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BERYLLIUM SAMPLING METHODS

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Three sampling methods for airborne beryllium are compared to validate observaitons made in a 1973 NIOSH industry wide study of the beryllium industry which found that, in general, the three methods yielded differing results for samples taken in the same environment. A NIOSH contractor sampled its beryllium production facility by the Atomic Energy Commission, personal total, and personal respirable sampling methods over a period of one year. All samples were analyzed by atomic absorption spectroscopy. Statistical analysis of the resulting data by NIOSH confirms the conclusions made in the 1973 study. No reliable conversion was found to exist between results obtained from the three methods on a single sample basis. However, it appears that for large numbers of samples taken under the same sampling conditions that when the concentration is 2 micrograms beryllium per cubic meter as determined by the AEC sampling method, that the value as determined by the personal respirable sampling method will be approximately 1 micrograms beryllium per cubic meter and the value as determined by the personal total sampling method will be approximately 3 micrograms beryllium per cubic meter.

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BERYLLIUM SAMPLING METHODS

COMPARISON OF TWO PERSONAL SAMPLE COLLECTION METHODS WITH THE AEC SAMPLE COLLECTION METHOD AS USED FOR ONE YEAR IN A BERYLLIUM PRODUCTION FACILITY

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ABSTRACT

Three sampling methods for airborne beryllium are compared to validate observations made in a 1973 National Institute for Occupational Safety and Health (NIOSH) industrywide study of the beryllium industry which found that, in general, the three methods yielded differing results for samples taken in the same environment. A NIOSH contractor sampled its beryllium production facility by the Atomic Energy Commission (AEC), personal total, and personal respirable sampling methods over a period of one year. All samples were analyzed by atomic absorption spectroscopy. Statistical analysis of the resulting data by NIOSH confirms the conclusions made in the 1973 study. No reliable conversion was found to exist between results obtained from the three methods on a single sample basis. However, it appears that for large numbers of samples taken under the same sampling conditions that when the concentration is 2 $\mu gBe/m^3$ as determined by the AEC sampling method, that the value as determined by the personal respirable sampling method will be approximately 1 $\mu gBe/m^3$ and the value as determined by the personal total sampling method will be approximately 3 $\mu gBe/m^3$.

INTRODUCTION AND BACKGROUND

In 1973 the National Institute for Occupational Safety and Health (NIOSH) conducted an industrywide environmental study of beryllium production facilities employing simultaneous monitoring of airborne beryllium using three different sampling methods. The results of this study indicated that the amount of airborne beryllium exposure found for each operation differed with the sampling method used. The results obtained from the personal total sampling method, which is currently used by the Occupational Safety and Health Administration (OSHA), gave higher results than both the Atomic Energy Commission (AEC) sampling method which is used by industry and upon which the standard of 2 $\mu gBe/m^3$ was set, and the personal respirable method for assessment of employee exposure in the same environment.

In order to further validate these observations a comparative sampling effort was initiated through NIOSH contract CDC 99-74-8 awarded to the Brush - Wellman Company.

METHODOLOGY

The Brush - Wellman Company operates an integrated beryllium production facility. The work under contract was performed by its industrial hygiene staff at its Elmore, Ohio plant. The sampling covered 21 plant operations in five different types of manufacturing areas and was repeated 18 times over a period of one year. These areas are listed in Table I of the appendix. Three different sampling methods were used: (1) AEC daily weighted average (AEC-DWA): (2) personal total; and (3) personal respirable.

Sampling Methods:

Atomic Energy Commission (AEC) Method - The AEC method of monitoring was formalized in 1956[2] and is used by the industry to determine the degree of compliance to the 2 $\mu gBe/m^3$ standard in beryllium production facilities. This method makes use of 2 high-volume samplers and a 4" Whatman #41 filter* paper. Two types of total dust samples are collected: (1) General Area usually varying from 15 minutes to an hour in duration; and (2) Breathing Zone varying from about two to ten minutes in duration. The results of General Area and Breathing Zone samples are used along with a time and motion study of the worker's job to calculate his daily weighted average (DWA) for a three month period.

The personal sampling methods differ from the AEC method in that the sampling equipment used in the personal methods is worn by the workers during the work shift. With dusts, both total and respirable personal samples may be obtained.

Personal Total Sample[3] - A personal total sample collects all particle sizes of dust in the air to which the worker is exposed. Total samples are collected directly on a 37 mm, 0.8 μm pore size membrane filter in a plastic cassette worn on the lapel. A MSA pump is used to pull the air through the filter at a flow rate of 2 lpm.

