

Measurements Research Branch

Analytical Method

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|---------------|---|-----------------|----------------------------------|
| Analyte: | Trace Metals (Tables 1 and 2) | Method No.: | P&CAM 173 |
| Matrix: | Air | Range: | Varies with analyte (Table 2) |
| Procedure: | Filter collection, acid digestion, AAS | Precision: | 3% RSD (Analytical) |
| Date Issued: | 9/17/73 | | |
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1. Synopsis

This procedure describes a general method for the collection, dissolution and determination of trace metals in industrial and ambient airborne material. The samples are collected on membrane filters and treated with nitric acid to ash the organic matrix and to dissolve the metals present in the sample. The analysis is subsequently made by atomic absorption spectrophotometry (AAS).

Samples and standards are aspirated into the appropriate AAS flame. A source of characteristic radiation energy is necessary for each metal. The absorption of this characteristic energy by the atoms of interest in the flame is related to the concentration of the metal in the aspirated sample. The flames and operating conditions for each element are listed in Table 1.

Metals for which other AAS procedures exist (e.g., Antimony-P&CAM 261 and Lead-S314) should be analyzed using that method.

2. Working Range, Sensitivity, and Detection Limit

The sensitivity, detection limit, and optimum working range for each metal are given in Table 2. The sensitivity is defined as that concentration of a given element which will absorb 1% of the incident radiation (0.0044 absorbance units) when aspirated into the flame. The detection limit is defined as that concentration of a given element which produces a signal equivalent to two times the standard deviation of the blank signal for aqueous solutions. Detection limits and blank values for real samples may be greater than those given in Table 2 since the

blanks resulting from the reagents and the filter material have not been taken into account. The working range for an analytical precision better than 3% is generally defined as those sample concentrations which will absorb greater than 10% of the incident radiation and are in the linear region of the calibration curve. The values for the sensitivity and detection limits are instrument dependent and many vary from instrument to instrument.

3. Interferences

3.1 In atomic absorption spectrophotometry, the occurrence of interferences is less common than in many other analytical determination methods. Interferences can occur, however, and when encountered are corrected for as indicated in the following sections. The known interferences and correction methods for each metal are indicated in Table 1. The methods of standard additions and background monitoring and correction (11.1-11.4) are used to identify the presence of an interference problem. Insofar as possible, the matrix of the samples and standards are matched to minimize the possible interference problems.

3.1.1 Background or non-specific absorption can occur from particles produced in the flame which can scatter the incident radiation causing an apparent absorption signal. Light scattering problems may be encountered when solutions of high salt content are being analyzed. Light scattering problems are most severe when measurements are made at the lower wavelengths (i.e., below about 250 nm). Background absorption may also occur as the result of the formation of various molecular species which can absorb light. The background absorption should be accounted for by the use of background correction techniques (use of D_2 or H_2 continuum or a nearby non-absorbing wavelength)(11.1, 11.6).

3.1.2 Spectral interferences are those interferences which occur as the result of an atom different from that being measured absorbing a portion of the incident radiation. Such interferences are extremely rare in atomic absorption. In some cases, multi-element hollow cathode lamps may cause a spectral interference by having closely adjacent radiation lines from two different elements. In such instances, multi-element hollow cathode lamps should not be used, or the use of more narrow spectral slits or alternate wavelengths may be used to alleviate the problem.

3.1.3 Ionization interferences can occur when easily ionized atoms are being measured. The degree to which such atoms are ionized is dependent upon the atomic concentration and presence of other easily ionized atoms in the sample.

Ionization interferences can be controlled by the addition to the sample of a high concentration of another easily ionized element which will buffer the electron concentration in the flame. Typically, 1000-2000 $\mu\text{g/mL}$ of an alkali metal (K, Na, Cs) salt is added to sample and standard solutions.

