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ANALYSIS OF BERYLLIUM AND DEPLETED URANIUM: AN OVERVIEW OF DETECTION METHODS IN AEROSOLS AND SOILS

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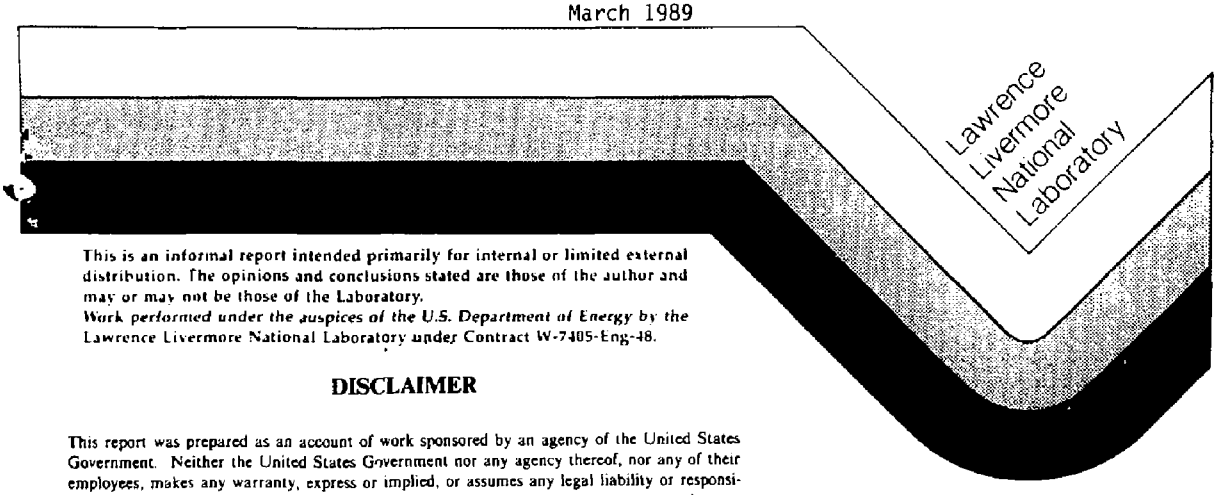
March 1989



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Abstract

We conducted a survey of commercially available methods for analysis of beryllium and depleted uranium in aerosols and soils to find a reliable, cost-effective, and sufficiently precise method for researchers involved in environmental testing at the Yuma Proving Ground, Yuma, Arizona. Criteria used for evaluation include cost, method of analysis, specificity, sensitivity, reproducibility, applicability, and commercial availability. We found that atomic absorption spectrometry with graphite furnace meets these criteria for testing samples for beryllium. We found that this method can also be used to test samples for depleted uranium. However, atomic absorption with graphite furnace is not as sensitive a measurement method for depleted uranium as it is for beryllium, so we recommend that quality control of depleted uranium analysis be maintained by testing 10 of every 1000 samples by neutron activation analysis. We also evaluated 45 companies and institutions that provide analyses of beryllium and depleted uranium.

Introduction

This report on procedures for detecting beryllium (Be) and depleted uranium (DU) in air and soil samples is intended for the researchers involved in environmental testing at the Yuma Proving Ground, Yuma, Arizona. In this report, we address methods and procedures for the quantitative analysis of Be and DU in air and soil samples. We have chosen these methods based on criteria of cost, method of analysis, specificity, sensitivity, reproducibility, and applicability. In Appendix A, we present our evaluation of 9 methods for quantitative analysis of Be and 10 methods for evaluation of DU. Appendix B contains the results of a survey of 45 companies and institutions that conduct some of these tests. The companies and institutions were evaluated on the the basis of cost, AIHA certification, method of analysis, turnaround time for 150 samples, sensitivity, and the ability to measure with precision 0.05 mg Be and 0.25 mg DU.

Methods of Air Sampling

There are four methods of collecting particles of Be and DU from air samples: (1) electrostatic precipitation, (2) dissolution in impinger solutions, (3) collection of settled dust particles in glass jars covered with 200-mesh U.S. standard series screens, and (4) high-volume air filtration. Both the National Institute of Occupational Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) recommend high-volume air filtration (SKC, 1986). "Its advantages include simplicity, low cost, versatility, and the fact that the quantity of collected material usually can be measured without removing it from the paper" (Schulte, 1976). Particles are collected by high-volume air samplers equipped with a cellulose-fiber, cellulose-ester, or fiberglass filter. The choice of filter depends on the sample, method of quantitative analysis, sensitivity limits, volume of air drawn, rate of air flow, and sampling duration. Cellulose-ester filters designated FLT 225-5 are recommended by NIOSH for collecting both Be and DU particles; FLT 225-9 is also recommended for Be particle collection (see Table 1).

Table 1. Filters recommended by NIOSH (from SKC, 1986).

Filter type	Analyte	Analysis method	Sensitivity	Volume (L)	Rate (mL/min)	Time (h)
FLT 225-5 mixed cellulose-ester, 37 mm diameter, 0.8 mm pore size	Be	Inductively coupled plasma excitation atomic emission spectrometry	0.002 mg/m^3	1200	2500	8
	Soluble U	Fluorescence	2 mg/m^3	960	2000	8
	Soluble U	Neutron activation	0.05 mg/m^3	960	200	8
FLT 225-9 mixed cellulose-ester, 37 mm diameter, 0.45 mm pore size	Be	Atomic adsorption	2 mg/m^3	90	1500	1

The sampler for high-volume air filtration includes (1) a high-speed, multistage blower for suction, (2) 8-x-10-in. filters to trap the particles, and (3) an orifice plate on the back of the blower for monitoring the rate of air flow. Exact measurement of the flow rate can be obtained using a sampler with a self-regulating flow controller to establish a constant flow rate that is independent of particulate loading on the filter.

Sampling time depends on the needs of each individual study. Most high-volume air samplers operate at a maximum flow of 100 m^3/h (60 cfm). If the concentration of suspended soil particles is 10 μg/m^3 (extremely clean air) and the background levels of Be and DU in the soil are 1 μg/g and 2 μg/g, respectively, we would expect the air samplers to collect 1 x 10^{-3} μg/h of Be and 2 x 10^{-3} μg/h of DU. Assuming a detection precision of 0.05 mg for Be and 0.25 mg for DU, we would operate the air samplers for 50 h to detect Be and 125 h to detect DU. Much more time is needed to collect samples to measure significant variations. Because of the trace amounts of suspended Be and DU to be collected and because air samplers can generally operate for two weeks before maintenance is needed, the samplers should be run at least two weeks to produce enough sample material for analysis of background values. Nevertheless, a longer duration may be desirable if the projected amount of sample material collected during this period is insufficient for the instruments used to detect Be and DU.

