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THE CONTROL OF BERYLLIUM HAZARDS

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ABSTRACT

The toxicological properties of beryllium and compounds of beryllium are briefly reviewed, together with the historical development of the recommendations for maximum permissible beryllium air concentrations. The application of the enclosure technique presently in use at this Laboratory for the control of beryllium hazards is described. Emphasis is placed on the design objectives of partial and total enclosures and the related function of auxiliary components. Monitoring procedures used to evaluate the performance of enclosures are discussed.

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Introduction

With the exception of certain radioisotopes, the toxicity of beryllium probably exceeds that of any material previously used in industry. Consequently, it has been necessary to develop special health and safety control procedures for its safe handling. This Laboratory has devoted considerable effort to the application of enclosure techniques developed for radioisotope control to the control of beryllium.

This report has been prepared in answer to requests for information regarding our procedures. It is hoped that the information will be of assistance to those who are investigating beryllium safety measures preparatory to undertaking work involving beryllium and its compounds.

Beryllium Toxicology and Maximum Permissible Air Concentrations

Although beryllium and compounds of beryllium in dust form may cause dermatitis¹ or beryllium granuloma and skin ulcers² following skin cuts and abrasions contaminated with beryllium, the principal hazard of beryllium is due to the toxic properties of inhaled dusts.³

Two types of respiratory damage, acute pneumonitis¹ and chronic pulmonary granulomatosis,⁴ have been seen in the beryllium industry occurring among workers exposed to beryllium dusts, fumes, and mists.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

The acute beryllium pneumonitis is similar in many ways to a chemical pneumonitis such as might be caused by the inhalation of corrosive chemicals. In both cases the effect is inflammation of the upper respiratory tract and, in extreme cases, involvement of the entire pulmonary system.

Acute beryllium pneumonitis may follow single short-term exposure to relatively large quantities of beryllium with usually prompt symptoms of damage. While there are reports of fatalities resulting from acute exposures, recovery when made is usually complete with no apparent permanent ill effects. Infrequently, the acute form of the disease progresses into the chronic.

Chronic pulmonary granulomatosis is usually a delayed disease and is more subtle in its disclosure, some cases manifesting themselves several years after exposure. The chronic pulmonary form is usually characterized by the presence of a diffuse pulmonary reaction with scattered granulomatous lesions throughout the lung. The symptoms of chronic berylliosis do not differ greatly from other types of pneumoconiosis. The first symptoms may be a mild and vague indisposition, slight but persistent loss of weight, loss of appetite, labored breathing accompanying even modest exertion, and general lack of energy. As the disease progresses there usually is a gradual decrease in vital capacity. The disease is often fatal. At present considerable progress is being made with chemotherapy agents to arrest the pulmonary deterioration, but as yet no specific cure has been found.

As noted above, chronic berylliosis exhibits marked variation in the time required for manifestation. The usual time interval appears to be from 3 months to 6 years. Delay times up to 16 years have been noted.⁵ Likewise, people differ greatly in respect to sensitivity toward beryllium

dusts. Some have worked in atmospheres containing 30 milligrams of beryllium per cubic meter without appearance of acute cases, whereas in other plants 4 milligrams per cubic meter produced a high incidence of acute berylliosis with several fatalities.⁶

As a result of these fatalities attending the case histories of individuals exposed to beryllium dusts, the Atomic Energy Commission formed a Beryllium Medical Advisory Committee in 1948 to review the problem and to establish maximum permissible concentrations of beryllium in the air as guides for their contractors. These MPC values, which were published by the AEC on August 10, 1951, were as follows:

1. The in-plant atmospheric concentration of beryllium should not exceed 2 micrograms per cubic meter as an average concentration throughout an 8-hour day.
2. Even though the daily average might be within the limits of Recommendation 1, no personnel should be exposed to a concentration greater than 25 micrograms per cubic meter for any period of time, however short.
3. In the neighborhood of a plant handling beryllium compounds, the average monthly concentration should not exceed 0.01 micrograms per cubic meter.

Although these values have been annually reviewed there have been essentially no changes since the recommendations were originally published. They appear to be reasonable from a compliance standpoint and adequate protection-wise in that the number of reported cases of berylliosis has been markedly reduced in spite of a large increase in the amount of beryllium and beryllium compounds processed.

