**Applied Occupational and Environmental Hygiene**
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713768777

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**To cite this Article** Stefaniak, Aleksandr B. , Weaver, Virginia M. , Cadorette, Maureen , Puckett, Leslie G. , Schwartz, Brian S. , Wiggs, Laurie D. , Jankowski, Mark D. and Breysse, Patrick N.(2003) 'Summary of Historical Beryllium Uses and Airborne Concentration Levels at Los Alamos National Laboratory', Applied Occupational and Environmental Hygiene, 18: 9, 708 — 715

**To link to this Article: DOI:** 10.1080/10473220301381

**URL:** http://dx.doi.org/10.1080/10473220301381

*Applied Occupational and Environmental Hygiene*, 18: 708–715, 2003

ISSN: 1047-322X print / 1521-0898 online
DOI: 10.1080/10473220390223084

# Summary of Historical Beryllium Uses and Airborne Concentration Levels at Los Alamos National Laboratory

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**Beryllium operations and accompanying medical surveillance of workers at Los Alamos National Laboratory began in the 1940s. In 1999 a Former Workers Medical Surveillance Program that includes screening for chronic beryllium disease was initiated. As part of this program, historical beryllium exposure conditions were reconstructed from archived paper and electronic industrial hygiene data sources to improve understanding of past beryllium uses and airborne concentration levels.**

**Archived industrial hygiene sampling reports indicated beryllium was principally used in technical areas-01 and -03, primarily being machined. Beryllium was also used at 15 other technical areas in activities that ranged from explosives detonation to the manufacture of X-ray windows. A total of 4528 personal breathing zone and area air samples for beryllium, combined for purposes of calculating summary statistics, were identified during the records review phase. The geometric mean airborne beryllium concentration for the period 1949–1989 for all technical areas was 0.04 $\mu$g Be/m$^3$ with 97 percent of all sample below the 2.0 $\mu$g Be/m$^3$ occupational exposure limit (OEL). Average beryllium concentrations per decade were less than 1 $\mu$g Be/m$^3$ and annual geometric mean concentrations in technical area-03, the largest user of beryllium, were generally below 0.1 $\mu$g Be/m$^3$, indicating exposure was generally well-controlled, that is, below the OEL.**

**Typical of many retrospective exposure assessments, not all archived data could be extracted and summarized. Despite this, we report a reasonable summary of potential beryllium uses and airborne concentration levels a worker may have encountered from 1949–1989. These data can be used to more effectively identify former worker populations at potential risk for chronic beryllium disease and to offer these workers screening as part of the Former Worker Medical Surveillance Program, and in the event that a case is diagnosed, help to understand historical exposure conditions.**

**Keywords** Chronic Beryllium Disease, Historical Exposure, Machining

Reports from the 1940s first implicated beryllium as hazardous to human health, with exposure linked to causing both acute[(1)] and chronic[(2)] pulmonary diseases. In 1949, an occupational exposure limit (OEL) of 2 $\mu$g beryllium per cubic meter of air ($\mu$g Be/m$^3$) was recommended for the control of chronic beryllium disease (CBD)[(3)] (International Classification for Disease-9 code 985.3). By the early 1980s compliance with the 2 $\mu$g Be/m$^3$ OEL was believed to have prevented new cases of CBD.[(4)] However, in 1984 a new case of CBD was diagnosed in a beryllium machinist at Rocky Flats.[(5)] Since 1984 the incidence of CBD within the United States Department of Energy (DOE) nuclear weapons complex has increased; for example, at Rocky Flats 41 cases of CBD were diagnosed from 1987 to 1995.[(6,7)] These cases of CBD were often associated with beryllium exposures that occurred decades ago, making it difficult to reconstruct past exposure conditions.[(8)]

In response to concern over the potential health impact caused by exposures incurred from work at facilities within the DOE nuclear weapons complex, Congress passed the National Defense Authorization Act of 1993, which mandated implementation of Former Worker Medical Surveillance Programs. At Los Alamos National Laboratory (LANL), beryllium operations and accompanying medical surveillance of current workers began in the 1940s. In 1999 a Former Worker Medical Surveillance Program that included screening for CBD was initiated at LANL.[(9)] While no cases of CBD have been diagnosed as part of this program to date, five cases were diagnosed at LANL prior to the 1980s.[4] Thus, the possibility for diagnosis of new cases of CBD caused by exposures that occurred decades ago exists, necessitating a better understanding of historical beryllium uses and airborne concentration levels at LANL.