Mention of company or product names is not to be considered as an endorsement by NIOSH.

Personal Respirable Sample[4,5] - A personal respirable sample is designed to collect only that dust in the air which can reach the lungs. Personal respirable sampling involves attaching a 10 mm nylon cyclone upstream from a 37 mm, 0.8 μm pore size membrane filter in a plastic cassette worn on the lapel. The cyclone collects the larger particles allowing only the smaller respirable particles to pass through to be collected on the filter. A MSA dampened pump operating at a flow rate of 1.7 lpm pulls the air through the system. Since the total and respirable samples were collected simultaneously, the worker wore both types of equipment attached to his lapels.

Analysis of Samples:

All samples were analyzed by the contractor using the atomic absorption method. Initially and periodically during the course of the contract, the analysis of split samples collected on Whatman #41 paper, one-half of which were run in a NIOSH laboratory and the other one-half in the contractor's laboratory, showed that results were essentially the same. NIOSH personnel calibrated all sampling equipment supplied by the contractor. Sample results generated during the course of the contract were transmitted to NIOSH where statistical analyses were made.

STATISTICAL ANALYSIS

Sample values, along with the corresponding area where collected, and reports by time period were coded and entered into a computer data file. Analysis was performed utilizing standard Statistical Package for Social

Science (SPSS) computer programs. Tables referred to here are given in the Appendix.

Table 1 gives the areas and operations where sampling was carried out. Table 2 lists the dates represented by each of the eighteen reports.

Table 3 presents a summary of the data set, giving the arithmetic means by reports, area, and sample type. This table, and some preliminary graphs (not included in this report) brought out some noteworthy points. One is the tendency for a consistent ordering of sample types. That is, the personal total is usually the highest, the personal respirable is usually the lowest, with the AEC-DWA usually in between. This initial impression is substantiated by subsequent analysis. Second, looking across time (report number) there appears to be no consistent trend in the level of any of the sample types. Third, there are instances where levels measured by the personal respirable method are higher than their personal gross counterparts (i.e. area 3 report 3, area 4 report 13). This undoubtedly is a reflection of errors generated in the collection or analysis of the original samples. Last, it should be noted that the levels for area 5 report 10 are substantially higher than the other levels. Their influence may also be seen in the overall averages for report 10. However, since they do represent real levels they were included in subsequent analysis, for which log values of all samples were used.

Table 4 gives the arithmetic means, standard deviations, and number of samples for each area and for the total set. It is presented primarily for comparison with Table 5.

As would be expected in sampling data of this sort, the levels are skewed toward the lower values such that a base 10 logarithmic transformation is appropriate. Table 5 gives the logarithmic means and standard deviations for each area and for the total data set along with the antilog of each mean. Comparison of the means of Table 4 with the antilog means of Table 5 shows the effect of the logarithmic transformation which yields more accurate measures of central tendency and variability, especially in the case of area 5.

From Table 5 it may be seen that the means of the log transformed distributions follow a consistent ordering. That is, the personal total method is higher than the AEC-DWA which is in turn higher than the personal respirable method. These differences were tested for statistical significance using a one way analysis of variance. In each of the five areas and for the overall data set the differences were significant at p<05. Therefore, multiple comparisons were made on pairs of sample types in order to determine which types were different from the others. The results of those comparisons are given in Table 6. The simultaneous p values given refer only to that specific set of comparisons. For example, for area 1 the statement that all three pairs of sample means differ significantly may be made at the 99% level of confidence. Likewise for area 3 the statement that the personal total and personal respirable differ significantly while the other two pairs do not differ may be made at the 95% level of confidence. The results for the entire data set indicate that all three means differ significantly. The lack of significant results for areas 3, 4 and 5 is due at least in part to the smaller number of samples for those areas.

Having established that the different sampling procedures yield different answers it is reasonable to ask if a reliable conversion may be made from one sample type to another. Therefore a regression analysis was done on personal respirable samples with AEC-DWA, and personal total with AEC-DWA, again using the logarithms of the original levels. Linear least squares regression lines were fitted to the data, thus allowing the calculation of a predicted personal respirable and personal total sample value for any given AEC-DWA sample value. Of particular interest is the predicted value at an AEC-DWA value of 2 μgBe/m^3. The results, given in Table 7, indicate the predicted personal respirable value to be 0.92 μgBe/m^3. The approximate 95% confidence interval for the mean predicted value is 0.83 to 1.02 μgBe/m^3. The approximate 95% confidence interval for a single predicted value is 0.13 to 6.33 μgBe/m^3. The predicted personal total value is 2.99 μgBe/m^3. The approximate 95% confidence interval for the mean predicted value is 2.75 to 3.25 μgBe/m^3. The approximate 95% confidence interval for a single predicted value is 0.63 to 14.31 μgBe/m^3.