We recommend a minimum of two weeks of sampler operation even though the resulting sample may be larger than 10 μg/m^3. We also recommend flow and elapsed-time monitoring during this period. If the detection precision is as assumed above, the samples will have 2.6 times the minimum detectable amount of DU and 6.7 times the minimum detectable amount of Be.

There is, however, at least one disadvantage to a two week sampling period. Single events, such as plumes of elevated Be and DU from explosives tests or from resuspension by a gust of wind blowing over contaminated sites, will have very little effect on a value determined over two weeks. In such cases, some other method should be considered for detecting single-event concentrations.

Methods of Soil Sampling

Soil sampling requires a strategy for obtaining representative samples of deposited Be and DU. This strategy is straightforward; it consists of randomLy taking shallow scoops of surface soil and pooling them. If details about horizontal deposition patterns are required, then the scooping and pooling should be done over a small area (on the order of 1 m^2), but otherwise a larger area should be randomly sampled. After drying, sieving, and mixing the sample, a small aliquot can be removed for analysis. Please note, however, that because background concentrations of Be and DU can be quite variable, it may be difficult to detect the slight changes in the surface soil caused by a particular event.

Methods of Sample Preparation

Many of the quantitative analytical methods for detection of Be and DU require pretreatment of the sample, which includes grinding, fusion, and ashing. Large samples of soil may have to be ground small enough to pass through a 200-mesh sieve. The sample must then be agitated in a mixer mill, and either fused or ashed before it can be quantitatively analyzed.

Fusion is an efficient method for removing refractory contaminants, such as silicates and fluorides, from samples. The decomposition of refractory ores is essential to ensure quantitative results by a spectrographic method. Two common fusion methods are carbonate/tetraborate fusion and potassium fluoride/sodium pyrosulfate fusion. Carbonate/tetraborate fusion yields a complete analysis of the sample including silica. Dehydration and separation of silica should follow. Potassium fluoride/sodium pyrosulfate fusion is excellent for the decomposition of refractory silicates with the elimination of silica and fluorides.

Ashing destroys all organic matter in the sample before ore separation. There are two types of ashing: dry and wet. Dry ashing is recommended only for large soil samples or bone samples. This method must be followed by a concentration procedure to reduce the sample volume and suspend the sample in solution for further analysis. Wet ashing is favored over dry ashing because it reduces the risk of exchanging Be and DU to or from the glaze of containers and it is more adaptable to the simultaneous processing of large numbers of samples. Moreover, because the wet ashing procedure suspends the sample in solution, standardized calibration curves of known concentrations, which are difficult to prepare when analyzing solids, are easily created.

Nitric acid and perchloric acid are two examples of wet ashing reagents. Other strong acids, such as hydrofluoric acid, can be used as well. Nitric acid wet ashing has been proven to provide quantitative recoveries of known activities of ^{7}Be tracer (U.S. Public Health Service, 1966). After nitric acid wet ashing, potassium fluoride/sodium pyrosulfate fusion may be needed to convert all the Be to soluble form; if all Be is already in soluble form, nitric acid wet ashing alone is sufficient before quantitative analysis by spectrographic or chemical methods. Perchloric acid wet ashing is an excellent alternative method to fusion when eliminating refractory oxides in ore samples. The use of perchloric acid, however, requires special safety measures; the perchloric wet ashing method must be contained in specially fabricated perchloric acid fume hoods for proper ventilation.

Wet ashing provides many benefits for sample preparation above those provided by dry ashing; thus, we recommend it before any instrumental analysis of Be or DU.

Methods of Quantitative Analysis

After the sample is pretreated, it is ready for quantitative analysis. There are a variety of methods, chemical treatments, and instruments used for the detection of Be and DU. Atomic absorption (AA) spectrometry, emission spectroscopy with an inductively coupled plasma excitation source (ICP), x-ray fluorimetry (XRF), and neutron activation analysis (NAA) are the most commonly used analytical methods in industry (see Appendix B). These methods can be automated; they are highly specific and extremely sensitive and, thus, yield results that can be more accurately reproduced than those from traditional wet-chemistry methods. We recommend AA spectrometry with graphite furnace for the highly sensitive

analysis of Be air particles and as a quality control method for Be sample testing. We recommend NAA for 10 of every 1000 DU samples as a quality control measure and AA spectrometry with graphite furnace or XRF for the routine analysis of DU samples.

Beryllium Analysis by AA Spectrometry

An exact method of Be analysis from sampling to AA determination has been described by Zdrojewski et al. (1976). This group has quantitatively compared the flame and flameless (graphic furnace) modes of AA for Be detection. They found the Be sensitivity to be better with a graphite furnace than with the flame detector. We cite their method as an example of a total analysis procedure for Be.

The following is a general description of their procedure: (1) an air sample was drawn; (2) a sample was cut from the filter paper; (3) the sample was digested; (4) the digested volume was adjusted; and (5) the sample was either aspirated into the flame or furnace of the spectrometer. Each step of the procedure is described below.

Beryllium Air-Sampling Procedure

Zdrojewski and associates used cellulose, ashless, acid-washed, analytical-grade filters, 203 by 254 mm, without any pretreatment. For these filters, a sample volume of 1000 m^3 or less was used. Glass-fiber filters were also used, but were pretreated with copious amounts of distilled water. (Membrane filters are not recommended for use because of the nonuniformity of the exposed surface area and the resulting nonuniformity of particle collection.) The filters were mounted in a high-volume sampler with a flow rate between 66 m^3/h and 100 m^3/h for a 24-h duration. The total volume of air sampled was the result of the mean flow rate and elapsed time.

Beryllium Sample Preparation

Areal aliquots (discs) were cut from the filters with a metal punch, which was a sharp, circular, stainless steel die. The punch was wiped with tissue between samples to prevent sample contamination. This method provided an accurate replication of sample portions with little contamination. The amount of filter taken for analysis was, by design, 5% of the exposed 8-x-10-in. filter. One or more of the discs were placed in a Teflon beaker; then,1 mL 49% hydrofluoric acid was added dropwise to start dissolution. The solution was warmed gently until almost all the hydrofluoric acid had evaporated. Next, 1 to 2 mL 71% nitric acid was added, and the solution was heated until only a few drops were left. At this point,10 mL distilled water was added, and the solution was brought almost to boiling. The solution was then filtered through a Whatman-41 filter into a glass beaker and later transferred to a 25-mL volumetric flask. The Teflon beaker was rinsed with another 10 mL distilled water and warmed. This aliquot was also transferred into the 25-mL volumetric flask, and the flask was filled to 25 mL with distilled water at 25°C. This final volume was mixed thoroughly and run on the AA spectrometer.