The U.S. Atomic Energy Commission⁷ has recently established the Hygienic Guide Series⁸ as the responsible reference for maximum permissible

concentrations of airborne beryllium. The wording of this reference is as follows:

Occupational 8 hour	: 0.002 milligrams beryllium per cubic meter of air.
Occupational acute (less than 30 minutes)	: 0.025 milligrams beryllium per cubic meter of air.
Non-occupational, 24 hour	: 0.00001 milligrams of beryllium per cubic meter of air.

The Enclosure Technique for the Containment of Beryllium Dusts

Aside from the obvious dust potential from handling beryllium metal or compounds in powdered form, the most likely source of atmospheric contamination arises when such material is machined. Any such operation generates to a varying degree particles which are small enough to be airborne and be moved by gentle air currents. These particles can remain airborne near the operation long enough to be inhaled by the operator or by others nearby. The only effective method for preventing the spread of such contamination is to contain and remove the dust at its source.^{9, 10}

In the enclosure technique the worker and the environment are protected by maintaining the zone of dust generation at a negative pressure with respect to the area occupied by the worker. This is accomplished by exhaust ventilation augmented by total or partial secondary enclosure. By total enclosure is meant one which completely encloses the zone of dust generation permitting no direct working opening to the outside. All necessary hand work is done through gloves mounted on the enclosure frame. Circumstances may require enclosing the entire machine or operation if the geometry, necessary machine movements, or the manual manipulations do not lend themselves to an enclosure fitting only the dust-generation zone.

By contrast, partial enclosures may surround the zone of dust generation or the entire operation but do give direct open access to the work by means of front-opening canopies, sliding doors, or plastic curtains. Partial enclosures are usually constructed on a frame with solid top, bottom, back, and sides, and normal work access is made through the front via movable sections. Depending on the operation, sliding doors may exist in the sides or the top of the enclosure for passing work in or out but are normally closed during operation. To illustrate by examples: a chemistry hood is a partial enclosure while a gloved box (dry box) is a total enclosure.

All enclosures are ventilated. Inlet air for total enclosures is filtered to reduce the dust load on the high-efficiency exhaust filters, and to prevent contamination of environmental air by out-breathing if the enclosure becomes pressurized because of accident or loss of suction. Partial enclosures require larger air flows than total enclosures. Essentially, controlled directional air flows, achieved by the maintenance of regional pressure differentials, are utilized to restrict dust to the enclosure. Consequently, in partial enclosures local exhaust ventilation is added whenever feasible within the enclosure to assure the proper pressure gradient. Ideally, the exhaust is close capture in design, meaning that the dust pickup throat is in close proximity to the work and that guidance of the dust into the pickup is controlled by high face velocity.

Close-capture pickups in conjunction with "knockout pots" or dust-particle accumulators preceding the main filters permit recovery of material if this is required. In addition, this technique minimizes general contamination of the enclosure and is an important principle of "concentrate and confine" philosophy. Close-capture pickups are widely used to collect corrosive fumes if acids or other chemicals are present within

the enclosure. In this case, the close-capture system exhausts through a scrubber to protect the filter and external duct work.

Local exhaust ventilation in the form of close capture is mandatory if dusts are generated without enclosure protection, is preferred with partial enclosures, and is optional with total enclosures with the exception of the special cases of recovery intent or corrosive fume production as noted above.

Partial enclosures should be designed to permit a minimum face velocity of 100 fpm at any opening. If possible, the design should include provisions for preventing multiple openings being made simultaneously.

The general purpose of the enclosure philosophy is to isolate the contamination from the worker rather than isolating the worker from the contamination, and, since this is achieved by negative ventilation gradients, considerable engineering care should be taken in the design of the building ventilation. As previously noted, the close-capture zone should be at a negative pressure relative to the secondary container, and the secondary enclosure should be maintained at a negative pressure with respect to the area occupied by the worker. Furthermore, the shop or laboratory in which beryllium work is being performed should be at a negative pressure in respect to adjacent shops or laboratories. This is achieved most easily by introducing building make-up air in hallways or bays and thus assuring that these areas are pressurized with respect to laboratories and shops. This procedure has markedly minimized the potential building-wide contamination if local containment fails as might be occasioned by a fire or an explosion.