- 3.1.4 Chemical interferences occur in atomic absorption spectrophotometry when species present in the sample cause variations in the degree to which atoms are formed in the flame. Such interferences may be corrected for by controlling the sample and standard matrix, by using the method of standard additions, or by use of a higher temperature flame (11.2, 11.6).
- 3.1.5 Physical interferences may result if the physical properties of the samples vary significantly. Changes in viscosity and surface tension can affect the sample aspiration rate and thus cause erroneous results. Sample dilution and/or the method of standard additions are used to correct such interferences. High concentrations of silicates in the sample can cause an interference for many of the elements and may cause aspiration problems. No matter what elements are being measured, if large amounts of silicates are extracted from the samples, the samples should be allowed to stand for several hours and centrifuged to remove the silicates.
- 3.2 This procedure describes a generalized method for sample preparation which is applicable to the majority of samples of interest. There are, however, some relatively rare chemical forms of a few of the elements listed in Table 1 which will not be dissolved by this procedure. If such chemical forms are suspected, results obtained using this procedure should be compared with those obtained using an appropriately altered dissolution procedure. Alternatively, the results may be compared with values obtained utilizing a non-destructive technique which does not require sample dissolution (e.g., x-ray fluorescence, activation analysis).

4. Precision and Accuracy

The relative standard deviation of the analytical measurement is approximately 3% when measurements are made in the ranges listed in Table 2. The overall relative standard deviation will be somewhat larger than this value due to errors associated with the sample collection and preparation steps.

Collaborative testing of this method by 16 laboratories, using filters loaded at three concentration levels in a dynamic aerosol generation and sampling system, indicated that the average per-

cent recoveries and standard deviations for representative metals are: Cd, 100.8 ± 9.9 ; Co, 97.6 ± 13.9 ; Cr, 96.6 ± 10.8 ; Ni, 98.6 ± 10.3 ; and Pb, 98.7 ± 12.2 .

5. Advantages and Disadvantages

The sensitivity is adequate for all metals in air samples provided an adequate volume of air is sampled.

This method has been ruggedized for Be, Cd, Co, Cr, Cu, Mn, Mo, Ni and Pb and collaboratively tested for Cd, Co, Cr, Ni and Pb.

A disadvantage of the method is that approximately 2 mL of solution is necessary for each metal determination. Also, the necessary dilution limits the detection of small quantities of analyte or replicate analysis of several elements per sample.

6. Apparatus

6.1 Sampling Equipment. The sampling unit for the collection of personal air samples has the following components:

6.1.1 The filter unit, consisting of the filter media (6.2) and appropriate cassette filter holder, either a two- or three-piece filter cassette (Millipore Filter Corporation, Bedford, Massachusetts or equivalent).

6.1.2 A personal sampling pump of sufficient capacity to maintain a face velocity of 2.6 cm/sec (1-2 Lpm using a 37-mm filter). This pump must be calibrated so the volume of air sampled can be measured to an accuracy of $\pm 5\%$. The pump must be calibrated with a representative filter unit in the line.

6.1.3 Thermometer.

6.1.4 Manometer.

6.1.5 Stopwatch.

6.1.6 Various clips, tubing, spring connectors and belt for connecting sampling apparatus to worker being sampled.

6.2 Cellulose ester membrane filter, 0.8 μm pore size, 37-mm (Millipore Type AA or equivalent).

Glassware (borosilicate). Before use, all glassware must be cleaned in 1:1 nitric acid and rinsed several times with distilled water.

6.3.1 125-mL Phillips or Griffin beakers with watchglass covers.

15-mL graduated centrifuge tubes.

10-mL volumetric flasks.

100-mL volumetric flasks.

6.3.5 1-L volumetric flasks.

6.3.6 125-mL polyethylene bottles

6.3.7 Additional auxiliary glassware such as pipettes and different size volumetric glassware will be required depending on the elements being determined and the dilutions required to have sample concentrations above the detection limit and in the linear response range (i.e., see Table 2). All pipettes and volumetric flasks required in this procedure should be calibrated class A volumetric glassware.

6.4 Hotplate (suitable for operation at 165°C)

6.5 Steambath or 100°C hotplate.

6.6 Equipment for Analysis

6.6.1 Atomic absorption spectrophotometer with burner heads for air-acetylene and nitrous oxide-acetylene flames.

Hollow cathode or electrodeless discharge lamps for each metal and a continuum lamp (D₂ or H₂).