In summary, two statements are supported by this set of data:

1. The three types of samples tested do not yield equivalent results for measuring exposure to beryllium dust. Personal total sampling gives higher values than the AEC-DWA sampling which in turn gives higher values than personal respirable sampling.

2. For a larger number of samples an AEC-DWA level of 2 μgBe/m^3 is approximately equivalent to a personal respirable level of 1 μgBe/m^3 or a personal total value 3 μgBe/m^3. However, the samples are so variable that a single value may differ greatly from the mean predicted value.

DISCUSSION

Though the AEC method of monitoring has been effective in providing monitoring guide lines over a considerable period of time, it has several inherent disadvantages. The method involves conducting a time and motion study on each operation in the plant where the actual monitoring is performed, not on the operator, but on the machine. The monitoring results are then extrapolated to the operator. The actual monitoring is time consuming since the sample collector has to schedule his activities to the convenience of the operation and often has to wait around so he will not miss it. Another disadvantage is that only routine jobs can be monitored, since only on these operations can a time study be made. The maintenance crew, the decontamination crew, and others performing non-routine jobs cannot be monitored by the AEC method. In general, the AEC method is awkward, it is impractical for regulatory use, it does not measure directly the exposure to a worker, and it requires thorough knowledge of the facility which cannot be acquired in a short time.

As opposed to AEC area type monitoring, personal monitoring is a relatively new tool in industrial hygiene and in many respects appears to be an ideal method of evaluating the exposure of the worker. It has the advantage of measuring an individual's exposure over his work day with a single sample. Minimal knowledge of the plant or the process is required and many pumps can be readily put on employees involved in various tasks. These pumps will operate with little attention over a worker's full shift, and several samples can be collected in any one facility on a given day.

There is, however, some resistance to the wearing of these pumps by the worker which may be justifiable where the work involves considerable physical activity. Another disadvantage from a regulatory point of view is that a single sample may not be representative of exposure.

The AEC method on which the present standard is based evidently recognizes the limitation in taking a small number of samples and makes compensations for the uncertainty of a single sample. For example, in this method a minimum of three surveys are taken over a three month period and these results are averaged in arriving at the DWA. Also when a AEC method Breathing Zone sample exceeds the value of 100 $\mu gBe/m^3$, the operation must be resurveyed within ten days to confirm or refute the original sample result. If the second monitoring results agree with the first, only then is the operation shut down and modifications made to bring the process under control.

In summary, it is apparent that both the personal and the AEC methods of sampling have advantages as well as disadvantages. It is, however, only logical and necessary, that both the industry and the regulatory agencies employ the same method of sampling, and that standards be established for the method to be used.

CONCLUSIONS AND RECOMMENDATIONS

Statistical analysis of the comparative sampling data collected under contract shows that the three types of sampling methods tested do not yield the same numerical results for measuring exposures to airborne beryllium in the same environment. In general, for the same environment, personal total sampling gives higher values than AEC-DWA sampling which in turn gives higher values than personal respirable sampling. Not only do personal methods give results different than the AEC method, but probably no hard and fast factors can be found which could be used under all circumstances to convert other sampling results into a comparable AEC result.

Since the AEC method is not a practical method for monitoring a beryllium facility for regulatory purposes, it is desirable to use a personal sampling method.

It is of interest to compare the results obtained from the two personal sampling methods with the current standard of 2 $\mu gBe/m^3$ as determined by the AEC method. Regression analysis of data collected in this study indicates that for a large number of samples a respirable sample value of 1.0 $\mu gBe/m^3$ and a total sample value of 3.0 $\mu gBe/m^3$ are approximately equivalent to an AEC value of 2.0 $\mu gBe/m^3$. It must be recognized, however, that the large variability involved in these data could make prediction based on single samples or a small number of samples highly misleading.

Regardless of what values are used as standards or substitute standards, particular emphasis should be given to the fact that both the industry and OSHA should use the same monitoring method when sampling an environment for airborne beryllium.