Beryllium AA Furnace Conditions

The furnace operating conditions for Be detection were the following: (1) the monochrometer wavelength was set at 234.8 nm; (2) the purging gas was argon or nitrogen; (3) a sample size of 20 mL was used, and (4) a deuterium-amp background compensator was recommended. Under these conditions, 20 s at 100°C caused thermal decomposition, 20 s at 1100°C caused charring, and 20 s at 2400°C caused atomization. Experiments indicated that the maximum response for Be was an atomization voltage between 9 and 10. The total amount of Be in the sample was determined by comparison to a standardized calibration curve.

Beryllium Calibration Curve

The range of the calibration curve was 0.2 to 1.0 ng of Be in steps of 0.2 ng (0.01 to 0.05 µg/mL for a 20-mL sample). A plot was drawn with the standardized Be concentration in µg/mL on the horizontal axis and the response in arbitrary units on the vertical axis.

Beryllium Blank Test

Blanks of all the acids used were run with the procedural dilutions and extractions; those of distilled water were also run to establish any background contamination. (Blanks with unusually high readings would require purification or change of reagents.) Unexposed filters were digested and run on the spectrometer to standardize the background level of Be and to determine sources of contamination,if any.

Spikes

As an added quality control measure, we also recommend National Bureau of Standards (NBS) standardized samples of preweighed Be to be placed on unexposed filters and carried through the entire analysis from digestion to instrumentation.

Calculations of Be Concentrations

For the determination of the unknown Be concentration "X" (µg/mL) in a sample, Zdrojewski et al., subtracted the blank concentration X_2 (µg/L) from the measured value X_1, and the result was multiplied by the dilution factor of 25:

$$X = 25(X_1 - X_2).$$

For determining Be in air from high-volume filters sized 203 mm by 254 mm, the following formula was used:

$$T = \frac{(X_1 - X_2) \times 20.43 \times 25}{V},$$

where
- T = total Be concentration in $\mu g/m^3$ air,
- V = volume of air sampled in m^3,
- X_1 = response,unknown test portion,
- X_2 = response,total blank,
- 25 = dilution factor in mL,
- 20.43 = surface multiplication factor for the total exposed filter surface of 4.159×10^4 mm^2 and an areal sample of 2 x 36 mm discs, or 2036 mm^2.

Beryllium Results

Zdrojewski et al. (1976) found their method for AA with a graphite furnace sufficiently sensitive to measure 0.00005 $\mu g/m^3$. They found the filter blank to be about 0.001 µg/mL to 0.0009 µg/mL because of interference from elements such as Na, Ba, Si, Ca, Zn, K, and Al in the filter. In addition, they observed a relative uniformity between filters of ±10%. Furthermore, their instrumental precision maintained a standard deviation of 0.040 ± 0.0011 µg/mL for 10 repeated measurements of Be standards. The minimum amount of Be they were able to measure was 0.0002 µg/mL in solution and 0.00005 $\mu g/m^3$ in air.

Beryllium Soil Samples

Soil samples of Be should be analyzed in a manner similar to air samples, although large aliquots would have to be dissolved to measure low Be concentrations, which would be difficult and very time consuming.

Depleted Uranium Analysis by Neutron Activation Analysis

For precise, accurate measurements of DU on airborne particles, we recommend NAA, which is commercially available. It should be noted that NAA requires no sample preparation; the filter papers can be analyzed directly. The limitations of this method are that it is costly and that results may be delayed up to six weeks to allow for radioactive decay of the sample. For this reason, we recommend routine analysis by ICP or XRF, with quality control of 10 out of every 1000 samples on NAA. Another suitable technique is AA spectrometry with a graphite furnace, although this technique is not as sensitive to DU as it is to Be.

For the analysis of DU on AA with a graphite furnace, ICP, or XRF, a procedure for sample preparation similar to the one just described for Be should be used, but the operating conditions, as well as the preliminary chemistry for the air filters, will be slightly different to ensure DU specificity.

As an example of a preparation method developed for the analysis of DU, we cite procedures carried out here at Lawrence Livermore National Laboratory. The DU air filters are analyzed in three parts using a preliminary chemistry technique, an anion-exchange separation method, and a uranium-purification step (Garrison, 1988). The preliminary chemistry, anion exchange, and purification are described in more detail below. Again, note that should NAA be used, no sample preparation is necessary because the filters can be analyzed directly.

Depleted Uranium Preliminary Chemistry

The preliminary chemistry for DU begins with tracing the air-sampler filters and ashing them in a furnace at 475°C for at least two days. Ashed samples not already in platinum beakers should be transferred to such beakers using a minimum amount of concentrated nitric acid. After transfer of the sample, more nitric acid is added to give a total volume of 30 mL. Next, 30 mL of hydrofluoric acid is added. The sample is heated to dryness in an acid fume scrubber; then, 30-mL aliquots of both concentrated nitric acid and perchloric acid are added. The solution is heated in the scrubber until the fuming ceases. As much of the residue as possible is dissolved by heating the residue again with 20 mL 8 M nitric acid and a few drops of 30% hydrogen peroxide. Next, a minimal amount of 8 M nitric acid is used to transfer the solution to a 250-mL plastic bottle. Finally, all samples are treated with 0.5 g of sodium nitrite ($NaNO_2$) to adjust the uranium valence to $^{+4}$ for anion exchange, and the samples are set aside for at least four hours before further processing.

Depleted Uranium Anion-Exchange Separation

For the anion-exchange separation step, a large column is loaded with preconditioned 1 x 8, 50 to 100 mesh (Cl^- form) anion-exchange resin to a height of about 24 cm, followed by 1 cm of preconditioned AG1-X8, 100 to 200 mesh (Cl^- form) anion-exchange resin. After the column is conditioned with 50 mL 8 M nitric acid, the sample is filtered through a 934 AH glass-fiber filter paper onto the column. When the liquid is has run through the column, the filter paper is rinsed well with 8 M nitric acid, and the the column reservoir is rinsed twice with 8 M nitric acid. Then, the resin is washed with 50 mL of 8 M nitric acid. At this point, the column is rinsed with concentrated hydrochloric acid and the resin washed with 100 mL hydrochloric acid. The DU is eluted with 80 mL 0.1 M HCl into a 150-mL beaker and evaporated to dryness. Depleted uranium purification is the next step.

