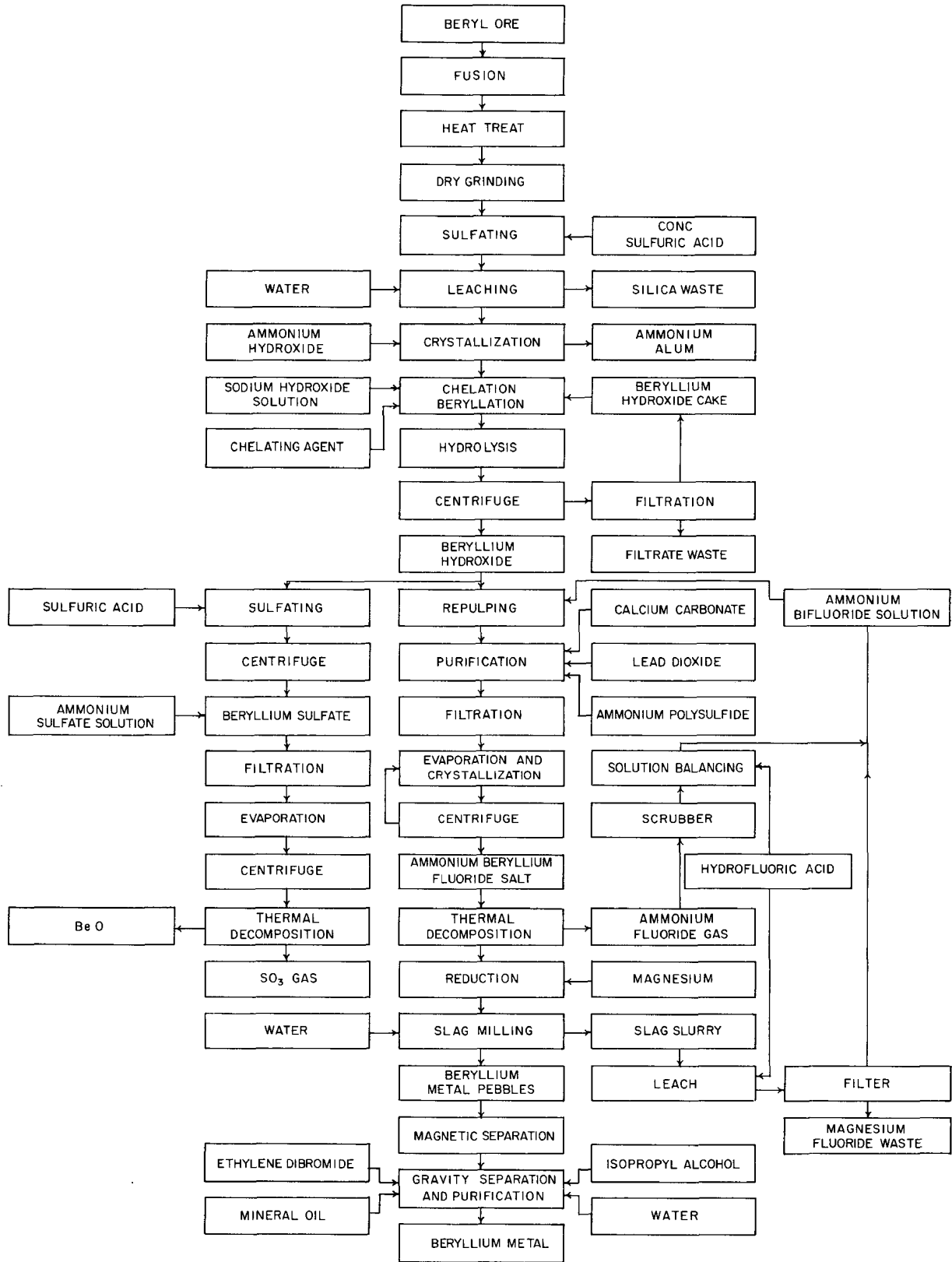


Figure 43. Sulfate extraction of beryllium from beryl.

bromide and mineral oil, washed with isopropyl alcohol and water, and dried.

The process is outlined in Figure 43.

