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Beryllium Sampling Methods

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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 indicated that, in general, the three methods yielded different results for samples taken in the same environment. Under NIOSH contract a beryllium production facility was sampled in 1974 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 observations made in the 1973 study that samples collected by the three methods produced different results. No reliable relationship was found to exist which would permit conversion of the result obtained by one method to a result obtained by either of the alternate methods. It appears that, in general, for large numbers of samples taken under the same sampling conditions, the values determined by the personal respirable sampling method will be lower than those obtained by the AEC method and the values determined by the personal total sampling method will be greater.

Beryllium sampling methods

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introduction

In 1973 the National Institute for Occupational Safety and Health (NIOSH) conducted an industry wide environmental study of beryllium production facilities employing simultaneous monitoring of airborne beryllium using three different sampling methods.[1] The methods used were:

1. Personal total sampling designed to collect a sample of the airborne dust which the worker breathes.[2] This was accomplished by a pump worn on the worker's belt which operates at 2 Lpm and which draws air through a 37 mm mixed cellulose ester filter attached to his collar;
2. Atomic Energy Commission (AEC) designed to collect intermittent area and breathing zone samples with a Hi-Vol pump on a cellulose filter;[3,4]
3. Personal respirable sampling designed to collect only that dust which may reach the lungs.[5] This was accomplished by attaching a 10 mm nylon cyclone upstream from a 37 mm, 0.8 μm pore size mixed cellulose ester filter in a plastic cassette worn on the worker's lapel over his full work day.

Chemical analysis of the samples collected by the three methods indicated that the amount of airborne beryllium exposure found for each operation in the plant differed with the sampling method used. Sample results obtained from the personal total sampling method (method 1) which is currently used by OSHA for compliance purposes were highest. Results from the AEC method (method 2) which was introduced by the Atomic Energy Commission and is still used by the beryllium industry were lower than method 1 but higher than method 3. The personal respirable method (method 3) produced the lowest sampling values.[1]

In order to further validate these observations, a comparative sampling effort was initiated in 1974 through a NIOSH contract with the management of a beryllium production facility. The information in this report deals with this comparative study.

Under this contract, in 1974, the industry's industrial hygiene staff using the three sampling methods indicated above sampled 21 plant operations which covered five different types of manufacturing areas. This was repeated 18 times over a period of one year. These areas are listed in Table I.

sampling methods

In this study, three different types of samples were collected by the following methods: (1) personal total, (2) AEC and (3) personal respirable. The personal samples were collected by having each operator wear two personal pumps with the two filter cassettes fastened to his shirt collar. The AEC samples were collected on the same day and in the same locations where the worker wearing the personal pumps was stationed. In this way a comparison of a worker's exposure by the three sampling methods was obtained. The sampling methods are described in detail below.

1. The personal total sample method is designed to collect all particle sizes of dust in the air to which the worker is exposed. Total samples were collected

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

TABLE I

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

Note: Areas 1 and 2 are in the same building and are for all practical purposes inseparable. The other areas are each in a separate building.

directly on a 37 mm, 0.8 μm pore size mixed cellulose ester filter in a plastic cassette worn on the lapel. A pump on the worker's belt was used to pull the air through the filter at a flow rate of 2 Lpm. By analyzing the sample and knowing the air flow pulled through the filter, an estimate of the worker's time weighted average exposure to airborne beryllium was obtained.

2. The AEC method is a general method in use for collecting samples of airborne contaminants in industrial environments.[3,4] Both general area and breathing zone samples were collected at a flow rate of 0.25 m^3/min. with a Hi-Vol pump equipped with a 10.16 cm Whatman no. 41 filter paper. The sample results in micrograms of beryllium per cubic meter along with a time study of a worker's 8-hour shift permit the calculation of a worker's daily time weighted average exposure. For example, a furnace operator spends 15 minutes loading a furnace four times a day. A breathing zone sample result shows exposure to be 10 μg Be/m^3 for 15 minutes, and assuming that the concentration is the same for each furnace loading period, he is exposed to 10 μg Be/m^3 for one hour of his working day. He spends the remaining seven hours in the area of the furnace where a general area sample is collected for about one hour and indicates an exposure of 1 μg Be/m^3. It is assumed that the general area exposure is representative of exposures during the remaining seven hours. If the general area exposure for seven hours is 1 μ Be/m^3, and the breathing zone exposure for one hour is 10 μg Be/m^3, the worker's daily time weighted average exposure is calculated to be 2.1 μg Be/m^3.
3. The personal respirable method[5] is designed to collect only that dust (less than 10 micron diameter) which may reach the lungs. This was accomplished by attaching a 10 mm nylon cyclone upstream from a 37 mm, 0.8 μm pore size mixed cellulose ester filter in a plastic cassette worn on the worker's lapel over his full work day. This was operated at a flow rate of 1.7 L/min. by a pump worn on the worker's belt. The cyclone separates the non-respirable fraction of the dust which is discarded, allowing only the respirable portion to reach the filter. By analyzing the sample and knowing the air flow pulled through the filter, an estimate of a worker's time weighted average exposure to respirable airborne beryllium was obtained.