Two-stage regulators for air, acetylene and nitrous oxide.

6.6.4 Heating tape and rheostat for nitrous oxide regulator (second regulator stage and connecting hose to the instrument should be heated to approximately 60°C to prevent freeze up).

6.7 Supplies

6.7.1 Acetylene gas (cylinder) of a grade specified by the manufacturer of the instrument employed. (Replace cylinder when pressure decreases below 100 psi.)

6.7.2 Nitrous oxide gas (cylinder).

Air supply with a minimum pressure of 40 psi filtered to remove oil and water.

7. Reagents

Purity. ACS analytical reagent grade chemicals or equivalent shall be used in all tests. References to water shall be understood to mean double distilled water or equivalent. Care in selection of reagents and in following the listed precautions is essential if low blank values are to be obtained.

Concentrated nitric acid (68-71%), redistilled, specific gravity 1.42.

7.3 10% nitric acid.

7.4 Standard stock solutions (1000 $\mu\text{g}/\text{mL}$) for each metal in Table 1, commercially prepared or prepared per instrument manufacturer's recommendations.

7.5 Lanthanum nitrate ($\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$).

Cesium nitrate (CsNO_3).

8. Procedure

Cleaning of Equipment

8.1.1 Before initial use, glassware is cleaned with a saturated solution of sodium dichromate in concentrated sulfuric acid (NOTE: Do not use for chromium analysis) and then rinsed thoroughly with warm tap water, concentrated nitric acid, tap water and deionized water, in that order, and then dried.

8.1.2 All glassware is soaked in a mild detergent solution immediately after use to remove any residual grease or chemicals.

8.1.3 For glassware which has previously been subjected to the entire cleaning procedure, it is not necessary to use the chromic acid cleaning solution.

Collection and Shipping of Samples

8.2.1 Ambient atmospheric particulate matter and industrial dusts and fumes are sampled with cellulose membrane filters. Sample flow rate is monitored with a calibrated rotameter (11.5) or the equivalent. The flow rate, ambient temperature and barometric pressure are recorded at the beginning and the end of the sample collection period.

- 8.2.2 For personal sampling, 37-mm diameter filters in holders are used. The personal sampling pumps for this application are operated at 1.5 Lpm. In general, a two-hour sample at 1.5 Lpm will provide enough sample to detect the elements sought at air concentrations of 0.2 x TLV.
- 8.2.3 After sample collection is complete, plug the openings of the cassette and submit the sampling unit to the laboratory. Losses of sample due to overloading (>2 mg) of the filter must be avoided.
- 8.2.4 Filter samples should be sealed in individual plastic filter holders for storage and shipment.
- 8.3 Preparation of Samples
- 8.3.1 The samples and blanks (minimum of one filter blank for every 10 filter samples) are transferred to clean 125-mL Phillips or Griffin beakers and 6.0 mL HNO₃ is added. Each beaker is covered with a watchglass and heated on a hotplate (165°C) in a fume hood until the sample dissolves and a slightly yellow solution is produced. Approximately four hours of heating will be sufficient for most air samples. However, subsequent additions of HNO₃ may be needed to completely ash and destroy high concentrations of organic material and, under these conditions, longer ashing times will be needed. Once the ashing is complete, as indicated by a clear solution in the beaker, the watchglass is removed and rinsed into the sample beaker with 10% HNO₃. The beakers are then placed on a 100°C steambath and allowed to go to dryness.
- 8.3.2 Once a sample is dry, rinse the walls of the beaker with 3-5 mL of 10% HNO₃ and reheat for five minutes at 100°C to solubilize the residue. The solution is quantitatively transferred with 10% HNO₃ to a 10-mL volumetric flask. If any elements are being determined which require the ionization buffer, 0.2 mL of 50 mg/mL Cs is added to the volumetric flask (see Table 1, footnote d). If any elements requiring the releasing agent are being determined, 0.2 mL of 50 mg/mL La is added to each volumetric flask (see Table 1, footnote 3). The samples are then diluted to volume with 10% HNO₃.
- 8.3.3 The 10-mL solution may be analyzed directly for any element of very low concentration in the sample. Aliquots of this solution may then be diluted to an appropriate volume for the other elements of interest present at higher concentrations. (NOTE: Approximately 2 mL of

solution are required for each element being analyzed.) The dilution factor will depend upon the concentration of elements in the sample and the number of elements being determined by this procedure.