### Purification of Beryllium Oxide

Raw oxide is pneumatically removed from drums to hoppers and discharged automatically through motor-driven rotary valves into a furnace where it is fused to produce clinker. Clinker is removed from the furnace, allowed to cool, broken into chunks, and fed to a jaw crusher which discharges to a screener for separation of fines from oversize material. The latter is collected in a drum for recrushing; the fines are fed to a wet ball mill incorporated in a wet classifier system and run off as slurry. The slurry is leached at an elevated temperature with a mixture of hydrochloric and nitric acids together with injected chlorine gas, and then allowed to settle. The acid is decanted, and the oxide residual is washed with acid and water in a centrifuge and dried. The oxide is oven dried to drive off the remaining moisture, heated in a muffle furnace, cooled, and crushed in a roll crusher. The process is outlined in Figure 44.

### Production of Beryllium by the Electrolysis of Beryllium Chloride

Measured quantities of beryllium oxide, carbon (furnace black), and pulverized pitch are added to a drum, intimately mixed together with added quantities of water during a drum tumbling operation, and then passed through a briquetting machine; the last operation is repeated several times to reduce the amount of included fines, which are screened out and refeed with new material.

The briquettes are then fed periodically into the chlorinating chamber of an electric arc furnace to which chlorine is added continuously; the reaction is maintained at an elevated temperature. The volatilized reaction product, beryllium chloride, is led from the furnace into condensers where it solidifies and is scraped periodically into steel drums.

In the event that extremely pure chloride is required for subsequent electrolysis, the beryllium chloride is transferred to a retort or boiler and distilled at an elevated temperature in a hydrogen atmosphere into a primary condenser, the hydrogen being vented through a liquid trap.

Beryllium chloride is transferred to a preheated electrolytic cell together with a mixture of sodium

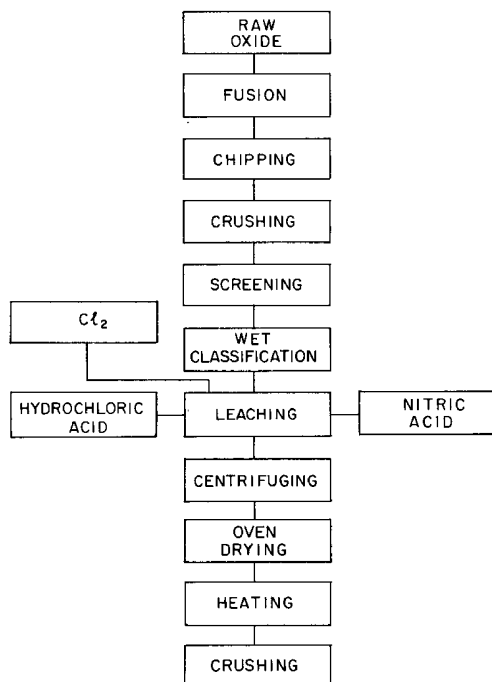


Figure 44. Flow sheet for purification of beryllium oxide.

and potassium chloride and electrolyzed, after which the entire content of the cell is transferred to another container and allowed to cool to a hard cake of solidified salt and reduced beryllium metal flakes. After the cake has been removed from the container, the flake bearing salts are chipped from it, broken into small chunks, and placed in cold water, where the salt is dissolved to free the beryllium flake. The remainder of the salt cake is ground in a jaw crusher and used for refeed to the cells.

The contents of the salt dissolver tank are passed through a cascade of screens to separate the larger sized beryllium flake, with a final separation in a filter press (the filter press cake is returned to the process for conversion to beryllium oxide). The flake is then washed with dilute nitric acid at elevated temperatures, floated in a mixture of bromoform and carbon tetrachloride, washed in methanol, decanted, dried, and packaged.

This process is outlined in Figure 45.

### Purification of Beryllium by Vacuum Casting

The vacuum furnace used for beryllium purification may be one of two types. The unit currently used is a tilting type induction unit containing both a graphite mold and a BeO melting cru-