Dust collection by high-efficiency¹¹ filtration is of prime importance in the enclosure approach. These filters, placed in close proximity to each dust-generating operation, protect the manifold from being grossly

contaminated and, of course, are of paramount importance in removing hazardous dust from effluent air exhausts. Where possible, in particularly hazardous operations, providing each segment of the operation with its own exhaust manifold so as not to contaminate the entire shop manifold if a filter rupture occurs.

The filters are changed when the buildup of dust causes a pressure drop high enough to prevent the flow of sufficient air to properly ventilate the dust-producing zone. When this occurs, the dust-loaded filters are removed, bagged, and disposed as contaminated waste.

Choice of enclosure type depends on the potential hazard of the operations to be performed, the movements of the operator, and the motion of the machine. Certainly visual or measurement inspection of freshly machined solid forms, if free of loose surface contamination, do not require total enclosure. This operation may be done in the open or at most requires only an open-front inspection box as shown in Fig. 1. Lathe work on solid elemental beryllium may usually be placed in a partial enclosure, similar to that shown in Fig. 2, if machining is performed with the aid of a coolant. If dry machining is employed the lathe should be totally enclosed. Such a lathe enclosure is shown in Figs. 3 and 4. Beryllium welding should be done in a total enclosure; a prefilter (several types are available) should be provided to remove smoke or fumes and thus prevent plugging of the high-efficiency filter. Milling operations, due to the degrees of machine motion, generally must be placed in a partial enclosure. Grinding operations are preferably totally enclosed. Processing of beryllium oxide in the powder form should always be totally enclosed (Fig. 5).

Figure 6 shows a pictorial schematic drawing illustrating a typical gloved box enclosure system. This enclosure is suitable for processing

powdered beryllium oxide. The bag out port (Item 13) is a useful means for removing surface contaminated material from the enclosure. The port is fitted with a retaining groove for a plastic bag held in place by an "O" ring. Material is placed within the bag, the plastic is thermally sealed between the material and the port, the plastic is cut along the thermal seal, and the bag is removed for transfer into another enclosure or disposed of as waste. The terminal plastic on the port is covered by a new plastic bag which is secured to the port using the same technique as is used for changing gloves. The terminal plastic is then placed within the enclosure and disposed of via a waste drum attached to the enclosure or by subsequent bagging out transfers. Although this appears involved, the manipulations become routine and the procedure is quite effective in eliminating environmental beryllium-oxide-powder contamination.

Volumes of air to be filtered and the requisite sizing of air movers and filters often influence the enclosure type. A nominal 20-cubic-foot total enclosure requires a flow of 10 to 20 cfm. This same volume as a partial enclosure with 2 square feet of fixed opening requires approximately 200 cfm to maintain the minimal recommended face velocity of 100 fpm at the opening. Again, assuming a face velocity of 100 fpm, a partial enclosure for a lathe with 5 square feet of opening likewise requires 500 cfm and, while high-efficiency filters are available with larger capacities, it is impractical to process more than 1250 cfm without multiple filter banks.

Considerably more care is required for partial enclosures where the opening area is adjustable than is required for total enclosures. Many cases have been noted in which doors, panels, etc., were left open when potentially hazardous operations were resumed after adjustments made by the operator in the course of the operation. The resulting deficiency in face velocity endangers the operator and his co-workers, because the

the reduced velocity allows the contamination to escape the enclosure.

Protective Clothing, Respiratory Protection, and Housekeeping

With well-designed, properly operating equipment, contamination is restricted to enclosures. The floors, machine surfaces, and the general working areas are normally uncontaminated and any loss of containment is localized and should be cleaned promptly. Respirators are worn only in special cases of work not conforming to enclosure or in cases of accidental failure of enclosures. Protective clothing is used but does not constitute a first line of defence against contamination.

In areas where beryllium is processed it is recommended that floors be surfaced with smooth material such as linoleum to facilitate cleaning and that a routine janitorial program be maintained. Floors should be heavily waxed and should be damp-mopped between wax applications.

Beryllium Monitoring

Air Monitoring

A continuing air monitoring program is required to evaluate the performance of enclosures and to assure that hazardous concentrations of beryllium are not released to the room atmosphere. However, with adequate enclosures the airborne beryllium concentration usually may be maintained at levels approximately two orders of magnitude below the $2 \mu\text{g}/\text{m}^3$ occupational 8-hour MPC value. As a consequence any incipient loss of containment is easily detected and signifies enclosure difficulties. As a working rule, a beryllium concentration of about $0.2 \mu\text{g}/\text{m}^3$ is considered as an "alert" and immediate attempts are made to remedy the situation.