Data describing historical beryllium exposure conditions at LANL are limited; the most recent data available was published in the 1950s.[10–12] Shulte et al.[10] reported that exposure was generally controlled below 0.5 $\mu$g Be/m$^3$ while beryllium was machined. Similarly, Hyatt and Milligan[11] reported that air samples collected in the LANL machine shop were generally below the 2 $\mu$g Be/m$^3$ OEL; however, during infrequent processes where workers wore adequate protective equipment exposure was considerably higher. Mitchell and Hyatt[12] reported that only 3% of air samples collected in the LANL beryllium machine shops from 1952 to 1956 exceeded the 2 $\mu$g Be/m$^3$ OEL. In general, these data were collected prior to 1956 and were restricted to a few buildings within LANL technical areas (TAs)-01 and -03. The purpose of this article is to present a summary of beryllium exposure data collected from 1949 to 1989 within 20 TAs, including 15 different buildings at LANL. This data helps to better understand historical beryllium uses, activities, and airborne concentration levels at LANL.

## METHODS

Reconstruction of historical airborne beryllium levels required assessment and abstraction of available information from archived paper and electronic industrial hygiene data sources at LANL. Archived industrial hygiene sampling reports were reviewed and information that pertained to activities that involved beryllium was extracted. From this data a summary of historical job locations and activities that potentially resulted in beryllium exposure was developed. Quantitative exposure information was obtained from the LANL Industrial Hygiene Sampling (IHS) electronic database. This database contains results of exposure monitoring for over 300 chemical, physical, and biological agents. Data pertaining to the location, date, and a description of the work activity performed during industrial hygiene sampling are stored in a separate LANL electronic database referred to as the Workcard Form (WF) database. The IHS and WF databases were created by the LANL Toxicology and Information Services Team. Each workcard is assigned a unique identifier number so that sampling data in the IHS database can be linked to the corresponding description of work activities in the WF database.

The WF database was created in the early 1990s, necessitating a review of hard copies of archived industrial hygiene sampling reports to evaluate historical exposure conditions. Archived industrial hygiene paper records from the 1940s through the 1980s were reviewed and reports that contained sampling results for beryllium were identified. Project industrial hygienists reviewed all reports to determine whether information was complete and calculations were accurate. If possible, errant calculations were corrected based on calibration and sampling data provided in the reports. If the report was complete and accurate a workcard number was retrospectively assigned and the appropriate data entered into the WF and IHS databases by LANL staff. All data entered retrospectively were verified by comparing database records to the hard copy reports. LANL staff then queried the databases for records containing the word "beryllium," which returned all beryllium samples regardless of type or duration.

Typical of any retrospective exposure assessment effort, some historical records were found to be incomplete. For example, in some cases it could not be determined if a sampling result was from personal or general area air monitoring. In other cases the sample duration was not given. Because of these inherent limitations, both area and personal breathing zone (PBZ) air sampling results were combined to calculate summary statistics of airborne beryllium concentration levels and no attempt was made to differentiate between short-term and full-shift sample results. At LANL, area samples have been collected for purposes that include continuous monitoring of a specific operation, for example, machining beryllium, and when PBZ samples approached the OEL. Collection techniques have varied, for example, in the 1950s area samples were collected using an electrostatic precipitator and by drawing air through Whatman filters placed in the vicinity of a beryllium operation at flow rates up to 20 liters per minute.[12]

Data analysis and summary statistics were calculated using the SPSS statistical package (SPSS Inc., Chicago, IL) assuming a value equal to the analytical limit of detection (LOD) divided by $\sqrt{2}$ for censored data, where a value of 0.01 $\mu$g Be/m$^3$ was assumed for the LOD. According to Hornung and Reed[13] this correction is appropriate because the distribution of non-censored data is lognormal and the proportion of censored data points is such that the LOD is not greater than the mode. Note that while analytical techniques have changed with time, the LOD has remained relatively stable. Since June 1951 all industrial hygiene samples have been analyzed at LANL.[12] In 1951 the analytical LOD was 0.05 $\mu$g Be/filter[12] currently, a modified U.S. Occupational Safety and Health Administration (OSHA) Method 125G[14] with LOD of 0.03 $\mu$g Be/filter is used.