Depleted Uranium Purification

The first action in purifying the DU is to dissolve the sample in 1 to 2 mL concentrated HNO_3 with heat and transfer it with water to a 50-mL glass centrifuge tube. Next, 1 mL (5 mg/mL) lanthanum carrier is added to all DU samples (except those derived from soil chemistry). The sample is made alkaline with concentrated NH_4OH. After the sample is heated in an 80°C water bath for at least 5 min, it is centrifuged and the supernatent is discarded. The precipitate is dissolved with a minimum amount of 1 M sulfuric acid and heated in a water bath to facilitate the dissolution. The solution is then diluted to 5 mL with distilled water. All steps after the addition of the lanthanum carrier are repeated twice. After the precipitate is dissolved and diluted to 5 mL a third time, it is diluted to 15 mL with 0.06 M sulfuric acid. Then, a small ion-exchange column is loaded to a height of 2 to 3 cm with preconditioned AG1-X8, 30 to 70 mm/min uranium anion-exchange resin (sulfate ion). This column is conditioned with 10 mL 0.06 M H_2SO_4 and the sample is loaded onto it. After the liquid is run through the column, the column reservoir is rinsed four times with 5 mL 0.06 M H_2SO_4; the reservoir is allowed to drain completely between rinses. Next, the resin is washed with 5 mL concentrated HCl, followed by a wash with 5 mL 6 M HCl, and the DU is eluted into vials with 10 mL 0.1 M HCl. Finally, each vial is labelled, and the contents of the vials are evaporated to dryness under a heat lamp. Samples frequently need to be dissolved in aqua regia and evaporated to dryness again before instrumental analysis.

Method of Analysis

Lawrence Livermore National Laboratory uses emission spectroscopy with inductively coupled plasma/mass spectrometry (ICP/MS) for the detection of DU air particles in solution, but AA with graphite furnace, XRF, or ICP are commercially available and can also be used after this method of preparation.

Depleted Uranium Calculations

The calculations for determining DU concentration should be carried out in the same manner as those set out for Be concentrations, based on the creation of a calibration curve. Blanks and spikes must be used for quality control.

Summary

Zdrojewski et al. (1976) have described an exact method for analyzing Be. By comparing modes of AA spectrometry for Be determination, they determined that the graphite furnace was more sensitive to Be than the flame detector. They found their filter blank to be about 0.001 µg/mL to 0.0009 µg/mL because of interference from elements such as Na, Ba, Si, Ca, Zn, K, and Al. They also found a relative uniformity between filters of ±10%. After reviewing their method, we conclude that it is the most accurate commercially available procedure for the determination of Be. (The soil analysis of Be following the same procedures that were described on the previous pages would require large aliquots of soil, which would be difficult to dissolve and time consuming to analyze.)

At the Lawrence Livermore National Laboratory, DU air filters are prepared for analysis using a preliminary chemistry technique, an anion-exchange separation method, and a uranium purification step. The method of instrumental analysis is ICP/MS, but other instruments such as AA with graphite furnace, XRF, or ICP can be used. However, AA with graphite furnace is not as sensitive to the measurement of DU as it is of Be. Neutron activation analysis, on the other hand, is more sensitive than AA to DU; but the limitations of NAA are that it is both costly and time consuming (results may be delayed up to six weeks to allow for radioactive decay of the sample) and, therefore, it is only recommended as a quality control measure.

Recommendations

We make the following recommendations for measuring and analyzing Be and DU:

- High-volume air samplers with cellulose-ester fiber filters should be used for obtaining samples.
- Atomic absorption with graphite furnace should be used for analyzing Be air particles and soil samples.
- We strongly recommend that depleted uranium samples be analyzed by NAA for quality control on 10 of every 1000 samples analyzed
- Routine analysis of DU can be performed using AA with graphite furnace, ICP, or XRF.
- Standards should be run for calibration curves to establish the concentrations of both Be and DU.
- Blanks and spikes should be analyzed to establish background levels and to ensure instrumental precision.
- If the readings for blanks of acid or blanks of the distilled water with procedural dilution are high, purification is necessary. Unexposed filters should then be digested and run on AA to standardized the background levels of Be,and prevent unnecessary sources of contamination.
- The calculations of Be and DU should be similar to the calculations presented in this report.
- Other methods of instrumental analysis than AA with graphite furnace for Be and NAA for DU should be used if great sensitivity is not needed and background monitoring demonstrates high levels of Be and DU.

Acknowledgments

I thank Mike Angel and Tom Kulp for the opportunity to write this report.

References

Garrison, J., Nuclear Chemistry Department, Lawrence Livermore National Laboratory, Livermore, CA, private communication (1988).

Schulte, H. G., "Radionuclide Surveillance," in Air Pollution: Volume III: Measuring, Monitoring and Surveillance or Air Pollution, A. C. Stern, Ed. (Academic Press, New York, NY, 1976), pp. 413-451.

SKC, Guide to NIOSH/OSHA Air Sampling Standards, (1986).

U.S. Public Health Service, Beryllium: Its Industrial Hygiene Aspects, U.S. Public Health Service, Division of Occupational Health, Toxicology Section (Academic Press, New York, NY, 1966).

Zdrojewski, A., L. Dubois, and N. Quickert, "Reference Method for the Determination of Beryllium in Airborne Particulates, " Sci. Total Environ. 6, 165-173 (1976).

Appendix A. Quantitative Analyses: Comparison and Evaluation

Several analytical methods used to detect Be and DU were reviewed.and evaluated based on the following criteria:

1. Specificity.
2. Sensitivity.
3. Reproducibility.
4. Applicability.

Sources for the information about the methods and an overall evaluation are given in a tabular form on the following pages. (Because most analytical instruments used for the determination of the amount of Be and DU require samples that are in solution, we used the conversion factor 1 μg/mL = 1×10^6 μg/m^3 to convert air concentrations to concentrations in solution in μg/mL.)

Sources of Methods Reviewed

Amiel, S., " Analytical Applications of Delayed Neutron Emission in Fissionable Elements," Anal. Chem. 34, 1683-1692 (1962).

Cheremisinof, P. N., Air Pollution Sampling Analysis Deskbook (Ann Arbor Science, Ann Arbor, MI, 1978).

Dionex, "Dionex Technical Note 10R," Dionex 2000i Ion Chromatography Manual, Dionex, Sunnyvale, CA.

Dulka, K. K., and T. H. Risby, "Ultratrace Metals in Some Environmental Biological Systems," Anal. Chem. 48, 640A-653A (1976).

Maccioli, F. K., and T. H. Risby, Determination of Toxic Metals a nd Metalloids in Ambient Air (The Pennsylvania State University Press, University Park, PA, 1978).

Mallessa, H., Analysis of Airborne Particles by Physical Methods (CRC Press, Palm Beach, FL, 1978).

Myers, W. G., and J. A. White, "Mass Spectrometry and Fission Track Analysis in Nuclear Environmental Measurements," in Proceedings of American Nuclear Society Topical Meeting on Nuclear Methods in Environmental Research, August 23-24 (1971).

Pankartz, D., Aerovironment, Monrovia, CA, private communication (1988).