Analysis of Samples

- 8.4.1 Set the instrument operating conditions as recommended by the manufacturer. The instrument should be set at the radiation intensity maximum for the wavelength listed in Table 1 for the element being determined.
- 8.4.2 Standard solutions should match the sample matrix as closely as possible and should be run in duplicate. Working standard solutions, prepared fresh daily, are aspirated into the flame and the absorbance recorded. Prepare a calibration graph as described in Section 9.2.3 (NOTE: All combustion products from the AA flame must be removed by direct exhaustion through the use of a good separate flame ventilation system).
- 8.4.3 Blank filters must be carried through the entire procedure each time samples are analyzed.
- 8.4.4 Aspirate the appropriately diluted samples directly into the instrument and record the absorbance for comparison with standards. Should the absorbance be above the calibration range, dilute an appropriate aliquot to 10 mL. Aspirate water between each sample. A mid-range standard must be aspirated with sufficient frequency (i.e., once every five samples) to assure the accuracy of the sample determinations. To the extent possible, all determinations are to be based on replicate analysis.

9. Calibration and Standardization

Ionization and chemical interference suppressants

- 9.1.1 Lanthanum solution (50 mg/mL). Dissolve 156.32 g of lanthanum nitrate ($\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$) in 2% (v/v) HNO_3 . Dilute to volume in a 1-L volumetric flask with 2% (v/v) HNO_3 . When stored in a polyethylene bottle, this solution is stable for at least one year.
- 9.1.2 Cesium solution (50 mg/mL). Dissolve 73.40 g of cesium nitrate (CsNO_3) in distilled water. Dilute to volume in a 1-L volumetric flask with distilled water. When stored in a polyethylene bottle, this solution is stable for at least one year.

- 9.2.1 Dilute standards (100 μg metal/mL). Pipet 10 mL of the stock (1000 μg metal/mL; Section 7.3) into a 100-mL volumetric flask, add 10 mL HNO_3 and dilute to volume with distilled water. Prepare these standards fresh weekly. (NOTE: Silver standards must be stored in amber bottles away from direct light.)
- 9.2.2 Working standards. Working standards for each metal of interest are prepared by dilution of the dilute standards (9.2.1) or the stock standards (7.3) such that the final acid concentration is the same for the samples and standards (i.e., 10% v/v HNO_3 in most cases). Lanthanum or cesium is added to samples and standards as indicated in Table 1 such that the final concentration is 1000 μg La or Cs/mL. Concentrations of the working standards should cover the range for the metal of interest (Table 2). Prepare these solutions fresh daily.
- 9.2.3 The standard solutions are aspirated into the flame and the absorbance (or concentration) recorded. If the instrument used displays transmittance, these values must be converted to absorbance. A calibration curve is prepared by plotting absorbance (units) versus metal concentration. The best fit curve (calculated by linear least square regression analysis) is fitted to the data points. This line or the equation describing the line is used to obtain the metal concentration in the samples being analyzed.
- 9.2.4 To insure that the preparation procedure is being properly followed, clean membrane filters are spiked with known amounts of the elements being determined by adding appropriate amounts of the previously described standards and carried through the entire procedure. The amount of metal is determined and the percent recovery calculated. These tests will provide recovery and precision data for the procedure as it is carried out in the laboratory for the soluble compounds of the elements being determined.
- 9.2.5 Analysis by the method of standard additions. In order to check for interferences, samples are initially and periodically analyzed by the method of standard additions and the results compared to those obtained by the conventional analytical determination. For this method, the sample is divided into three 2-mL aliquots. To one of the aliquots an amount of metal approximately equal to that in the sample is added. To another aliquot twice this amount is added. (NOTE: Additions should be made