At this Laboratory environmental samplers for measuring occupational routine concentrations are operated on a 24-hour, 7-day week basis, drawing air through 10.3-centimeter-diameter paper at a flow rate of 4 cfm. Papers are changed daily Monday through Friday. The filter paper is identified as Staplex TFA-41 and the air mover is a modified Gast Model 0440 air pump. This sampler unit is shown in Fig. 7. Spot, short-duration samples are taken at breathing-zone heights at potentially hazardous locations or during new unevaluated operations. These samples are taken with a Staplex Hi-Vol Sampler at flow rates of 10 to 20 cfm.

A program is currently under way to determine airborne beryllium on a continuous basis in order to improve the detection of momentary high concentrations of beryllium. Short-term samples, although superior in this respect to a sample collected continuously over an 8- or 24-hour period, still do not reflect the time-dependent factor as recommended by the occupational acute MPC. No sampling program has yet successfully shown the exact time during the sampling period that the beryllium was collected on the paper. Consequently, one cannot be sure in a 100-cubic-meter sample containing 30 micrograms of beryllium that the beryllium was not all in the first cubic meter collected. If so, the occupational acute value would have been exceeded while the occupational routine value as normally calculated from the data would have been $0.30 \mu\text{g}/\text{m}^3$.

In practice, while continuous indication of airborne beryllium concentration would be of assistance, lack of such information is not too serious because operations with contamination potentials are usually well recognized in advance. Consequently, workers know when to expect trouble and can take appropriate measures. Furthermore, a Hazards Control Representative, who is usually in attendance, can assist in evaluating the safety problems inherent in a new operation.

The fact remains, however, that no continuously indicating beryllium air monitor is employed and development effort is under way to satisfy this need. Two approaches, both spectrographic in principle, are being investigated. One is the Harwell continuous spectrographic monitor¹² which is reported to possess the required sensitivity and range to cover both the occupational 8-hour and occupational acute recommendations. The second method, although not continuously indicating, is a rapid spectrographic method also developed in England. It is designed to collect and give an analytical result within three minutes elapsed time. Considerable research time is being allotted to these techniques since either or both would greatly advance the state of beryllium air monitoring.

Samples also should be taken downstream from prevailing wind either outside buildings processing beryllium or at perimeter property stations to determine that concentrations exceeding the non-occupational 24-hour MPC are not exceeded.

Surface Contamination

Floors and working surfaces should be "swiped" daily to determine whether contamination has occurred. The value of $0.01 \mu\text{g}/\text{cm}^2$ is used as a working limit. A surface having a beryllium content of over $1 \mu\text{g}$ removed by a filter paper when rubbed over 100 cm^2 of area is considered contaminated and decontamination is undertaken.

Analysis of Samples for Beryllium Content

At present the determination of beryllium in all samples is based upon a fluorometric method using the fluorescence produced by beryllium with morin dye.¹³

Summary

The enclosures as described have been applied to a wide variety of operations ranging from chemical processing of finely divided beryllium oxide powder conducted in total enclosures to machining of elemental beryllium castings in partial enclosures fitted with plastic curtains. No operations thus far have been accompanied by average daily air concentrations exceeding $2 \mu\text{g}$ of beryllium per cubic meter and the average value is approximately two orders of magnitude below this figure.

The importance of matching the degree of enclosure with the degree of hazard cannot be overemphasized. However, it is mandatory that continual review and surveillance be maintained to assure that enclosures designed for low-hazard operations are limited to those operations. If programmatic changes that involve more-hazardous operations occur, then the enclosure must be modified accordingly.

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SN-16044

Fig. 1. Open-front inspection box.

SN-10441

Fig. 2. Lathe fitted with a partial enclosure.

SN-10446

Fig. 3. Totally enclosed lathe enclosure.

SN-15689

Fig. 4. Another type of totally enclosed lathe enclosure.

Fig. 5. Bank of total enclosures for processing beryllium oxide in powder form.

MUL-7517

Fig. 6. Pictorial schematic drawing of a typical gloved-box enclosure system.

Fig. 7. Environmental sampler for measuring occupational routine concentrations.