Russ, P. Nuclear Chemistry Department, Lawrence Livermore National Laboratory, Livermore, CA, private communication.

Sill., C. W., "Determination of Thorium and Uranium Isotopes om Ores and Mill Tailings by Alpha Spectrometry," Anal. Chem. 49, 618-621 (1977).

U.S. Public Health Service, Beryllium: Its Industrial Hygiene Aspects, U.S. Public Health Service, Division of Occupational Health, Toxicology Section (Academic Press, New York, NY, 1966).

Zittel, H. E., and L. B. Dunlap, "Polarographic Determination of Uranium (IV) in Sodium Tripolyphosphate Supporting Electrolyte," Anal. Chem. 34, 1757-1760 (1962).

Table A-1. Evaluation of colorimetry as a method for the quantitative analysis of beryllium (U.S. Public Health Service, 1966).

Specificity	Sensitivity (µg/mL)		Reproducibility	Applicability
Method alone is nonspecific. Method must be used in conjunction with other methods to eliminate interference compounds.	Depends on reagent:		Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal
	0.004	Chrome Azurol S		
	0.1	Aluminon		
	0.04	Eriochrome Cyanine R		
	0.01	Fast Sulfon Black F		
	0.01	8-Hydroxyquinaldine		
	0.05	Alkannin & Naphthazarin		
	0.5	p-Nitrobenzene-azoorcinol		
	0.1	Naphthochrome Green G		
	0.1	2-Phenaxyquinizarin-3,4'-disulfonic acid		
	0.05	Quinizarin-2-Sulfonic acid		
	0.01	Acetylacetone		

Overall Evaluation

The colorimetric method is subjective and therefore results are difficult to reproduce. This method is recommended as an inexpensive qualitative analysis method for Be.

Table A-2. Evaluation of atomic absorption as a method for the quantitative analysis of beryllium (Macciolí and Risby, 1978).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific.	0.003 $\mu g/m^3$ flame (3×10^{-9} µg/mL) 0.007 ng/m^3 graphite furnace (7×10^{-12} µg/mL)	Coefficient of variation is about 0.5 to 2%. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

Atomic absorption spectrometry with flame detector is a very good method to use for the detection of Be. The flame detector is as accurate as the graphite furnace apparatus, but is not as highly sensitive.

Atomic absorption spectrometry with a graphite furnace is an excellent method for the detection of Be. The operation can be fully automated; it is extremely sensitive; Be spectra are highly specific; an operator can easily be trained to maintain the instrument; the analysis is not extremely labor intensive; and there are few interferences.

Table A-3. Evaluation of emission spectroscopy with high-energy excitation source, such as flame, AC arc, DC arc, and AC spark, as a method for the quantitative analysis of beryllium (U.S. Public Health Service, 1966).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific provided an instrument of sufficient dispersion is used.	0.005 $\mu g/m^3$	Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

Emission spectroscopy with high-energy excitation source can be automated; however, the radiation intensities can be difficult to reproduce from one analysis to another and the error ranges from ±10 to ±20%. The method can be optimized with due care to reproducibility and have an error range of only ±1 to 2%.

Table A-4. Evaluation of emission spectroscopy with inductively coupled plasma excitation source (ICP or ICAP) as a method for the quantitative analysis of beryllium (Mallessa, 1978).

Specificity	Sensitivity	Reproducibility	Applicability
Method can give simultaneous information on several elements at one time. However, the plasma zone is highly specific for each element.	0.0005 µg/mL	Reproducibility is excellent, the method can be fully automated. Although solid samples can be measured directly, standardization is difficult for solids; therefore, samples should be in solution. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

The ICP method requires the addition of internal standards, which would be more labor intensive than other methods. This method can be readily automated; it is highly sensitive; it can analyze more than one element at a time, and is, therefore, excellent for multiple analyses.

Table A-5. Evaluation of fluorimetry as a method for the quantitative analysis of beryllium (U.S. Public Health Service, 1966).

Specificity	Sensitivity (µg/mL)		Reproducibility	Applicability
Method alone is nonspecific. Method must be used in conjunction with other methods to eliminate interference compounds.	Depends on reagent:		Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal
	0.0002	Morin		
	0.025	1,4-Dihydroxyanthraquinone		
	0.006	3,8-Hydroxyquinaldine		

Overall Evaluation

There are several compounds that may interfere with Be fluorescence and must be eliminated; this can be a very labor-intensive procedure.

Table A-6. Evaluation of gas-liquid chromatography with electron capture detector as a method for the quantitative analysis of beryllium (Maccioli and Risby, 1978).

Specificity	Sensitivity	Reproducibility	Applicability
Method alone is nonspecific. Method must be used in conjunction with other methods to eliminate interference compounds.	4×10^{-14} g (4×10^{-7} (µg/mL)	Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

An excellent method. It is highly sensitive, extremely accurate and can be easily automated. There are interferences that must be chemically eliminated.

Table A-7. Evaluation of gravimetric precipitation as a method for the quantitative analysis of beryllium (U.S. Public Health Service, 1966).

Specificity	Sensitivity	Reproducibility	Applicability
Method alone is nonspecific. Method must be used in conjunction with other methods to eliminate interference compounds.	1 to 5 (µg/mL)	Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Ores and alloys

Overall Evaluation

The results are often difficult to reproduce when using gravimetric methods and working with trace quantities. Losses occur due to occlusion, adsorption, and coprecipitation. This method is not recommended by itself; it must be coupled with other methods and carefully tested before any routine use.

Table A-8. Evaluation of ion chromatography (IC) as a method for the quantitative analysis of beryllium (Dionex, 1983).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific. However, it must be combined with a postcolumn derivatization and subsequent flow through absorbance detector.	Mid to low parts per billion (ng/mL). Excellent for trace analyses. (1×10^{-3} µg/mL)	Samples must be completely in solution and free of particulates; therefore,precision is dependent upon the performance of the chemistry technique, not the actual analytical method.	Excellent for micro-samples

Overall Evaluation

There are interferences that must be chemically eliminated. Also, some problems exist with the oxidation of Be; this might be eliminated if IC is combined with colorimetry.

Table A-9. Evaluation of x-ray fluorescence as a method for the quantitative analysis of beryllium (Maccioli and Risby, 1978).

Specificity	Sensitivity	Reproducibility	Applicability
Spectra of each elements is highly specific; however, interfering elements can change fluorescent intensity.	7.5 µg/g (assuming 10 mg/m^3 air, then concentration equals 75 µg/mL)	Can eliminate problems associated with interfering compounds by using a monochromatic source for selective excitation. A very time-consuming process.	Solid state

Overall Evaluation

The analysis of Be samples using x-ray fluorescence can be labor intensive, due to the necessary elimination of interference compounds to the Be spectra. A monochromatic source would definitely be needed to reduce the interferences and automate the system.