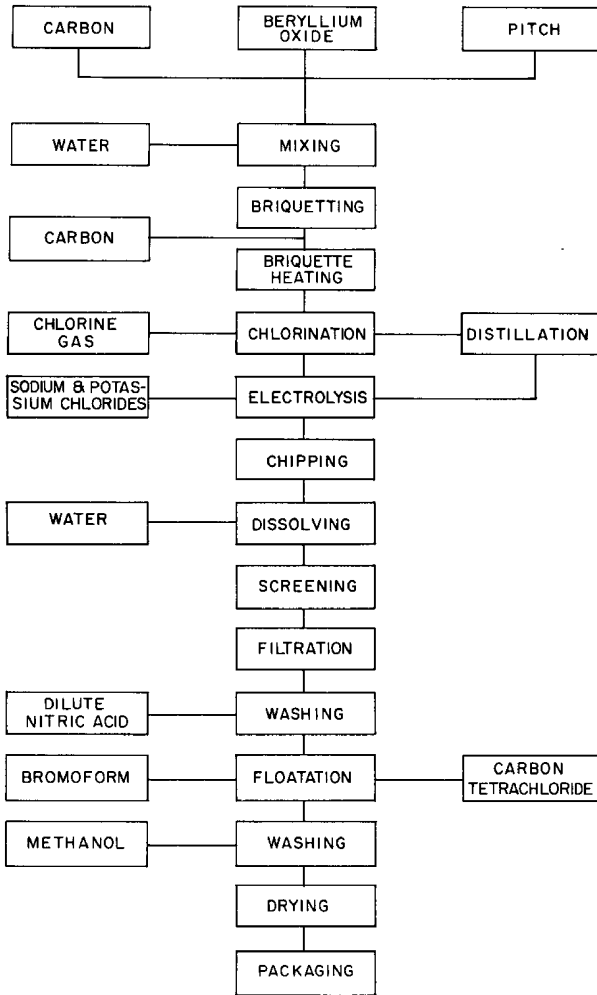


Figure 45. Flow sheet for production of beryllium by electrolysis of beryllium chloride.

cible and evacuated through one of the trunnions by two Kinney pumps and one oil vapor ejector. A dust filter is provided in the vacuum line between the furnace and the pumps. In the operating cycle, a mixture of fine scrap and beryllium metal pebbles is charged into the crucible, the mold cover is put in place, the furnace is sealed and pumped down to vacuum, and power is applied. When melting has proceeded nearly to completion, helium is admitted to the furnace, more metal is added, and melting is resumed. When degassing has progressed to completion, the mold cover is removed by means of a reach rod, and the molten charge is quickly poured into the graphite mold.

The older type of casting furnace is a bottom pour unit. Large melts (up to 100 lb) can be made

in a bottom tap quartz tube induction-type vacuum furnace containing both a BeO melting crucible placed inside a graphite crucible lined with BeO powder and a graphite mold. The metal may be poured in a vacuum, but operating experience seems to favor the admission of argon to atmospheric pressure just prior to casting. Since a thin layer of powdery carbide always forms on the graphite mold, it must be wire brushed after each use and must be stored in an oven at 390°F when not in use. A new graphite mold must be heated to high temperature in vacuum before use in order to remove gases.

**Process for Manufacturing BeO Ceramic Ware**

Refractory grade oxide is mixed in a muller with either water glass or magnesium chloride. A crucible is then hand tamped into a graphite liner and fired by induction heating of the graphite liner in an argon atmosphere with finely divided carbon as insulation.

In an alternative process, refractory grade oxide is ground dry in a ball mill, water is added, and the slurry is ground for a short time. After iron is removed from the slurry by magnetic separation in a Frantz Ferro Filter, the slurry is acid washed with HCl, decanted, cast or applied as desired, and kiln dried.

Both processes are outlined in Figure 46.

**Fabrication of Beryllium by Powder Metallurgy**

Vacuum-cast ingots are reduced through a multiple turning operation to chips, which are

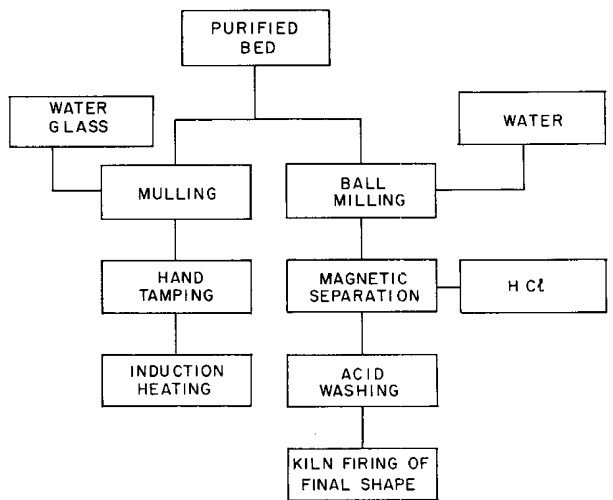


Figure 46. Flow sheet for manufacturing BeO ceramic ware.

collected by vacuum, transferred to a glass bottle, and fed into a water-cooled, beryllium-faced attrition mill operating in a dry nitrogen atmosphere. The beryllium powder is ground between a stationary and a contacting beryllium-faced plate and transferred to a vibrating screen at the bottom of the mill; the  $>200$  mesh powder is returned to the top of the mill for further attritioning and the  $<200$  mesh portion is collected in bottles for subsequent fabrication.