## RESULTS

### Beryllium Uses at LANL

Archived industrial hygiene sampling reports indicated that beryllium metal, beryllium oxide, copper-beryllium alloy, beryllium-steel alloy, beryllium metal-nonmetal mixtures, or beryllium salts were used at 20 different LANL TAs from 1949 to 1989. At 3 of these 20 TAs (-22, -43, -59), no information on specific uses of beryllium could be determined from the sampling reports, although exposure data were available. In 4 of the 20 TAs (-8, -9, -14, -21) historical reports indicated beryllium was used but no air sampling data was located.

**TABLE I**
Locations, historical uses, and activities involving beryllium at Los Alamos National Laboratory

| TA | Bldg. | Bldg. name | Beryllium uses and operations |
|---|---|---|---|
| 01 | D000 | Delta | Machining, welding |
| | S000 | Old Sigma | Extrusion, welding |
| | V000 | V-Shop | Machining, furnace treatment |
| 03 | 0016 | Van de Graaf Generator | Sanding |
| | 0029 | CMR | Soldering, vaporizing, casting, sanding |
| | 0039 | Shops | Machining, grinding, sandblasting, brazing |
| | 0040 | Branch Shop | Machining |
| | 0066 | New Sigma | Coating, etching, brazing, casting, welding |
| | 0102 | Shops | Machining |
| | 0141 | Rolling Mill | Coating, rolling |
| 06 | | | Making foils and X-ray windows |
| 08 | | | Storage |
| 09 | | | Handling targets |
| 14 | | | Detonating explosives |
| 15 | | | Detonating explosives |
| 16 | | | Fabricating, molding, cutting, machining, laundering clothes |
| 18 | | | Handling rods |
| 21 | | | Machining, ball-milling, arc melting |
| 33 | | | Machining |
| 35 | | | Handling salts |
| 39 | | | Firing projectiles |
| 40 | | | Vaporizing, milling |
| 41 | | | Sanding |
| 46 | | | Thermal treatment |
| 53 | | | Making targets (sintering, pressing) |

TA = technical area.



Table I is a summary of historical uses and activities involving beryllium by TA. TA-01 was the first TA at LANL and the site of the original Manhattan Project. Here, beryllium was primarily machined, but exposure may have also occurred when it was welded, extruded, flame plated, or treated in a furnace. Note that TA-01 Sigma building is also referred to as "Old Sigma" because in 1962 the operations were moved to TA-03 building 0066 (referred to as "New Sigma"). In 1952, the Chemistry-Metallurgy Division (CMR) was moved from the TA-01 V-shop building to TA-03 building 0029. In 1953 the beryllium machine shop was also moved from TA-01 V-shop building to TA-03 building 0039.[12]

With the closure of TA-01, TA-03 became the primary site of beryllium operations at LANL. Archived records revealed beryllium was used in 12 buildings within TA-03. However, information on uses could only be determined for 7 of these buildings. Beryllium was primarily machined at TA-03, but it was also soldered, welded, vaporized, cast, sandblasted, coated, etched, and rolled. Industrial hygiene records indicated beryllium was used at 15 other LANL TAs in operations that ranged from detonation of explosives to the manufacture of X-ray windows. Incidental exposure to beryllium may have also occurred as the result of specific activities; for example, when contaminated clothes were laundered at TA-16.

## Historical Airborne Beryllium Concentrations at LANL

The IHS and WF databases were queried for beryllium and returned over 8100 sample results collected from 1949 to 1989. When bulk, swipe, and atmosphere samples (i.e., stack and rooftop monitors) were removed, the query yielded 4528 area and PBZ air samples. The last atmospheric samples at what was TA-01 were collected from March to May 1970 and averaged 0.0004 $\mu$g Be/m$^3$. The level of detail provided in sampling reports was sufficient to link samples to a TA and in some cases even a specific building within the TA; however, data was insufficient to consistently link sample results to individual workers or job activities.

Table II presents a summary of airborne beryllium concentrations by TA for the period 1949–1989. The geometric mean (GM) beryllium air concentration for all TAs was 0.04 $\mu$g Be/m$^3$ and approximately 3 percent of all sample results exceeded 2.0 $\mu$g Be/m$^3$. Individual airborne concentrations ranged from <LOD (0.01 $\mu$g Be/m$^3$) to 2100 $\mu$g Be/m$^3$ collected in TA-53. Airborne beryllium concentrations were generally higher in