analysis of samples

All the samples were analyzed by the contractor using the atomic absorption method.[6] Several Whatman* no. 41 filter paper samples were split, permitting analysis by the NIOSH laboratory and also by the contractor laboratory. Analytical results from both laboratories were essentially the same. NIOSH personnel calibrated all sampling equipment prior to use. 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 the Social Sciences (SPSS) computer programs.[7]

Selected examples of the sampling data are presented in Table II wherein the arithmetic means of the beryllium concentrations by reports, area, and sample type are given. This table brings out some noteworthy points. One is the tendency for an ordering of sample types. That is, the personal total is usually the highest, the personal respirable is usually the lowest, with the AEC-TWA usually in between. Second, looking across time (i.e. report number) there appears to be no consistent trend in the concentrations of any of the sample types. Third, there are instances where concentrations measured by the personal respirable method are higher than their personal total counterparts (i.e. area 3

TABLE II
Selected Examples of Arithmetic Means[A] by Report, Area and Sample Type from Data Collected in a Beryllium Production Facility

Area	Sample Type	Report Number 1	3	6	10	13	16	18
1	Personal Total	2.5	2.6	5.2	3.5	8.0	2.3	3.1
	Personal Resp	.5	.4	.6	1.0	1.6	1.0	.8
	AEC TWA	.9	1.7	1.4	1.0	5.5	1.1	.7
2	Personal Total	2.1	3.6	3.5	2.8	2.0	1.9	1.7
	Personal Resp	.4	2.3	.6	2.0	1.3	1.8	.8
	AEC TWA	2.2	2.0	3.3	3.4	1.9	.7	1.3
3	Personal Total	.8	2.9	1.7	.2	1.4	9.6	.8
	Personal Resp	.1	4.2	1.3	.1	.3	.9	.2
	AEC TWA	1.7	.4	.8	.2	1.1	3.4	.5
4	Personal Total	8.2	12.9	4.1	3.4	1.6	3.4	10.0
	Personal Resp	2.6	.4	.6	.5	5.4	1.2	2.6
	AEC TWA	7.3	4.0	1.4	1.2	1.2	2.6	1.7
5	Personal Total	1.3	2.4	.9	153.3	4.1	1.3	.6
	Personal Resp	.3	1.1	.1	42.0	1.0	.7	1.1
	AEC TWA	.7	1.7	1.2	285.4	8.8	1.0	.3
All	Personal Total	3.0	4.9	3.1	32.6	3.4	3.7	3.2
	Personal Resp	.8	1.7	.6	9.1	1.9	1.1	1.1
	AEC TWA	2.6	2.0	1.6	58.2	3.7	1.8	.9

[A]Units are in $\mu g/m^3$

report 3, area 4 report 13). This probably 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 sample values they were included in subsequent analyses. A summary of the air sampling results giving the arithmetic means, standard deviations, and number of samples for each area and for the total set is given in Table III.

As would be expected in sampling data of this sort, the levels are skewed toward the higher values such that a logarithmic transformation is appropriate. Table IV gives the mean and standard deviations of the logarithms for each

TABLE III
Arithmetic Means, Standard Deviations and Number of Samples of Data Collected in a Beryllium Production Facility

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

[A]Units are in $\mu g/m^3$

TABLE IV

Means and Standard Deviations of the Logarithms and Geometric Means for Data Collected in a Beryllium Production Facility

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

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

area and for the total data set along with each geometric mean. Comparison of the means of Table III with the geometric means of Table IV shows the effect of the logarithmic transformation. This transformation is required so the data will satisfy the assumptions of normality and homogeneity of variances necessary for the subsequent statistical analysis.

From Table IV it may be seen that the means of the log transformed concentrations follow a consistent ordering. That is, the personal total method is higher than the AEC-TWA 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 V. 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 performed on personal respirable samples with AEC-TWA, and personal total with AEC-TWA, again using the logarithms of the original

TABLE V

Simultaneous Comparison of Differences Between Pairs of Means of Logarithms from Data Collected in a Beryllium Production Facility

Area	Personal Total vs Personal Resp	Personal Total vs AEC TWA	Personal Resp vs AEC TWA	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	$p < .01$

levels. Linear least squares regression lines were fitted to the data, thus allowing the calculation of an estimated personal respirable and personal total sample value for any given AEC-TWA sample value. Of particular interest is the estimated value at an AEC-TWA value of 2 $\mu m\ Be/m^3$. Analysis of the residuals from the linear least squares regression indicated that the linear model was appropriate for the data and that the variances were constant over the range of concentrations analyzed. The results, given in Table VI, indicate the estimated personal respirable value to be .92 $\mu m\ Be/m^3$ with a 95% confidence interval of .13 to 6.33 $\mu g\ Be/m^3$. The estimated personal total value is 2.99 $\mu g\ Be/m^3$ with a 95% confidence interval of .63 to 14.31 $\mu g\ Be/m^3$. The corresponding correlation coefficients of .33 and .49 indicate that approximately 11% and 24% of the variability in the AEC-TWA values may be accounted for by the linear association with the personal respirable and personal total samples respectively. The wide confidence intervals for the estimated values along with the low percentage of variability accounted for by the regression indicate that, based on this data set, accurate estimation of personal respirable and personal total values from AEC-TWA values is not possible.