A forger or hammer mill may be employed to comminute pebbles, crop-ends of ingots, and other solid pieces of metal to small particles which are then ground in an attrition mill. Other equipment such as a Wiley mill, ball mill, fluid energy mill, or a mechanized mortar and pestle are sometimes used for particle reduction on an experimental basis. (See Figure 47.).

Three basic groups of processes are available for fabricating beryllium by powder metallurgy.

1) Methods involving consolidation of large billets which are usually brought to final dimension by machining.

a) *Vacuum hot pressing.* Powder is loaded into a steel die and the powder mass is sintered at around  $1050^{\circ}\text{C}$  under the mechanical pressure of a heavy plunger (75 to 150 psi) for about 4 to 20 hr.

b) *Direct pression of semiconsolidated powder without protection from the atmosphere.* Powder is preconsolidated by vibration and cold pressing, then subjected to the direct application of pressure and heat at temperatures of  $1000^{\circ}$  to  $1150^{\circ}\text{C}$  for 5 to 30 min.

2) Methods involving the direct production of shapes as near to final density and dimension as possible.

a) *Warm pressing or coining.* Warm pressing involves the compaction of powder to density between  $400^{\circ}$  and  $500^{\circ}\text{C}$  at pressures of 50,000 to 200,000 psi.

b) *High temperature pressing of powders without atmospheric protection (medium pressure).* With hard graphite, small parts may be produced rather rapidly in the temperature range of hot pressing.

c) *Hot coining subdensity compacts (medium to high pressure).* Semiconsolidated parts involving cold-pressed and sintered, warm-pressed, or hot-pressed material, usually below theoretical density, can be brought to density when heated by an external source at temperatures of  $600^{\circ}$  to  $1000^{\circ}\text{C}$ .

d) *Forging powder at elevated temperatures.* Beryllium powder can be pressed to shape in contoured

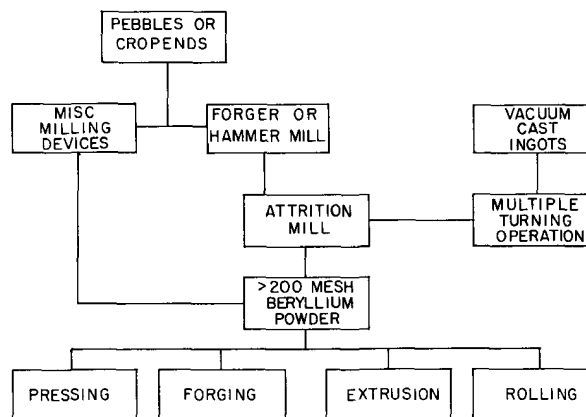


Figure 47. Flow sheet for fabrication of beryllium by powder metallurgy.

steel cans heated in an inert atmosphere to  $1000^{\circ}$  to  $1150^{\circ}\text{C}$ , placed in a die heated to  $400^{\circ}$  to  $800^{\circ}\text{C}$  and subjected to pressures of 2000 to 10,000 psi.

3) Methods involving the fabrication of semi-finished bodies processed into such shape and form that they can be brought to final dimension by mechanical deformation methods such as extrusion, forging, rolling, etc.

a) The principal processes utilized are warm pressing, direct atmospheric hot pressing, and cold pressing followed by sintering.

b) Hydrostatic or pneumostatic vacuum hot pressing.

### Machining of Beryllium

Various machining operations such as turning, milling, drilling, reaming, grinding, and sawing can be successfully performed on beryllium. Precautions are necessary both to secure uncontaminated beryllium chips and to avoid atmospheric dispersal of beryllium particles or dust in working areas. In general, all machining or metal removal operations should be done under high-speed air exhaust equipment adapted to the operation. For all machining operations performed without an exhaust system, a coolant such as any ordinary soluble oil or cutting fluid should be used, primarily to suppress metallic dust and secondarily to cool the work and wash away chips if necessary.