**TABLE II**
Airborne beryllium concentrations ($\mu$g Be/m$^3$) by technical area (TA) from 1949 to 1989[A]

| TA | N | Mean | Std. dev. | GM[B] | GSD[C] | Max | % > 2 $\mu$g/m$^3$ |
|---|---|---|---|---|---|---|---|
| 01 | 89 | 7.07 | 25.24 | 0.34 | 15.40 | 180.00 | 25.8 |
| 03 | 4243 | 0.99 | 21.00 | 0.04 | 6.47 | 909.00 | 2.6 |
| 06 | 8 | 48.23 | 88.14 | 1.78 | 61.30 | 247.49 | 62.5 |
| 15 | 19 | 2.46 | 8.85 | 0.06 | 13.70 | 38.80 | 10.5 |
| 16 | 31 | 2.96 | 8.25 | 0.14 | 11.70 | 38.00 | 16.1 |
| 18 | 45 | 1.99 | 7.30 | 0.19 | 9.23 | 45.00 | 8.9 |
| 22 | 7 | 0.03 | 0.01 | 0.03 | 1.38 | 0.04 | 0 |
| 33 | 8 | 0.04 | 0.02 | 0.04 | 1.38 | 0.07 | 0 |
| 35 | 28 | 0.13 | 0.39 | 0.02 | 9.51 | 2.09 | 3.6 |
| 39 | 2 | 0.72 | 0.98 | 0.22 | 13.58 | 1.41 | 0 |
| 40 | 1 | 1.62 | — | 1.62 | — | 1.62 | 0 |
| 41 | 16 | 0.57 | 0.72 | 0.12 | 9.15 | 2.00 | 0 |
| 43 | 3 | 1.07 | 1.10 | 0.25 | 22.51 | 2.20 | 33.3 |
| 46 | 5 | 1.25 | 2.66 | 0.15 | 8.05 | 6.00 | 20.0 |
| 53 | 18 | 117.42 | 494.79 | 0.38 | 21.5 | 2100.00 | 16.7 |
| 59 | 5 | 0.09 | 0.07 | 0.07 | 2.05 | 0.20 | 0 |

[A]Combined results for general area and personal breathing zone air samples.
[B]GM = geometric mean.
[C]GSD = geometric standard deviation.



TAs-03, -06, and -53. Geometric mean airborne concentrations were much less than the arithmetic means due to a few extreme values.

Airborne beryllium concentrations, summarized by decade in Table III, were generally stable over time except for the late 1940s. Geometric mean airborne concentrations were all less than 1 $\mu$g Be/m$^3$ per decade.

Table IV presents annual average airborne beryllium concentrations at TA-03, the principal site of beryllium use at LANL since closure of TA-01, for the period 1953–1989. Overall, 94 percent of all air samples were collected in TA-03. Airborne beryllium levels at TA-03 ranged from <LOD to a maximum of 909 $\mu$g Be/m$^3$ in 1986, and only 2.6 percent of all samples exceeded the 2 $\mu$g Be/m$^3$ OEL. Note that air sampling data were not available for every year in this time period. In general, GM airborne beryllium concentrations at TA-03 were relatively constant over time.

An evaluation of airborne concentrations by building within TAs-01 and -03 from 1949 to 1989 is presented as Table V. The majority of samples collected in TA-01 were from the Old Sigma building and approximately 25 percent exceeded the 2 $\mu$g Be/m$^3$ OEL. Fewer sample results were reported for the V-shop (old machine shop), but nearly all were above 2 $\mu$g Be/m$^3$. For TA-03, the majority of samples were collected in the new shops (buildings 0039 and 0102), and only a few percent of these samples exceeded 2 $\mu$g Be/m$^3$. Other areas in TA-03 with significant sampling activity included CMR, New Sigma, and the Rolling mill buildings.

**TABLE III**
Airborne beryllium concentrations ($\mu$g Be/m$^3$) at Los Alamos National Laboratory by decade[A]

| Decade | N | Mean | Std. dev. | GM[B] | GSD[C] | Max | % > 2 $\mu$g/m$^3$ |
|---|---|---|---|---|---|---|---|
| 1940s | 8 | 31.94 | 64.08 | 0.93 | 34.71 | 180.00 | 37.5 |
| 1950s | 410 | 2.30 | 15.43 | 0.12 | 7.28 | 247.49 | 10.0 |
| 1960s | 310 | 0.25 | 0.95 | 0.03 | 7.16 | 10.00 | 3.2 |
| 1970s | 2599 | 1.34 | 41.74 | 0.03 | 6.09 | 2100.00 | 2.4 |
| 1980s | 1201 | 2.36 | 38.20 | 0.04 | 7.49 | 909.00 | 3.4 |

[A]Combined results for general area and personal breathing zone air samples.
[B]GM = geometric mean.
[C]GSD = geometric standard deviation.