Table A-10. Evaluation of atomic absorption as a method for the quantitative analysis of depleted uranium (Cheremisinof, 1978).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific.	30 ppm flame (30 µg/mL) 0.09 µg/mL graphite furnace	Wet ashing is required. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

Atomic absorption spectrometry with flame detector is a very good method to use for the detection of DU. The flame detector is as accurate as the graphite furnace apparatus, but is not as highly sensitive.

Atomic absorption spectrometry with a graphite furnace is an excellent method for the detection of DU. The operation can be fully automated; it is extremely sensitive; DU spectra are highly specific; an operator can easily be trained to maintain the instrument; the analysis is not extremely labor intensive; and there are few interferences.

Table A-11. Evaluation of alpha spectrometry as a method for the quantitative analysis of depleted uranium (Sill, 1977).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific. Can be used for the isotopic determination of ^{238}U, ^{235}U, and ^{234}U.	100 µg/mL	Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

Method is extremely expensive and highly skilled professionals are needed to set up apparatus. Recommended only if isotopic ratios are needed, otherwise, a less expensive method is recommended.

Table A-12. Evaluation of delayed neutron emission as a method for the quantitative analysis of depleted uranium (Amiel, 1962).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific. Good method for measuring the isotopic composition of U.	1 µg/mL	Rapid, automated analyses can be performed at the rate of approximately 100 per 8-h day. Needs no professional staff. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

Beryllium can also be a source of neutrons and, therefore, a possible interference compound for the analysis of DU. Thus, this method would not be desirable for a multielement analysis of both Be and DU.

Table A-13. Evaluation of emission spectroscopy with inductively coupled plasma excitation source (ICP or ICAP) as a method for the quantitative analysis of depleted uranium (Mallessa, 1978).

Specificity	Sensitivity	Reproducibility	Applicability
Method can give simultaneous information on several elements at one time. However, the plasma zone is highly specific for each element.	0.03 µg/mL	Reproducibility is excellent, the method can be fully automated. Although solid samples can be measured directly, standardization is difficult for solids; therefore, samples should be in solution. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

The ICP method requires the addition of internal standards, which would be more labor intensive than other methods. This method can be readily automated; it is highly sensitive; it can analyze more than one element at a time, and is, therefore, excellent for multiple analyses.

Table A-14. Evaluation of emission spectroscopy with inductively coupled plasma excitation source and mass spectrometry (ICP/MS) as a method for the quantitative analysis of depleted uranium (Russ, 1988).

Specificity	Sensitivity	Reproducibility	Applicability
Method can give simultaneous information on several elements at one time. However, the plasma zone is highly specific for each element. Mass spectrometry can also fingerprint each element.	1 to 10 ppb (0.001 to 0.01 µg/mL)	Reproducibility is about 1 to 2%. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

The ICP method requires the addition of internal standards, which would be more labor intensive than other methods. There are also limitations in the upper concentration that can be measured, approximately 1 ppm is the limit. This method can be readily automated; it is highly sensitive; it can analyze more than one element at a time, and is, therefore, excellent for multiple analyses.

Table A-15. Evaluation of mass spectrometry (MS) with fission track analysis as a method for the quantitative analysis of depleted uranium (Myers and White, 1971).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific. MS provides isotopic ratios of U present. time. However, the plasma zone is highly specific for each element. Mass spectrometry can also fingerprint each element.	0.03 ng/m^3 (lowest reported) approximately 3×10^{-11} µg/mL	Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

MS with fission track analysis is an excellent method for the detection of DU in airborne particulate matter; however, the instrumentation is expensive and it requires highly skilled operators.

Table A-16. Evaluation of neutron activation analysis (NAA) as a method for the quantitative analysis of depleted uranium (Pankartz, 1988).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific. It can provide isotopic ratios of U.	2×10^{-10} µg/mL	Accuracy ±4%. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

NAA is an excellent method for the highly sensitive analysis of airborne DU particles. It is, however, an extremely expensive, commercially available technique, and samples can take up to six weeks before results are produced due to the radioactive nature of the analysis.

Table A-17. Evaluation of polarography as a method for the quantitative analysis of depleted uranium (Zittel and Dunlap, 1962).

Specificity	Sensitivity	Reproducibility	Applicability
Method alone is nonspecific. It must be used in conjunction with other methods to eliminate interference compounds. Fe(II) strongly interferes with DU.	100 to 400 µg/mL	Accuracy ±3%. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

There are several compounds that may interfere with DU and must be eliminated; this can be a very labor-intensive procedure.

Table A-18. Evaluation of thermal ionization mass spectrometry as a method for the quantitative analysis of depleted uranium (Russ, 1988).

Specificity	Sensitivity	Reproducibility	Applicability
Method is highly specific. It can provide the minor isotopes of U.	1 to 10 ppb (0.001 to 0.01 µg/mL)	Reproducibility about 0.1%. Precision is dependent upon the performance of the wet chemistry technique, not the actual analytical method.	Universal

Overall Evaluation

Thermal ionization MS is an excellent method for the detection of DU. The operation can be fully automated; it is extremely sensitive; DU spectra are highly specific; and there are few interferences. However, sample preparation can be quite labor intensive.

Table A-19. Evaluation of x-ray fluorescence as a method for the quantitative analysis of beryllium (Dulka and Risby, 1978).

Specificity	Sensitivity	Reproducibility	Applicability
Method alone is nonspecific. It must be used in conjunction with other methods to eliminate interference compounds. Fe(II) strongly interferes with DU.	0.002 µg/mL	Precision is dependent upon the performance of the wet chemistry technique not the actual analytical method.	Universal

Overall Evaluation

The analysis of DU samples using x-ray fluorescence is more sensitive than that of x-ray fluorescence detection of Be; it can, however, be labor intensive, due to the necessary elimination of interference compounds to the DU spectra. A monochromatic source would definitely be needed to reduce the interferences and automate the system.

Appendix B. Criteria for the Selection of Commercial Analysis of Be and DU

As part of our evaluation of analytical methods for the detection of Be and DU, we conducted a survey of about 50 companies and institutions and used the following criteria to evaluate them:

1. AIHA certification.
2. Turnaround time for 150 samples.
3. Cost per sample.
4. Method of analysis.
5. Sensitivity.
6. Ability to measure with precision 0.05 mg Be and 0.25 mg DU.

Of the companies and other institutions that were surveyed, we recommend the following in ranking order with regard to these criteria:

1. Aerovironment Inc., Monrovia, CA.
2. Nuclear Consulting Service, Columbus, OH.
3. Global Geochemistry, Pasadena, CA.
4. Fireman's Fund, Petaluma, CA.
5. Hazen Laboratories, Golden, CO.
6. Environmental Monitoring and Services Inc., Newberry Park, CA.
7. IT Corporation, Richmond, CA.
8. Radiation Detection Col, Sunnyvale, CA.
9. TMA-Norcal, Richmond, CA.
10. Kennedy/Jenks Engineers, San Francisco, CA.