Carbide-tipped tools are generally used for turning, milling, and drilling operations. The actual cutting speeds are determined by the capacity of the exhaust system and the method of collecting chips, since at excessive speed chips from these operations break into small pieces

which may be thrown beyond the exhaust hood. It is essential that all grinders be properly hooded for efficient air exhaust to remove airborne dust not carried away by the coolant. Sludge which collects under the liquid in the pit or on machine surfaces should be removed frequently to prevent the health hazard created when it dries out and becomes airborne.

## APPENDIX II: AIR SAMPLE ANALYSIS\*

Beryllium concentration should be determined to an accuracy of at least a tenth of the target concentrations, which are  $2 \mu\text{g}/\text{m}^3$  for in-plant and  $0.01 \mu\text{g}/\text{m}^3$  for neighborhood exposure. Total sample volumes generally run from 0.3 to  $30 \text{ m}^3$  for in-plant samples and from 100 to  $5000 \text{ m}^3$  for out-of-plant; therefore beryllium contents as low as 0.1 to  $5 \mu\text{g}$  are of interest, which require very sensitive analytical techniques. An additional complication is that varying types and amounts of impurities may be collected with the beryllium, depending on the atmosphere sampled, which necessitate chemical separations to obtain the beryllium in relatively pure solution. In view of the extremely small quantities of beryllium looked for in air samples, the danger of cross contamination during the analytical procedures must be avoided. It is advisable to keep air sample analysis apart from other laboratory operations, preferably in a separate room with limited access.

Two analytical methods have been used at HASL, spectrographic and fluorimetric. The fluorimetric method is the later development and is now used exclusively because of its greater sensitivity and reliability and simpler procedure. The chemical procedure outlined below is done as a preliminary to either spectrographic or fluorimetric analysis.

Three types of filter papers are used for sample collection: Whatman #41, MSA All Dust Filter No. 2133, and MSA Type S unimpregnated filter. All are approximately 10 cm in diameter. The chemical procedures for analysis are similar for the three papers except that smaller quantities of reagents are used for the first two in the wet-washing and extraction steps. The Type S paper requires greater quantities because its high ash

content ( $>10\%$ ,  $125 \text{ mg}/\text{filter}$ ) adds to the impurities of the sample. Blank runs on these papers show up to  $0.3 \mu\text{g}$  beryllium per filter.

### Chemical Procedure

The procedure below applies to analysis of dust on the Type S filter, but the treatment of the other papers differs only in the respect previously mentioned.

All chemicals used are reagent grade. The following solutions are needed.

*Standard beryllium solution.* Spectroscopically pure beryllium sulfate (0.982 g) is dissolved in 100 ml 20% hydrochloric acid and diluted to 1 liter with water. The nominal beryllium content is  $50 \mu\text{g}/\text{ml}$ . Further dilutions are made with water just before use.

*Standard aluminum solution.* A solution containing approximately 2.5 mg aluminum per ml is prepared by dissolving aluminum nitrate nonahydrate in water. This solution is prepared in large amounts and standardized gravimetrically.

*Oxine solution.* Twelve g oxine (8-quinolinol, 8-hydroxyquinoline) are dissolved in glacial acetic acid and made up to 100 ml. The solution should be prepared fresh weekly and kept out of the light when not in use.

The paper is stirred to a pulp in a 400-ml beaker with 100 ml nitric acid, 5 ml sulfuric acid are added, and the beaker is covered and taken to sulfur trioxide fumes on a hot plate. It is cooled slightly, 25 ml nitric acid and 0.5 ml 60% perchloric acid are added, and the sample is refluxed.

The addition of nitric acid is repeated until all organic matter is destroyed. The solution is transferred to a 50-ml platinum dish, 2 ml hydrofluoric acid are added, and the solution is evaporated to dryness on a sand bath.

After addition of 4 ml hydrochloric acid, the sample is transferred to a 50-ml centrifuge tube and the volume is adjusted to about 20 ml. It is neutralized with ammonium hydroxide to the first precipitate of iron or aluminum hydroxide, and 2 ml glacial acetic acid and then hydrochloric acid are added dropwise until the precipitate dissolves. Then 5 ml 12% oxine in glacial acetic acid and some paper pulp are added. The pH is adjusted to 6 with ammonium hydroxide, with test paper indicator, and the sample is centrifuged at about 300 rpm for 5 min. The liquid is decanted through a loose-textured paper into a 125-ml separatory funnel, the precipitate is washed

\*Note that the latter part of the Bibliography is devoted to references on beryllium analysis.



with water, and the washings are added to the original filtrate.