**TABLE IV**
Annual airborne beryllium concentrations ($\mu$g Be/m$^3$) in technical area (TA)-03[A] from 1953 to 1989[B]

| Year | N | Mean | Std. dev. | GM[C] | GSD[D] | Max | % > 2 $\mu$g/m$^3$ |
|---|---|---|---|---|---|---|---|
| 1953 | 52 | 0.75 | 1.04 | 0.12 | 13.62 | 4.90 | 11.5 |
| 1955 | 60 | 0.11 | 0.29 | 0.04 | 2.36 | 1.77 | 0 |
| 1956 | 6 | 0.52 | 0.70 | 0.11 | 10.57 | 1.41 | 0 |
| 1957 | 90 | 0.48 | 1.99 | 0.12 | 2.67 | 16.90 | 4.4 |
| 1958 | 80 | 0.14 | 0.39 | 0.09 | 1.72 | 2.85 | 2.5 |
| 1959 | 2 | 0.02 | 0.02 | 0.02 | 2.44 | 0.04 | 0 |
| 1961 | 1 | <0.01 | — | <0.01 | | <0.01 | 0 |
| 1963 | 10 | 1.49 | 2.77 | 0.32 | 7.90 | 9.09 | 20.0 |
| 1964 | 1 | 4.11 | | 4.11 | | 4.11 | 100.0 |
| 1966 | 2 | 0.04 | 0.00 | 0.04 | 1.00 | 0.04 | 0 |
| 1967 | 4 | 0.12 | 0.19 | 0.03 | 10.81 | 0.40 | 0 |
| 1968 | 2 | 0.04 | 0.01 | 0.04 | 1.28 | 0.05 | 0 |
| 1970 | 252 | 0.16 | 0.74 | 0.02 | 6.44 | 10.00 | 2.0 |
| 1971 | 241 | 0.26 | 3.24 | 0.01 | 3.52 | 50.00 | 0.8 |
| 1972 | 261 | 0.97 | 8.22 | 0.02 | 7.02 | 126.00 | 4.2 |
| 1973 | 352 | 0.14 | 0.61 | 0.02 | 5.28 | 5.60 | 2.3 |
| 1974 | 397 | 0.05 | 0.14 | 0.02 | 3.81 | 2.00 | 0 |
| 1975 | 254 | 0.21 | 2.84 | 0.02 | 3.38 | 45.20 | 0.4 |
| 1976 | 319 | 0.11 | 0.26 | 0.05 | 3.99 | 3.55 | 10.6 |
| 1977 | 227 | 0.11 | 0.15 | 0.06 | 3.64 | 1.40 | 0 |
| 1978 | 181 | 2.65 | 21.41 | 0.09 | 10.41 | 283.30 | 8.8 |
| 1979 | 178 | 1.46 | 8.55 | 0.17 | 6.78 | 105.00 | 5.6 |
| 1980 | 117 | 0.47 | 1.73 | 0.08 | 4.94 | 11.00 | 3.4 |
| 1981 | 34 | 0.10 | 0.24 | 0.02 | 5.22 | 1.18 | 0 |
| 1982 | 177 | 1.39 | 15.76 | 0.04 | 6.47 | 209.70 | 2.3 |
| 1983 | 121 | 2.24 | 20.63 | 0.02 | 4.71 | 223.00 | 1.7 |
| 1984 | 213 | 0.05 | 0.17 | 0.01 | 4.20 | 1.17 | 0 |
| 1985 | 196 | 0.31 | 1.13 | 0.03 | 8.06 | 11.87 | 2.6 |
| 1986 | 245 | 7.72 | 81.94 | 0.07 | 5.75 | 909.00 | 3.7 |
| 1987 | 20 | 0.22 | 0.38 | 0.04 | 12.16 | 1.40 | 0 |
| 1988 | 64 | 0.53 | 1.13 | 0.15 | 4.62 | 5.71 | 7.8 |
| 1989 | 84 | 2.57 | 8.10 | 0.17 | 14.37 | 57.00 | 14.0 |

[A]Since the early 1960s, TA-03 has been the primary location of beryllium use at LANL with 94% of all air samples collected within this technical area.
[B]Combined results for general area and personal breathing zone air samples.
[C]GM = geometric mean.
[D]GSD = geometric standard deviation.