by micropipetting techniques such that the volume does not exceed 1% of the original aliquot volume, i.e., 10 L and 20 L additions to a 2-mL aliquot.) The solutions are then analyzed and the absorbance readings are plotted against metal added to the original sample. The line obtained from such a plot is extrapolated to 0 absorbance and the intercept on the concentration axis is taken as the amount of metal in the original sample (11.2). If the result of this determination does not agree to within 10% of the values obtained with the procedure described in Section 9.2.3, an interference is indicated and standard addition techniques should be utilized for sample analysis.

10. Calculations

- 10.1 The corrected volume collected by the filter is calculated by averaging the beginning and ending sample flow rates, converting to cubic meters and multiplying by the sample collection time. The formula for this calculation is:

$$V = \frac{(F_B + F_E)t}{2000}$$

where: V = sample volume (m³)
F_B = sample flow rate at beginning of sample collection (Lpm)
F_E = sample flow rate at end of sample collection (Lpm)
t = sample collection time (minutes)

- 10.2 After any necessary correction for the blank has been made, metal concentrations are calculated by multiplying the micrograms of metal per mL in the sample aliquot by the aliquot volume and dividing by the fraction which the aliquot represents of the total sample and the volume of air collected by the filter:

$$\mu\text{g metal/m}^3 = \frac{(C \times V_A) - B}{v \times F}$$

where: C = concentration (μg metal/mL) in the aliquot
V_A = volume of aliquot (mL)
B = total μg of metal in the blank
F = fraction of total sample in the aliquot used for measurement (dimensionless)
v = volume of air sampled (m³)

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- 11.10 Analytical Data for Elements Determined by Atomic Absorption Spectroscopy, Varian Techtron, Walnut Creek, California, 1971.
- 11.11 Detection Limits for Model AA-5 Atomic Absorption Spectrophotometer, Varian Techtron, Walnut Creek, California, 1971.
- 11.12 Collaborative Testing of NIOSH Atomic Absorption Method, Final Report, NIOSH Contract No. 210-76-0151, HEW, NIOSH, DPSE, October, 1978.

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Table 1. Instrument Parameters