The filtrate and washings are extracted with 10 ml chloroform to remove excess oxine until the organic layer is colorless. The aqueous phase is transferred to a clean 50-ml centrifuge tube, and the pH is adjusted to 7. A visible precipitate at this point indicates incomplete removal of iron and aluminum, and the oxine separation must be repeated. If the solution is clear, 1.0 ml aluminum solution (2.5 mg aluminum per ml) is added, the sample is centrifuged, and the supernatant liquid is discarded.

### Spectrographic Procedure

The following equipment is used:

Spectrograph:	Baird 3-m grating, 50- $\mu$ slit.
Source unit:	Baird with Sola constant voltage transformer.
Lower electrode:	National Carbon Company 0.25-in. (0.6-cm) nominal diameter graphite, regular grade, 6.3 $\times$ 50 mm, with 4.5-mm cup, 5 mm deep.
Upper electrode:	Same type, sharpened to a 45° point.
Excitation:	Direct current air, 10 amp, 2 min.
Densitometer:	Baird nonrecording.

The final precipitate from the chemical procedure is dissolved and made up to 1 ml with 1:7 H<sub>2</sub>SO<sub>4</sub>.

The cupped electrodes are waterproofed with a solution of Duco cement in acetone and filled with sodium chloride to within 1 mm of the top by tamping in a dish of the salt. The weight of sodium chloride has been found to be 45  $\pm$  5 mg in all cases measured. Three electrodes for each sample are treated with 0.05 ml of the above solution and dried in an oven at 110°C.

The lower electrode is made the anode in the arc. The electrode spacing of 4.5 mm and the length of anode extending from the water-cooled electrode holders are set manually by using an auxiliary lens and screen. The arc image is focused on the grating with a quartz lens of long focal length.

The spectrum is recorded on Eastman Type 33 plates, and standard development and fixing procedures are used. The densities of Be 2348.6, Be 2650.8, and Al 2367.1 are read, and the ratio of the suitable beryllium line to the aluminum line is used as the analytical function. No plate calibration procedure is used; the ratio Be 2348/Al 2367 gives a straight line from 0.005 to above 0.2  $\mu$ g beryllium on the electrode, as does the ratio

Be 2650/Al 2367 from 0.1 to 10  $\mu$ g beryllium. Standards are run periodically, and the analytical curve is modified if excessive shifts appear.

The sample burns smoothly during the excitation period, giving a negligible background on the plate. Although reburning the electrodes shows that some beryllium is left, complete burning does not increase sensitivity or accuracy because an increased continuous background is produced.

### Fluorimetric Procedure

The final precipitate from the chemical procedure is dissolved and made up to 5 ml with 1 *N* sodium hydroxide. Triplicate 1-ml aliquots are treated with 1 ml 0.0001% morin and diluted to 5 ml, and the fluorescence is measured.

The fluorimeter was designed and built by the Instrument Branch of the Health and Safety Laboratory. It has a sensitivity of 0.005  $\mu$ g and is linear over a range of 100.

A General Electric AH-4 100-watt lamp is the source of ultraviolet, and a multiplier phototube, amplifier, and microammeter are used in the measuring circuit. Four solution cells of 5-ml capacity are held in a slide, the ultraviolet entering at the side and the fluorescence being measured at the top. This allows blank and triplicate samples to be measured in rapid succession.

A 0.01% quinine sulfate solution is used to set the high end of the scale by varying the phototube voltage until the quinine solution reads 20,000 scale units. The total scale range is 100,000 units with four decade scales. The blank reading is about 40 units, and 0.01  $\mu$ g beryllium gives an average reading of about 20 units above the blank.

Morin of better than 99% purity is available from L. Light & Co. Ltd., Colnbrook, Bucks, England, at reasonable prices. A 1% solution of this morin in acetone is used as the basis for further dilutions with distilled water. This solution is stable for months if kept in the dark. This reagent, in use at HASL for the past three years, gives a reagent blank of 20 deflection units at 0.0001% concentration. A typical calibration curve is linear over a range of 200. Addition of 0.005  $\mu$ g beryllium gives 10 deflection units above the blank.

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