## DISCUSSION

Approximately 96 percent of all beryllium samples were collected in TAs-01 and -03. This finding is consistent with the history of beryllium use at LANL. TA-01 was the original LANL site where, until closed in the early 1960s, the Old Sigma, Delta, and V-(old machine) shop buildings were located. With closure of TA-01, TA-03 became the primary location of beryllium operations at LANL. Geometric mean airborne beryllium concentrations at TAs-01 and -03 were below 2 $\mu$g Be/m$^3$ (see Table II). However, within specific buildings at these TAs, results were variable and airborne beryllium concentrations sometimes exceeded 2 $\mu$g Be/m$^3$ (see Table V).

As previously noted, among all LANL TAs airborne beryllium levels tended to be highest in TAs -03, -06, and -53. These elevated levels may be due to work activities, e.g., at TA-03 the primary beryllium activity is machining, which can result in higher average beryllium exposures than non-machining operations.[15] At TAs -06 and -53 operations involved pressing beryllium, probably as a powder. At a privately owned beryllium oxide ceramics facility pressing or forming beryllium powder is reported to result in exposure levels that exceed those from machining.[16]

The data presented in Tables II and V are consistent with historical reports that the average beryllium concentration in

**TABLE V**
Airborne beryllium concentrations ($\mu$g Be/m$^3$) by building in technical areas (TAs)-01 and -03[A] from 1949 to 1989[B]

| TA | Bldg. | Bldg. name | N | Mean | Std. dev. | GM[C] | GSD[D] | Max | % > 2 $\mu$g/m$^3$ |
|---|---|---|---|---|---|---|---|---|---|
| 01 | D000 | Delta | 7 | 0.19 | 0.39 | 0.03 | 7.77 | 1.05 | 0 |
| | S000 | Sigma | 78 | 4.81 | 16.83 | 0.35 | 13.4 | 88.30 | 25.6 |
| | V000 | V-Shop | 4 | 63.82 | 82.94 | 14.35 | 14.28 | 180.00 | 75.0 |
| 03 | 0016 | Van de Graaf Generator | 2 | 1.30 | 0.14 | 1.30 | 1.12 | 1.40 | 0 |
| | 0029 | CMR | 57 | 0.69 | 1.01 | 0.08 | 12.52 | 4.90 | 10.5 |
| | 0034 | Cryogenics Research Facility | 3 | 0.10 | 0.09 | 0.07 | 2.83 | 0.20 | 0 |
| | 0039 | Shops | 364 | 0.60 | 16.29 | 0.03 | 5.30 | 909.00 | 1.3 |
| | 0040 | Branch Shop | 4 | 0.03 | 0.02 | 0.02 | 3.16 | 0.04 | 0 |
| | 0043 | Administration | 2 | 0.02 | 0.02 | 0.02 | 2.44 | 0.04 | 0 |
| | 0066 | New Sigma | 125 | 5.24 | 23.90 | 0.12 | 12.11 | 223.00 | 17.6 |
| | 0102 | Shops | 290 | 3.64 | 53.37 | 0.13 | 5.25 | 909.00 | 4.8 |
| | 0141 | Rolling Mill | 89 | 2.69 | 7.87 | 0.17 | 18.47 | 57.00 | 20.2 |
| | 0184 | Old Occupational Health Lab (OHL) | 19 | 0.45 | 0.32 | 0.23 | 5.58 | 0.97 | 0 |
| | 0218 | Magnetic Energy and Storage Facility | 4 | 0.57 | 0.62 | 0.30 | 4.17 | 1.40 | 0 |
| | 0287 | Scyllac | 4 | 2.05 | 0.21 | 2.04 | 1.11 | 2.3 | 50 |

[A]TA-01 was the site of the original Manhattan Project. Upon closing, TA-03 became the principal site of beryllium use at LANL. Approximately 96% of all beryllium air samples collected at LANL were from these two TAs.
[B]Combined results for general area and personal breathing zone air samples.
[C]GM = geometric mean.
[D]GSD = geometric standard deviation.



the machine shops at TA-01 generally remained below 2 $\mu$g Be/m$^3$, except during infrequent processes.(11) The 2 $\mu$g Be/m$^3$ OEL was first recommended for use by the U.S. Atomic Energy Commission (AEC) in 1949(3) but was not recommended by the AEC to LANL until August 1951.(12) The earliest sampling data presented for TA-01 were collected in 1949; thus, in retrospect, airborne beryllium levels sometimes exceeded the current OEL, but occurred at the time when a recommended safe-working level for beryllium was first being developed and implemented.