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4. NIOSH, Sampling Data Sheet #3.01, Manual of Sampling Data Sheets, March 1974.
5. NIOSH, Criteria for a recommended standard - Occupational Exposure to Crystalline Silica, p. 102, HEW Publication No. (NIOSH) 75-120.
6. Federal Register, OSHA Occupational Safety and Health Standards, p. 23545, June 27, 1974.
7. American Conference of Industrial Hygienists, Documentation of the threshold limit values, 3rd Edition 1971, p. 24.

APPENDIX

Table 1

Areas and Operations in
Beryllium Production Facility

Area 1: Powder Metal Products

Billet Picking and Chipping Lathe
Sintering Furnace Operation
Sintering Machining Operation
Attrition Mill Operator
Miscellaneous Powder Materials (Reports 1-9 only)
Vacuum Cast Furnace Operation
Cold Press Operator (Reports 10-17 only)

Area 2: Extraction Oxide

Hydroxide Operator
Sulfate Mill Operation
Fluoride Furnace Operation
Reduction Furnace Operation
Beryl Furnace
Melts Crusher thru Pebble Inspection
Evaporator Operator
Be Metal Wet Plant Treater Operation

Area 3: Ceramics

Machine Operation
Press Operation

Area 4: Alloy

Ajax Furnace Operator
Arc Furnace Charge Man
Arc Furnace Crew Chief

Area 5: Maintenance

Furnace Rebuild Operation.

Table 2

Listing of Air Sampling Reports Received
From Beryllium Production Facility

Report Number	Period
1	March 1974
2	April No. 1 1974
3	April No. 2 1974
4	May 1974
5	June No. 1 1974
6	June No. 2 1974
7	July 1974
8	September No. 1 1974
9	September No. 2 1974
10	October 1974
11	November No. 1 1974
12	November No. 2 1974
13	December 1974
14	January No. 1 1975
15	January No. 2 1975
16	February 1975
17	March No. 1 1975
18	March No. 2 1975

Table 3

Arithmetic Means* by Report, Area and Sample Type from data collected in a Beryllium Production Facility

Report Number

Area	Sample Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Personal Total	2.53	3.28	2.6	2.55	3.68	5.15	2.76	12.4	3.8	3.52	4.62	2.4	7.97	3.7	22.2	2.3	5.32	3.08
	Personal Resp	.54	.47	.42	.42	1.68	.57	.68	1.04	.63	1.05	.53	.85	1.60	.85	3.45	1.02	1.8	.75
	AEC DWA	.9	1.5	1.7	2.08	1.2	1.4	.62	.68	.77	1.03	.80	2.1	5.5	1.8	2.0	1.14	1.5	.73
2	Personal Total	2.06	2.79	3.64	2.45	2.68	3.5	3.36	2.59	1.61	2.75	1.62	3.3	1.95	1.81	3.25	1.9	4.39	1.74
	Personal Resp	.41	1.1	2.3	1.0	.99	.59	1.8	2.36	.96	1.96	1.11	2.1	1.30	1.13	1.78	1.83	1.7	.8
	AEC DWA	2.2	1.9	2.0	1.8	1.09	3.3	1.7	1.0	1.2	3.4	.84	1.6	1.9	2.2	1.9	.68	1.7	1.3
3	Personal Total	.85	2.1	2.9	.9	.8	1.7	.7	2.45	.75	.2	.4	.6	1.35	1.85	1.4	9.65	.9	.8
	Personal Resp	.1	.5	4.2	.4	.3	1.3	.2	1.15	.55	.1	.35	.85	.30	.55	.9	.9	.35	.15
	AEC DWA	1.7	.8	.4	.75	.75	.8	.2	.7	.75	.25	.35	.45	1.1	2.3	3.0	3.4	.3	.5
4	Personal Total	8.2	6.6	12.9	12.43	5.03	4.1	4.47	4.0	2.9	3.37	2.37	1.53	1.63	.87	1.9	3.37	6.07	10.0
	Personal Resp	2.6	.7	.37	.8	.97	.6	1.14	1.00	.27	.47	1.63	.77	5.4	3.0	2.07	1.2	2.8	2.63
	AEC DWA	7.3	1.2	4.0	4.9	4.6	1.4	2.0	1.6	1.3	1.2	1.5	1.06	1.2	1.7	6.0	2.6	7.5	1.7
5	Personal Total	1.3	4.0	2.4	9.4	1.9	.9	4.4	2.1	31.9	153.3	1.5	3.8	4.1	3.1	3.8	1.3	3.4	.6
	Personal Resp	.3	.3	1.1	.9	.2	.1	1.1	1.4	10.2	42.0	.2	.7	1.0	.9	1.5	.7	.9	1.1
	AEC DWA	.7	1.0	1.7	21.7	3.3	1.2	6.9	3.8	1.2	285.4	.7	.8	8.8	1.7	2.8	1.0	2.3	.3
All	Personal Total	2.98	3.75	4.88	5.54	2.81	3.07	3.13	4.70	8.19	32.62	2.50	2.32	3.40	2.26	6.51	3.70	4.01	3.24
	Personal Resp	.79	.61	1.67	.70	.82	.63	.98	1.39	2.52	9.11	.89	1.05	1.92	1.28	1.94	1.13	1.51	1.08
	AEC DWA	2.56	1.28	1.96	6.24	2.18	1.62	2.28	1.55	1.04	58.25	.87	1.20	3.7	1.94	3.14	1.76	2.66	.90