In summary, statistical analysis of this data set indicates two main points. First, the results of the three sampling methods tested do not give equivalent concentrations when utilized in the same environment. Second, it appears that an accurate conversion from personal samples (total or respirable) to AEC values is not possible.

discussion

Though the AEC method of area monitoring has been effective in providing guidelines for engineering and maintenance improvements for many years, it has several inherent disadvantages when used to measure exposure of personnel. The method involves conducting a time and motion study of each worker's job to determine the amount of time he spends on each operation in the plant where the monitoring is performed. Actually the machine and the areas where the worker spends his time are being monitored and the monitoring results are assigned to the operator. The 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 in these operations can a time study be made. The maintenance crew, the decontamination crew, and others performing non-routine jobs cannot be adequately monitored by the AEC method.

As opposed to the AEC sampling method, the personal total and personal respirable methods are relatively new in industrial hygiene. They consist of a worker's wearing a pump and a sample collection media over his full work shift. This results in the collection of one sample which gives an estimate of his TWA over his full work day. The advantage of these personal monitoring methods is that the worker is being monitored continuously; one disadvantage is that peak exposures (15 minutes or less) probably cannot be monitored. This is due to the low air flow of the personal sampling pump which could result in securing a sample too small for analysis by existing analytical methods. However, since full shift exposures give the best indication of a worker's TWA, a personal sampling method appears to be the most satisfactory monitoring method. All three methods actually have a use in the monitoring of a plant.

conclusions

Statistical analysis of the comparative sampling data 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. With samples collected in the same environment, personal total sampling gives higher values than AEC sampling which in turn gives higher values than personal respirable sampling. Not only

TABLE VI

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 Estimate	.42681	.34676
Estimated Value[A] for AEC TWA = 2 $\mu g/m^3$	.92	2.99
Approximate 95% Confidence Interval for a Single Sample Concentration[A]	.13 to 6.33	.63 to 14.31

[A]Units are in $\mu g/m^3$

do personal methods give results different from the AEC method, but also based on statistical evaluation of data, no significant conversion factor has been found which would establish a reliable relationship for converting personal sampling results into a comparable AEC result or vice versa.

The findings of this study show that different sampling methods produce different numerical results in the same environment. They also emphasize the need for specifying the exact sampling method to be used in measuring compliance to a standard.

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ABIH annual certification examinations . . .

Certification examinations by the American Board of Industrial Hygiene will be held in Houston, TX on May 17 and 18, 1980, at the American Industrial Hygiene Conference, in the Hyatt Regency Hotel's Grand Ballroom. The following examinations will be conducted:

CERTIFIED INDUSTRIAL HYGIENIST — This consists of a two day written examination. The first day is the CORE examination in the basic principles of industrial hygiene practice. The second day consists of examinations in the Comprehensive Practice or in an Aspect of industrial hygiene, e.g., Acoustical, Air Pollution, Chemistry, Engineering and Toxicological. Persons who have completed one part of the examination successfully need take only the other part.

INDUSTRIAL HYGIENIST IN TRAINING — This consists of the CORE examination covering the basic principles of industrial hygiene practice. Qualifications for admission to the above examinations (include a baccalaureate degree in a science closely related to industrial hygiene and industrial hygiene experience varying from five years for a candidate for Certified Industrial Hygienist to one year for Industrial Hygienist in Training. Up to one year credit may be allowed for a completed graduate degree.

INDUSTRIAL HYGIENE TECHNOLOGIST — This consists of a one day written examination covering the principles of various technical aspects of industrial hygiene, e.g., air sampling, laboratory analyses, air monitoring, etc. Qualifications for admission to this examination are a high school diploma and five or more years of experience involving at least 25% of the time in industrial hygiene activities during each year. The Board may accept alternative education - experience requirements for persons having an associated degree or who have completed two years in an accredited college.

application deadline

All new applications, requests for reexamination and Industrial Hygienists in Training applying for examination in the Comprehensive Practice or an Aspect of industrial hygiene must notify the Board by March 1, 1980, and meet other requirements specified in the May 1, 1978, revised Bulletin of regulations.

Specific information about eligibility requirements, the examinations and application forms may be obtained from the American Board of Industrial Hygiene, Administrative Office, 475 Wolf Ledges Parkway, Akron, OH 44311, (216) 762-7707.