While TAs-01 and -03 were the principal sites of beryllium use at LANL, several other activities with potential for exposure to beryllium were performed at 13 additional TAs (Table I). Because many beryllium operations at LANL are specialized in nature, the available literature to compare airborne concentrations by operation or activity is scarce. Campbell(17) reported 20 percent (11/56) of general area samples collected inside a bunker used to house personnel during detonation of assemblies containing beryllium were below 0.01 $\mu$g Be/m$^3$. Outside the bunker, 75 percent (45/60) of breathing zone samples were less than 0.1 $\mu$g Be/m$^3$, with maximum exposure levels of 2.40 $\mu$g Be/m$^3$. At LANL TA-15, where explosives were detonated, airborne beryllium concentrations tended to be higher, with arithmetic mean 2.46 $\mu$g Be/m$^3$ and maximum 38.80 $\mu$g Be/m$^3$, although these values are for both indoor and outdoor activities. Variations in detonation assembly parameters, meteorological conditions, facility layout, personnel job tasks, etc., could also account for differences in exposure levels.

Eisenbud et al.(18) estimated the average exposure level incurred while shaking beryllium-contaminated garments in the home to be approximately 500 $\mu$g Be/m$^3$. Cohen(19) reported airborne beryllium levels in a change room of a machine shop where contaminated clothes were shook had GM of 0.11 $\mu$g Be/m$^3$. Eisenbud et al.(18) estimated that activities such as scrubbing garments or shaking and folding laundered garments have average exposures of 3.7 and 5 $\mu$g Be/m$^3$, respectively. Beryllium-contaminated clothes were laundered at LANL TA-16, but levels in the change room, (i.e., <0.01 $\mu$g Be/m$^3$), and in the laundry room, (<0.1 $\mu$g Be/m$^3$) were much lower. Note that data presented for TA-16 in Table II is for all work at this TA, but the values discussed here were specific to samples collected when contaminated garments were doffed and laundered.

Over a period of five decades, GM beryllium exposure levels at LANL decreased from 0.93 $\mu$g Be/m$^3$ in the 1940s to about 0.03 $\mu$g Be/m$^3$ from the 1960s to the 1980s (Table III). Concurrently, the percentage of air sample that exceeded 2 $\mu$g Be/m$^3$ decreased from 38 percent to approximately 3 percent per decade. Although historical GM exposure levels were maintained below the 2 $\mu$g Be/m$^3$ OEL, CBD can occur from exposures below this level.(15) The potential risk of CBD from even low-level beryllium exposure highlights the importance of understanding historical uses and exposure conditions at LANL for targeting former workers for medical screening through the LANL Former Workers Medical Surveillance Program.(9)

While airborne beryllium concentration levels were generally highest in the 1940s, this conclusion is based on a small number of samples extracted from useable historical records (Table III). Mitchell and Hyatt(12) reported that airborne beryllium concentrations in the V-shop building between 1948 and 1949 were below 2 $\mu$g Be/m$^3$ approximately 50 percent of the time. The data we present in Tables III and V is in general agreement with this published report. Differences in our value of 38 percent of airborne beryllium levels that exceeded the OEL (see Table III) from the 50 percent reported by Mitchell and Hyatt[12] are probably due to our inability to use all historical industrial hygiene data in archived reports. Mitchell and Hyatt[12] also reported that from 1948 to 1949 airborne beryllium concentrations in the old machine shop never exceeded 25 $\mu$g Be/m$^3$. Our results presented in Table V are in general agreement with this finding, although a sample of 180 $\mu$g Be/m$^3$ was collected in the V-shop building in October 1949.

Within TA-03, where 94 percent of all air samples were collected, beryllium was primarily machined. Annual GM exposure levels in TA-03 were generally below 0.1 $\mu$g Be/m$^3$ with few exceptions (see Table IV). These relatively low annual GM exposures are consistent with reports of the effectiveness of local exhaust ventilation employed in the LANL shops.[10,12] With few exceptions, annual arithmetic mean exposure levels in TA-03 tended to be less than 1 $\mu$g Be/m$^3$ and are similar to levels reported in the Rocky Flats beryllium machine shop using fixed airhead (FAH) general area samples.[8]

Results presented for the TA-01 V-shop building (old beryllium machine shop) are in general agreement with published reports of exposure levels for this workplace. The GM airborne beryllium level of four samples collected in 1949 was 14.4 $\mu$g Be/m$^3$ (Table V), consistent with Hyatt and Milligan,[11] who reported that beryllium exposure in the V-shop only exceeded the OEL during isolated infrequent processes. Again, the control of exposures below acceptable levels with infrequent higher excursions is attributed in part to effective local exhaust ventilation controls implemented in the V-shop.[10,12]