| Element | Type of Flame o = oxidizing r = reducing | Analytical Wavelength (nm) | Interferences ^b | Remedy ^b | References |
|-----------------|---|----------------------------------|--|---------------------|------------|
| Ag | Air-C ₂ H ₂ (o) | 328.1 | IO ₃ ⁻ , WO ₄ ⁻² , Mn ₄ ⁻³ | c | (5) |
| Al ^a | N ₂ O-C ₂ H ₂ (r) | 309.3 | Ionization, SO ₄ ⁻² , V, Fe, HCl, H ₂ SO ₄ | c, d, e | (4, 6) |
| As | Air-C ₂ H ₂ (o) | 193.7 | Background absorption | g | (6) |
| Ba | N ₂ O-C ₂ H ₂ (r) | 553.6 | Ionization, large conc. of Ca | d, f | (1, 4) |
| Be ^a | N ₂ O-C ₂ H ₂ (r) | 234.9 | Al, Si, Mn | e, c, g | (4) |
| Bi | Air-C ₂ H ₂ (o) | 223.1 | | g | |
| Ca | Air-C ₂ H ₂ (r) N ₂ O-C ₂ H ₂ (r) | 422.7 | Ionization and chemical | d, e | (1, 4) |
| Cd | Air-C ₂ H ₂ (o) | 228.8 | | e, g | |
| Co ^a | Air-C ₂ H ₂ (o) | 240.7 | | e, g | |
| Cr ^a | Air-C ₂ H ₂ (r) | 357.9 | Fe, Ni | e, c | (4) |
| Cu | Air-C ₂ H ₂ (o) | 324.8 | | | |
| Fe | Air-C ₂ H ₂ (o) | 248.3 | High Ni conc., Si | c, g | (1, 4) |
| In | Air-C ₂ H ₂ (o) | 303.9 | Al, Mg, Cu, Zn, H _x PO ₄ ^{x-3} | c | (10) |
| K | Air-C ₂ H ₂ (o) | 766.5 | Ionization | d | (1, 4) |
| Li | Air-C ₂ H ₂ (o) | 670.8 | Ionization | d | (11) |
| Mg | Air-C ₂ H ₂ (o) N ₂ O-C ₂ H ₂ (o) | 285.2 | Chemical ionization | e d | (1, 4) |
| Mn | Air-C ₂ H ₂ (o) | 279.5 | | | |
| Mo | N ₂ O-C ₂ H ₂ (r) | 313.5 | Ca and other ions | e, h | (6) |
| Na | Air-C ₂ H ₂ (o) | 589.6 | Ionization | e | (1, 4) |
| Ni | Air-C ₂ H ₂ (o) | 232.0 | | e, g | |
| Pb | Air-C ₂ H ₂ (o) | 217.0 283.3 | Ca, High conc. SO ₄ ⁼ | e, c, g | (7) |
| Pd | Air-C ₂ H ₂ (o) | 247.6 | Al, Co, Ni, Pt, Rh, Ru | e | (6) |
| Rb | Air-C ₂ H ₂ (o) | 780.0 | Ionization | d | (1, 8) |
| Si | N ₂ O-C ₂ H ₂ (r) | 251.6 | Avoided by not using multi-element lamp containing Fe | | |
| Sr | Air-C ₂ H ₂ (r) N ₂ O-C ₂ H ₂ (r) | 460.7 | Ionization and chemical | d, e | (1, 8) |
| Te | Air-C ₂ H ₂ (o) | 241.3 | | g | (6) |
| Tl | Air-C ₂ H ₂ (o) | 276.8 | | | |
| V ^a | N ₂ O-C ₂ H ₂ (r) | 318.4 | | | |
| Zn | Air-C ₂ H ₂ (o) | 213.9 | | g | |

a. Some compounds of these elements will not be dissolved by the procedure described here. When determining these elements one should verify that the types of compounds suspected in the sample will dissolve using this procedure (see Section 3.2).

- b. High concentrations of silicates in the sample can cause an interference for many of the elements in this table and may cause aspiration problems. No matter what elements are being measured, if large amounts of silicates are extracted from the samples, the samples should be allowed to stand for several hours and centrifuged or filtered to remove the silicates.
- c. Samples are periodically analyzed by the method of additions to check for chemical interferences. If interferences are encountered, determinations must be made by the standard additions method or, if the interferent is identified, it may be added to the standards.
- d. Ionization interferences are controlled by bringing all solutions to 1000 g/mL Cs (samples and standards).
- e. 1000 g/mL solution of La as a releasing agent is added to all samples and standards.
- f. In the presence of very large Ca concentrations (greater than 0.1%) a molecular absorption from $\text{Ca}(\text{OH})_2$ may be observed. This interference may be overcome by using background correction when analyzing for Ba.
- g. Use D_2 or H_2 continuum for background correction.
- h. Add 1000 g/mL Al to both standards and samples.
- i. Use alternate Sb line (231.2 nm).

