V. ENVIRONMENTAL DATA

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

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

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

According to Breslin,[102] Shilen reported in 1947 that beryllium dust concentrations were encountered up to 8.84 milligrams/m^3. Greater than 50 percent of the determinations were in excess of 100 μg Be/m^3. There is little doubt that early exposures were very high.[107,108] Williams[107] in reviewing the Beryllium Case Registry data, prepared a comparison of chronic and acute-to-chronic beryllium cases against the proximity of the patient's job (Table XIII). He cautioned that this did not necessarily reflect the severity of exposure and yet, as also noted by Breslin,[102] the relationship was striking. In a report[34] of 178 cases of pneumonitis and bronchitis in two plants observed from 1940 to 1948, 3 deaths occurred in 1943 and 10 deaths over the 8 year period. High concentrations of beryllium were invariably encountered, certainly in excess of 100 $\mu g/m^3$ and probably greater than 1 milligram/m^3.

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

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

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

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

Average breathing-zone concentrations (Tables XXI to XXV) were consistently below 50 $\mu g/m^3$ and less than 25 $\mu g/m^3$ most of the time. Where values exceeded 50 $\mu g/m^3$ they were of such magnitude as to indicate failure of control methods through either inadequate practices or accidental equipment breakdown. The range in effectiveness of control measures (Table XXIV) is illustrated in the chip transfer and blending operations where breathing-zone concentrations approximated 1,600 $\mu g/m^3$ in 1955, whereas subsequent levels in 1959 were within the 2 $\mu g/m^3$ range. The high concentrations just cited were not unusual when control measures were inoperative.

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

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

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

VI. DEVELOPMENT OF THE STANDARD

Basis for Standard

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

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

There still remained, however, the problem of recommendations for chronic occupational exposure to beryllium. Eisenbud's comments in 1961[108] are still appropriate in 1972. "There was not then, nor is there today, any substantial body of environmental information that could be correlated with clinical reports of occupational berylliosis, and such data as do exist are puzzling." Having no real empirical basis for the establishment of a limit for chronic occupational exposure, Eisenbud and Machle arrived at a figure of 2 $\mu g/m^3$ on the basis of information on animals and man and by analogy with industrial air limits for toxicity of heavy metals, such as lead, mercury, cadmium, and thallium.

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

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

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

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

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

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

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

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

<u>Other Beryllium Standards</u>

(1) Foreign Standards

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

(b) The World Health Organization, in 1969, issued a joint statement with the International Labor Organization on permissible levels of occupational exposure to airborne toxic substances. The recommended safe concentration zone[115] for beryllium and its compounds is 0.001 to 0.002 mg/m^3.

(2) Standards for Beryllium Rocket-Motor Firing

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

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

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

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

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

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

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

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

VII. COMPATIBILITY WITH EMISSION STANDARDS

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

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

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

(a) National Emission Standards for Beryllium

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

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

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

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

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

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

(c) Compatibility with Emission Standards

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

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