The following pages provide more information about these companies and about the other companies and institutions surveyed.

Recommended Companies

Table B-1. Aerovironment Inc., Monrovia, CA, a recommended company (contact Dave Pankartz at (818) 357-9983).

Criteria	Comment
AIHA certification	Analysis not done by this company, must subcontract, AIHA certification might be a problem
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for	
150 samples	10 to 20 days
Cost per sample	$20 to 30 for total analysis of sample, $5,000 for 150 samples excluding NAA
Be analysis method	AA with graphite furnace/ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.04 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	XRF or ICP or NAA ($300 to 400/sample, cannot do NAA with Be, results can take up to six weeks)
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.09 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Other	Also able to do Hi-Vol air sampling. Set up equipment and rental approximately 1,500/ year

Table B-2. Nuclear Consulting Service, Columbus, OH, a recommended company (contact Dr. Steve Monlar (614) 846-5710).

Criteria	Comment
AIHA certification	No, company does have a radioisotope license
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	30 days
Cost per sample	$25/sample/element, $50 for total analysis of sample
Be analysis method	AA with graphite furnace
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.04 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	AA with graphite furnace
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.09 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Other	Also able to do Hi-Vol air sampling approximately $275/day or $50/h.

Table B-3. Global Geochemistry, Pasadena, CA, a recommended company (contact Dr. Ian Kaplan (818) 992-4103).

Criteria	Comment
AIHA certification	Analyses not performed by this company, must subcontract, AIHA certification might be a problem
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 to 3 weeks
Cost per sample	$70 to $80 for total analysis of sample
Be analysis method	AA with graphite furnace
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.04 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	ICP or AA with graphite furnace
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.05 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-4. Fireman's Fund, Petaluma, CA, a recommended company (contact Jerry Tuma (707) 778-4173).

Criteria	Comment
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 to 3 weeks
Cost per sample	$70.40/sample total analysis
Be analysis method	AA with graphite furnace
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.04 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.05 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-5. Hazen Laboratories, Golden, CO, a recommended company (contact Bob Rostab (303) 279-4501).

Criteria	Comment
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 weeks
Cost per sample	$25.52/sample total analysis
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.2 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	Fluorimetric
Preliminary preparation	Acid digestion
Specificity	Some interference compounds that need chemical separation
Sensitivity	0.03 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-6. Environmental Monitoring and Services, Inc., Newberry Park, CA, a recommended company (contact Joe Matta (805) 388-5700).

Criteria	Comment
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 weeks
Cost per sample	$41.00/sample total analysis
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.2 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	50 µg/L or 50 ppb (0.05 µg/mL)
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-7. IT Corporation, Cerritos, CA, a recommended company (contact Karen Jozelak (213) 921-9831).

Criteria	Comment
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 weeks
Cost per sample	$46.00/sample total analysis
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.03 µg/L or 0.03 ppb (0.03 µg/mL)
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method.(Wet chemistry method may be less precise than purely instrumental analysis of sample.)
Applicability	Universal
Method of analysis for DU	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	2 mg/L or 2 ppb (2 mg/mL)
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method.
Applicability	Universal
Other	This lab also performs NIOSH proficiency sample tests quarterly

Table B-8. Radiation Detection Company, Sunnyvale, CA, a recommended company (contact lab supervisor (415) 735-8700).

Criteria	Comment
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 to 3 weeks
Cost per sample	$29 to $39 total analysis
Be analysis method	Fluorimetric
Preliminary preparation	Acid digestion
Specificity	Some interference compounds that require chemical separation
Sensitivity	0.05 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	Fluorimetric
Preliminary preparation	not stated
Specificity	Some interference compounds that require chemical separation
Sensitivity	0.25 µg
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-9. TMA-Norcal, Richmond, CA, a recommended company (contact Angela Davi (415) 235-2633).

Criteria	Comment
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 to 3 months
Cost per sample	$153.00/sample for air particles and $186.00/sample for soil (total analysis including preliminary preparation)
Be analysis method	Gel
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.2 pCi/m^3 air particles and 1 pCi/g soil
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	Fluorimetric
Preliminary preparation	Acid digestion
Specificity	Some interference compounds that require chemical separation
Sensitivity	0.5 pCi/g
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-10. Kennedy/Jenks Engineers, San Francisco, CA, a recommended company (contact Leverett Smith (415) 362-6065).

Criteria	Comment
AIHA certification	No, but hazardous waste certified
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 to 3 weeks
Cost per sample	$50.00/sample total analysis
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.05 mg/kg or 0.05 ppb (0.05 µg/mL)
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method. This lab also performs NIOSH proficiency sample tests quarterly.
Applicability	Universal
Method of analysis for DU	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	Not determined
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method. This lab also performs NIOSH proficiency sample tests quarterly.
Applicability	Universal

Other Companies and Institutions

Table B-11. Air Research Board, Riverside, CA, (contact Dr. Anga Bytnerowicz (714) 787-4716).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-12. Acurex Corporation, Mountain View, CA, (contact Claire Furguson (415) 964-3200).

Criteria	Comment
Comment	Can only analyze Be
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be
Turnaround time for 150 samples	2 to 3 weeks
Cost per sample	$15/sample
Be analysis method	ICP or AA
Preliminary preparation	No
Specificity	Highly specific
Sensitivity	0.01 ppm
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method

Table B-13. Battelle, Richland, WA (contact Monty Smith or Ron Brodzinski (509) 375-2121).

Criteria	Comment
Comment	Analyses done on extremely sensitive instruments, however, for routine analyses use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria
AIHA certification	No
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 to 3 weeks
Cost per sample	$5000 for 150 samples
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.01 ppm
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	ICP/MS. Gamma-ray spectrometry, Mass spectrometry, Laser Fluorimetry
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	1 ppb or 1 ppt
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-14. Brown and Coldwell, Emeryville, CA, (contact Barbara Danielson (415) 428-2300).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-15. Cal Analytical Labs, Sacramento, CA (contact Keri Freeman (916) 372-1393).

Criteria	Comment
Comment	Can only analyze Be
AIHA certification	No
Measurement precision	More precise than 0.05 mg Be
Turnaround time for	
150 samples	3 to 4 weeks
Cost per sample	$14/sample total analysis
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.01 ppm
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-16. Chem West, Sacramento, CA (contact Margi Namba (916) 923-0840).