Table 2. Sensitivity Data

| Element | Sensitivity ^a µg/mL | Solution Detection Limits ^a µg/mL | Range ^{a,b} | | Minimum ^{e,f} TLV µg/m ³ |
|---------|-----------------------------------|---|----------------------|-----------------------|---|
| | | | µg/mL | µg/m ³ c,d | |
| Ag | 0.06 | 0.002 | 0.5-4.0 | 21-170 | 10 (metal and soluble compounds) |
| Al | 1.0 | 0.02 | 5-50 | 210-2100 | NL |
| As | 0.8 | 0.2 | 10-50 | 420-2100 | 50 (arsenic trioxide production) 500 (arsenic and compounds as As) |
| Ba | 0.4 | 0.008 | 1-25 | 42-1050 | 500 (soluble compounds) |
| Be | 0.025 | 0.001 | 0.1-2.0 | 4.2-84 | 2 |
| Bi | 0.5 | 0.025 | 1-30 | 42-1250 | NL |
| Ca | 0.08 | 0.005 | 0.1-5.0 | 4.2-210 | 2,000 (CaO) |
| Cd | 0.025 | 0.001 | 0.1-2.0 | 4.2-84 | 50 (metal dust, soluble salts, cadmium oxide fume) |
| Co | 0.15 | 0.01 | 0.5-5.0 | 21-210 | 50 (metal fume and dusts) |
| Cr | 0.1 | 0.003 | 0.5-5.0 | 21-210 | 500 (soluble chromic, chromous salts) 100 (chromic acid and chromate, as CrO ₃) 100 (chromite ore processing, as CrO ₃) |
| Cu | 0.09 | 0.002 | 0.5-5.0 | 21-210 | 1,000 (dusts and mists) 200 (fume) |
| Fe | 0.12 | 0.005 | 0.5-5.0 | 21-210 | 5,000 (iron oxide fume, as iron oxide) 1,000 (soluble compounds) |
| In | 0.7 | 0.02 | 5-50 | 210-2100 | 100 (metal and compounds) |
| K | 0.04 | 0.002 | 0.1-2.0 | 4.2-84 | 2,000 (as KOH) |
| Li | 0.035 | 0.0003 | 0.1-2.0 | 4.2-84 | 25 (as lithium hydride) |

| Element | Sensitivity ^a μg/mL | Solution Detection Limits ^a μg/mL | Range ^{a,b} | | Minimum ^{e,f} TLV μg/m ³ |
|---------|-----------------------------------|---|----------------------|-----------------------|---|
| | | | μg/mL | μg/m ³ c,d | |
| Mg | 0.007 | 0.0001 | 0.05-0.50 | 2.1-21 | 10,000 (as magnesium oxide fume) |
| Mn | 0.055 | 0.002 | 0.5-3.0 | 21-125 | 5,000 (metal and com- pounds) |
| Mo | 0.5 | 0.02 | 15-40 | 625-1650 | 5,000 (soluble, as Mo) 10,000 (insoluble, as Mo) |
| Na | 0.015 | 0.0002 | 0.05-1.0 | 2.1-42 | 2,000 (as NaOH) |
| Ni | 0.15 | 0.005 | 0.5-5.0 | 21-210 | 100 (metal and soluble compounds) |
| Pb | 0.5 | 0.01 | 1-20 | 42-840 | 150 (inorganic compounds, fumes and dusts) |
| Pd | 0.25 | 0.02 | 4-15 | 170-625 | NL |
| Rb | 0.1 | 0.002 | 0.5-5.0 | 21-210 | NL |
| Si | 1.8 | 0.02 | 50-150 | 2100-6300 | 10,000 |
| Sr | 0.12 | 0.002 | 0.5-5.0 | 21-210 | NL |
| Te | 0.5 | 0.03 | 5-25 | 210-1050 | 100 |
| Tl | 0.5 | 0.01 | 5-20 | 210-840 | 100 (soluble compounds) |
| V | 1.7 | 0.04 | 10-150 | 420-6300 | 500 (V ₂ O ₅ dust) 50 (V ₂ O ₅ fume) |
| Zn | 0.018 | 0.001 | 0.1-1.0 | 4.2-42 | 5,000 (ZnO fume) |

- a. Data from "Analytical Methods for Atomic Absorption Spectrophotometry," Perkin-Elmer Corp., Norwalk, Connecticut, 1976.
- b. Data from "Analytical Methods for Flame Spectroscopy," Varian Techtron, Australia, 1972.
- c. The atmospheric concentrations were calculated assuming a collection volume of 0.24 m³ (2 Lpm for two hours) and an analyte volume of 10 mL for the entire sample.
- d. For elements whose TLV is less than the lower limits of the range, a larger sampling volume will be required.
- e. Threshold limit values of airborne contaminants and physical agents with intended changes adopted by ACGIH for 1976. All values listed are expressed as elemental concentrations except as noted.
- f. NL signifies No Limit expressed for this element or its compounds.