



Standard Test Method for Elements in Water by Inductively Coupled Plasma—Mass Spectrometry¹

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1. Scope

1.1 This test method covers the determination of dissolved elements in ground water, surface water, and drinking water. It may also be used for the determination of total-recoverable elements in these waters as well as wastewater.²

1.2 This test method should be used by analysts experienced in the use of inductively coupled plasma—mass spectrometry (ICP-MS), the interpretation of spectral and matrix interferences and procedures for their correction.

1.3 It is the user's responsibility to ensure the validity of the test method for waters of untested matrices.

1.4 Table 1 lists elements for which the test method applies, with recommended masses and typical estimated instrumental detection limits using conventional pneumatic nebulization. Actual working detection limits are sample dependent and, as the sample matrix varies, these detection limits may also vary. In time, other elements may be added as more information becomes available and as required.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:³

- D 1066 Practice for Sampling Steam
- D 1129 Terminology of Terms Relating to Water
- D 1192 Specification for Equipment for Sampling Water and Steam in Closed Conduits
- D 1193 Specification for Reagent Water
- D 3370 Practices for Sampling Water from Closed Conduits

¹ This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.05 on Inorganic Constituents in Water.

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² EPA Test Method: Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma—Mass Spectrometry, Method 200.8.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Recommended Analytical Mass and Estimated Instrument Detection Limits

| Element | Recommended Analytical Mass | Estimated Instrument Detection Limit, µg/L ^A |
|------------|-----------------------------|---|
| Aluminum | 27 | 0.05 |
| Antimony | 121 | 0.08 |
| Arsenic | 75 | 0.9 |
| Barium | 137 | 0.5 |
| Beryllium | 9 | 0.1 |
| Cadmium | 111 | 0.1 |
| Chromium | 52 | 0.07 |
| Cobalt | 59 | 0.03 |
| Copper | 63 | 0.03 |
| Lead | 206, 207, 208 | 0.08 |
| Manganese | 55 | 0.1 |
| Molybdenum | 98 | 0.1 |
| Nickel | 60 | 0.2 |
| Selenium | 82 | 5.0 |
| Silver | 107 | 0.05 |
| Thallium | 205 | 0.09 |
| Thorium | 232 | 0.03 |
| Uranium | 238 | 0.02 |
| Vanadium | 51 | 0.02 |
| Zinc | 66 | 0.2 |

^AInstrument detection limits (3σ) estimated from seven replicate scans of the blank (1 % v/v HNO₃) and three replicate integrations of a multi-element standard.

D 5810 Guide for Spiking into Aqueous Samples

D 5847 Practice for the Writing Quality Control Specifications for Standard Test Methods for Water Analysis

3. Terminology

3.1 *Definitions*—For definitions of other terms used in this test method, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration blank*—a volume of water containing the same acid matrix as the calibration standards (see 11.1).

3.2.2 *calibration stock solution*—a solution prepared from the stock standard solution(s) to verify the instrument response with respect to analyte concentration.

3.2.3 *calibration standards*—a series of known standard solutions used by the analyst for calibration of the instrument (that is, preparation of the analytical curve) (see Section 11).

3.2.4 *dissolved*—those elements that will pass through a 0.45-µm membrane filter.

3.2.5 *instrumental detection limit (IDL)*—the concentration equivalent to a signal, which is equal to three times the standard deviation of the blank signal at the selected analytical mass(es).

3.2.6 *internal standard*—pure analyte(s) added in known amount(s) to a solution. This is used to measure the relative instrument response to the other analytes that are components of the same solution. The internal standards must be analytes that are not a sample component.

3.2.7 *method detection limit (MDL)*—the minimum concentration of an analyte that can be identified, measured and reported with 99 % confidence that the analyte concentration is greater than zero. This confidence level is determined from analysis of a sample in a given matrix containing the analyte(s).

3.2.8 *quality control reference solution (QCS)*—a solution with the certified concentration(s) of the analytes, prepared by an independent laboratory, and used for a verification of the instrument's calibration.

3.2.9 *reagent blank*—a volume of water containing the same matrix as the calibration standards, carried through the entire analytical procedure.

3.2.10 *total-recoverable*—a term relating to forms of each element that are determinable by the digestion method included in this procedure (see 12.2).

3.2.11 *tuning solution*—a solution that is used to determine acceptable instrument performance prior to calibration and sample analysis.

4. Summary of Test Method

4.1 This test method describes the multi-element determination of trace elements by inductively coupled plasma—mass spectrometry (ICP-MS). Sample material in solution is introduced by pneumatic nebulization into a radiofrequency plasma where energy transfer processes cause desolvation, atomization, and ionization. The ions are extracted from the plasma through a differentially pumped vacuum interface and separated on the basis of their mass-to-charge ratio by a quadrupole mass spectrometer. The ions transmitted through the quadrupole are detected by a continuous dynode electron multiplier assembly and the ion information processed by a data handling system. Interferences relating to the technique must be recognized and corrected for (see Section 7 on interferences). Such corrections must include compensation for isobaric elemental interferences and interferences from polyatomic ions derived from the plasma gas, reagents, or sample matrix. Instrumental drift as well as suppressions or enhancements of instrument response caused by the sample matrix must be corrected for by the use of internal standardization.