In September 1953 the TA-01 V-shop building (old beryllium machine shop) was moved to TA-03 building 0102. According to Mitchell and Hyatt,[12] nearly 100 percent of area and PBZ air samples collected in this new location between 1953 and 1956 were less than 2 $\mu$g Be/m$^3$ and none exceeded 25 $\mu$g Be/m$^3$ while beryllium was machined. Consistent with Mitchell and Hyatt,[12] of 290 area and PBZ sample results from New Shop (building 0102) presented in Table V, 5 percent were above 2 $\mu$g Be/m$^3$ and annual average beryllium exposure levels at TA-03 from 1953 to 1956 (see Table IV) revealed 88–100 percent of samples were below 2 $\mu$g Be/m$^3$.

Data reported as Tables II–V do not exactly match published reports from the 1950s for a variety of reasons typically encountered in any retrospective exposure assessment. First, historical sampling reports reviewed did not always indicate whether an air sample was PBZ or area; thus, all samples were grouped to summarize airborne beryllium concentration levels. In contrast, many of the early reports, for example, Hyatt and Milligan,[12] were able to separate area samples from PBZ samples. Second, for some reports only aggregate or summary information was available; for example, a report from the 1950s may have read 50 air samples were collected and no significant exposure was detected or 95 percent of all samples analyzed were less than 2 $\mu$g Be/m$^3$. In these cases no useable data could be extracted to calculate the summary statistics. Third, archived sampling reports were not used if errant calculations—for example, air volume sampled—could not be corrected using data available in the report. Thus, not all historical sampling results were included in our retrospective review. Finally, it is possible that not all of the industrial hygiene sampling reports presented in previous publications, for example, Mitchell and Hyatt,[12] were found. Therefore, previously reported results might have been missed during the data review and entry phase of this project. Despite the lack of a record keeping requirement prior to implementation of OSHA 29 CFR 1910.20,[20] LANL archived hundreds of boxes of sampling records (16% of the data presented was collected prior to 1970—see Table III), which provided a unique opportunity to reconstruct historical airborne beryllium concentration levels over a period of 40 years.

Although the compilation of exposure information is extensive, there are inadequacies typical of historical documentation as noted above. It is possible that there may have been some bias associated with the types of records retained. We have no evidence of such a bias, however. In addition, changes in sampling[12,21] and analytical techniques may also limit intercomparison of data collected over several decades. Unfortunately, historical quality control data were not archived but it is our understanding that beryllium analyses have been performed with a high standard of quality control. As a result the data presented in this article should be interpreted with caution. These results are not intended to imply individual exposures but rather, in a broader context, document historical airborne beryllium concentration levels encountered within specific TAs and buildings at LANL.

## SUMMARY

A query of the IHS and WF databases for beryllium samples collected from 1949 to 1989 returned 4528 area and PBZ air samples from 16 TAs within LANL. The GM beryllium air concentration for all TAs was 0.04 $\mu$g Be/m$^3$ and approximately 3 percent of all sample results exceeded the 2.0 $\mu$g Be/m$^3$ OEL. Geometric mean airborne beryllium concentration levels were usually less than 1 $\mu$g Be/m$^3$ per decade, indicating exposure at LANL was generally controlled below the OEL. Although PBZ and area samples were combined for the purposes of summarizing airborne beryllium concentrations and not all archived data could be extracted and summarized, this report presents a reasonable summary of potential beryllium uses and historical airborne concentration levels a worker at LANL may have encountered. These data can help to identify former worker populations at potential risk for CBD more effectively and offer these workers screening as part of the LANL Former Worker Medical Surveillance Program.

## ACKNOWLEDGMENTS

The authors acknowledge B. Hargis and B. Gallimore of the LANL Industrial Hygiene and Safety Group, and D. Erickson of the former ESH Division for their support of this project. We also thank the LANL Toxicology and Information Services Team (H. White, J. Conwell, J. Encinias, and B. Hargraves) for assistance with queries of the IHS and WF databases, B. Rooney of Johns Hopkins University for analysis of the data, and H. Ettinger of LANL for helpful discussions throughout this project. This project was funded by the U.S. Department of Energy Cooperative Agreement with the Johns Hopkins University Bloomberg School of Public Health DE-FC03-98SF21541 Development of a Medical Screening Program for Former LANL Workers.

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