*Units are in $\mu g/m^3$

Table 4

Arithmetic Means, Standard

Deviations and Number of Samples
of Data collected in a Beryllium Production Facility

Area	Type of Sample	Mean*	Standard* Deviation	Number of Samples
Area 1	Personal Total	5.20	10.73	105
	Personal Resp	1.02	1.63	105
	AEC DWA	1.55	1.97	105
Area 2	Personal Total	2.63	1.88	144
	Personal Resp	1.40	1.26	144
	AEC DWA	1.75	2.16	144
Area 3	Personal Total	1.69	3.06	36
	Personal Resp	.75	1.36	36
	AEC DWA	1.03	1.43	36
Area 4	Personal Total	5.09	6.75	54
	Personal Resp	1.58	1.90	54
	AEC DWA	2.93	3.44	54
Area 5	Personal Total	12.96	35.74	18
	Personal Resp	3.59	9.85	18
	AEC DWA	19.18	66.63	18
Overall	Personal Total	4.18	10.47	357
	Personal Resp	1.36	2.66	357
	AEC DWA	2.68	15.22	357

*Units are in $\mu g/m^3$

Table 5

Logarithmic Means and Standard Deviations from Data Collected in a Beryllium Production Facility

Area	Type of Sample	Logrithmic Mean*	Antilog of Mean*	Logrithmic Standard Deviation*
Area 1	Personal Total	.472	2.96	.376
	Personal Resp	-.193	.64	.398
	AEC DWA	.008	1.02	.368
Area 2	Personal Total	.323	2.10	.294
	Personal Resp	-.034	.92	.445
	AEC DWA	.069	1.17	.356
Area 3	Personal Total	-.008	.98	.407
	Personal Resp	-.387	.41	.429
	AEC DWA	-.197	.64	.377
Area 4	Personal Total	.469	2.94	.446
	Personal Resp	-.034	.92	.437
	AEC DWA	.275	1.88	.390
Area 5	Personal Total	.546	3.52	.564
	Personal Resp	-.045	.90	.606
	AEC DWA	.398	2.50	.683
Overall	Personal Total	.367	2.33	.398
	Personal Resp	-.117	.76	.451
	AEC DWA	.072	1.18	.412

*Units are in $\mu g/m^3$

Table 6

Comparison of Differences Between

Pairs of Logarithmic Means from Data Collected in a Beryllium Production Facility

Area	Personal Total vs Personal Resp	Personal Total vs AEC DWA	Personal Resp vs AEC DWA	Simultaneous p value
Area 1	Yes	Yes	Yes	$p < .01$
Area 2	Yes	Yes	Yes	$p < .05$
Area 3	Yes	No	No	$p < .05$
Area 4	Yes	Yes	Yes	$p < .05$
Area 5	Yes	No	No	$p < .05$
Overall	Yes	Yes	Yes	$p < .01$

Table 7

Regression Analysis of Sampling Data
from a Beryllium Production Facility

	Personal Respirable w/AEC Method	Personal Total w/AEC Method
Correlation Coefficient	.33	.49
Linear Least Squares Regression Equation	y - .14253+.35602x	y = .33236+.47712x
F value for Regression (1 and 355 df)	42.0	114.3
Standard Error of the Estimate	.42681	.34676
Predicted Value*for AEC DWA = 2 $\mu g/m^3$	.92	2.99
Approximate 95% Confidence Interval for Mean Predicted Value*	.83 to 1.02	2.75 to 3.25
Approximate 95% Confidence Interval for a Single Predicted Value*	.13 to 6.33	.63 to 14.31

*Units are in ug/m^3

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