Criteria	Comment
Comment	Can only analyze Be soil samples
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be
Turnaround time for	
150 samples	2 to 3 weeks
Cost per sample	$55/sample
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.01 ppm
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-17. Clayton Laboratories, Pleasanton, CA (contact Mary Beck (916) 923-0840).

Criteria	Comment
Comment	Can only analyze Be
AtHA certification	Yes
Measurement precision	More precise than 0.05 mg Be
Turnaround time for 150 samples	2 to 3 weeks
Cost per sample	$18/metal/sample for air, $24/metal sample + sample preparation $25. For 150 samples, there is a 10%reduction in price; therefore, approximately $44.10 for total analysis
Be analysis method	ICP or AA
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.05 ppm
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-18. J.M. Cohen and Company, Mountain View, CA (contact Tim Borman (415) 349-9737).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-19. Curtis and Tomkins, San Francisco,CA (contact Debbie Howard (415) 861-1863).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-20. Dames and Moore, Santa Barbara, CA (contact Bruce Whales (805) 685-4415).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-21. Desert Research Institute, Reno, NV (contact John Watson (702) 972-1676).

Criteria	Comment
Comment	Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria
AIHA certification	No
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	2 to 3 weeks, a couple of months before free to start
Cost per sample	Not determined
Be analysis method	AA
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	50 ng/mL
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	X-ray fluorescence
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	50 ng/cm^2 deposit. (50 x 10^{-3} µg/m^3 if Hi-Vol 8' x 10' filters used)
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-22. Dionex, Sunnyvale, CA (contact Peter Kanesky (408) 737-0700).

Criteria	Comment
Comment	Problems with IC in the detection of Be. Would like to develop a new Be method using IC and willing to give as much technical information as needed. Uranium oxide can easily be run on IC down to 10 ppb with technique they have developed, which uses HPIC CS2 column and 50 mM NH_4SO_4, 50 mM HNO_3 eluent as well as PAR suppressant. For more precise information on IC, call Peter Kanesky.

Table B-23. Ecology and Environment Inc., San Francisco, CA (contact Mike Williams (415) 362-1010).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-24. Ecoserve, Pittsburg, CA (contact Ripley Hunter (415) 439-5766).

Criteria	Comment
Comment	Can only analyze Be. Able to do Hi-Vol air sampling for continuous sampling with quarts/glass of paper filters
AIHA certification	No, but California Air Resources Board certified
Measurement precision	More precise than 0.05 mg Be
Turnaround time for	
150 samples	10 days
Cost per sample	$260/sample for total analysis
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.01 ppm
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-25. Engineering-Science Company, Arcadia, CA (contact Melony Baltezore (213) 445-7560).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-26. Hager Laboratory, San Francisco, CA (contact Maggy (800) 282-1835).

Criteria	Comment
Comment	Can only analyze Be.
AIHA certification	Yes
Measurement precision	More precise than 0.05 mg Be
Turnaround time for	
150 samples	2 to 3 weeks days
Cost per sample	not determined
Be analysis method	MOA
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	0.01 ppm
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-27. Joe Gorman, Ph.D. Associates, Claremont, CA (contact Dr. Gorman (714) 626-6675).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-28. Lawrence Berkeley National Laboratory, Berkeley, CA (contact Jack Leveck (415) 486-4000).

Criteria	Comment
Comment	Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria

Table B-29. Metcalf and Eddy, Palo Alto, CA (contact Russell C. Holt (415) 969-9985).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-30. Oil Well Research, Long Beach, CA (contact Victor Hoff (213) 436-4254).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-31. Parsons Corporation, Pasadena, CA (contact Roy Gaunt (213) 440-2000).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-32. R.I. Corporation, Ogden, UT (contact Richard Hentz (801) 393-8220).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-33. Rockwell International Environmental Monitoring and Services Center, Newberry Park, CA (contact G. Colovos (805) 498-6771).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-34. Salt Lake City Research Center, Salt Lake City, UT (contact Dr. Al Whitehead, Jim Allen, or Bob Davidson (801) 524-5350).

Criteria	Comment
Comment	This group has been extremely helpful. Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria

Table B-35. Sonoma Tech., Santa Rosa, CA (contact Don Blumenthal (805) 498-6771).

Criteria	Comment
Comment	Does not do the work directly, must subcontract; however, might be able to do the air sampling

Table B-36. SRI, Menlo Park, CA (contact Ted Mill (415) 859-3605).

Criteria	Comment
Comment	Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria

Table B-37. Trotter-Yoder and Associates, Lafayette, CA (contact (415) 284-2980).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-38. Truesdail Laboratories, Los Angeles, CA (contact (213) 225-1654).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-39. Ultrachem Corporation, Walnut Creek, CA (contact E.H. Gallagher (415) 935-3115).

Criteria	Comment
Comment	Does not do the work directly, must subcontract

Table B-40. UC Davis, Davis, CA (contact Tom Cahill (916) 752-1460).

Criteria	Comment
Comment	Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria

Table B-41. UCLA, Los Angeles, CA (contact Dr. Romney (213) 825-8776).

Criteria	Comment
Comment	Can analyze Be only. Send all criteria necessary, with 10 to 20 samples in poly v-caps, sealed tightly or glass scintillation vials approximately 20 mL. Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria
AIHA certification	No
Measurement precision	More precise than 0.05 mg Be
Turnaround time for 150 samples	Not determined
Cost per sample	$5/sample
Be analysis method	ICP/EM
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	Not determined
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-42. UC Riverside, Riverside, CA (contact Gordon Bradford (714) 787-5109).

Criteria	Comment
Comment	Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria
AIHA certification	No
Measurement precision	More precise than 0.05 mg Be and 0.25 mg DU
Turnaround time for 150 samples	Less than 3 weeks
Cost per sample	$25/sample
Be analysis method	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	ppb or less
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal
Method of analysis for DU	ICP
Preliminary preparation	Acid digestion
Specificity	Highly specific
Sensitivity	ppm or less
Reproducibility	Precision based on performance of wet chemistry, should send spikes and blanks to test method
Applicability	Universal

Table B-43. US Department of Agriculture Forest Fire Lab, Riverside, CA (contact Dave Hamilton (714) 351-6523).

Criteria	Comment
Comment	Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria

Table B-44. US Department of Agriculture Salinity Laboratory, Riverside, CA (contact Don Saurez (415) 752-1460).

Criteria	Comment
Comment	Can only perform analyses if ambient Be and DU are affecting environment. Analyses done on extremely sensitive instruments, however, for routine analyses, use a commercial laboratory recommended to meet the AIHA certification, rapid turnaround, and cost criteria

Table B-45. Woodward-Clyde Consultants, San Francisco, CA (contact Jim Sarter (415) 434-1955).

Criteria	Comment
Comment	Does not do the work directly, must subcontract