5. Significance and Use

5.1 The test method is useful for the determination of element concentrations in many natural waters and wastewaters. It has the capability for the determination of up to 20 elements. High analysis sensitivity can be achieved for some elements that are difficult to determine by other techniques.

6. Interferences

6.1 Several types of interference effects may contribute to inaccuracies in the determination of trace elements. These interferences can be summarized as follows:

6.1.1 *Isobaric Elemental Interferences*—Isobaric elemental interferences are caused by isotopes of different elements

TABLE 2 Recommended Analytical Isotopes and Additional Masses That Are Recommended To Be Monitored

| Isotope ^A | Element of Interest |
|--------------------------------------|---------------------|
| <u>27</u> | Aluminum |
| <u>121</u> , 123 | Antimony |
| <u>75</u> | Arsenic |
| 135, <u>137</u> | Barium |
| <u>9</u> | Beryllium |
| 106, 108, <u>111</u> , 114 | Cadmium |
| <u>52</u> , 53 | Chromium |
| <u>59</u> | Cobalt |
| <u>63</u> , 65 | Copper |
| <u>206</u> , <u>207</u> , <u>208</u> | Lead |
| <u>55</u> | Manganese |
| 95, 97, <u>98</u> | Molybdenum |
| 60, 62 | Nickel |
| 77, <u>82</u> | Selenium |
| <u>107</u> , 109 | Silver |
| 203, <u>205</u> | Thallium |
| <u>232</u> | Thorium |
| <u>238</u> | Uranium |
| <u>51</u> | Vanadium |
| 66, 67, 68 | Zinc |
| 83 | Krypton |
| 99 | Ruthenium |
| 105 | Palladium |
| 118 | Tin |

^AIsotopes recommended for analytical determination are underlined. These masses were recommended and are reflected in the precision and bias data. Alternate masses may be used but interferences must be documented.

which form singly or doubly charged ions of the same nominal mass-to-charge ratio and which cannot be resolved by the mass spectrometer in use. All elements determined by this test method have, at a minimum, one isotope free of isobaric elemental interference. Of the analytical isotopes recommended for use with this test method (see Table 2), only molybdenum-98 (ruthenium) and selenium-82 (krypton) have isobaric elemental interferences. If alternative analytical isotopes having higher natural abundance are selected in order to achieve greater sensitivity, an isobaric interference may occur. All data obtained under such conditions must be corrected by measuring the signal from another isotope of the interfering element and subtracting the appropriate signal ratio from the isotope of interest. A record of this correction process should be included with the report of the data. It should be noted that such corrections will only be as accurate as the accuracy of the isotope ratio used in the elemental equation for data calculations. Relevant isotope ratios and instrument bias factors should be established prior to the application of any corrections.

6.1.2 *Abundance Sensitivity*—Abundance sensitivity is a property defining the degree to which the wings of a mass peak contribute to adjacent masses. The abundance sensitivity is affected by ion energy and quadrupole operating pressure. Wing overlap interferences may result when a small ion peak is being measured adjacent to a large one. The potential for these interferences should be recognized and the spectrometer resolution adjusted to minimize them.

6.1.3 *Isobaric Polyatomic Ion Interferences*—Isobaric polyatomic ion interferences are caused by ions consisting of more than one atom that have the same nominal mass-to-charge ratio as the isotope of interest, and which cannot be resolved by the mass spectrometer in use. These ions are commonly formed in

TABLE 3 Common Molecular Ion Interferences

| Background Molecular Ions | | |
|--|------------|-----------------------------------|
| Molecular Ion | Mass | Element Interference ^A |
| NH ⁺ | 15 | ... |
| OH ⁺ | 17 | ... |
| OH ₂ ⁺ | 18 | ... |
| C ₂ ⁺ | 24 | ... |
| CN ⁺ | 26 | ... |
| CO ⁺ | 28 | ... |
| N ₂ ⁺ | 28 | ... |
| N ₂ H ⁺ | 29 | ... |
| NO ⁺ | 30 | ... |
| NOH ⁺ | 31 | ... |
| O ₂ ⁺ | 32 | ... |
| O ₂ H ⁺ | 33 | ... |
| ³⁶ ArH ⁺ | 37 | ... |
| ³⁶ ArH ⁺ | 39 | ... |
| ⁴⁰ ArH ⁺ | 41 | ... |
| CO ₂ ⁺ | 44 | ... |
| CO ₂ H ⁺ | 45 | Sc |
| ArC ⁺ , ArO ⁺ | 52 | Cr |
| ArN ⁺ | 54 | Cr |
| ArNH ⁺ | 55 | Mn |
| ArO ⁺ | 56 | ... |
| ArOH ⁺ | 57 | ... |
| ⁴⁰ Ar ³⁶ Ar ⁺ | 76 | Se |
| ⁴⁰ Ar ³⁸ Ar ⁺ | 78 | Se |
| ⁴⁰ Ar ₂ ⁺ | 80 | Se |
| Matrix Molecular Ions | | |
| Chloride | | |
| ³⁵ ClO ⁺ | 51 | V |
| ³⁵ ClOH ⁺ | 52 | Cr |
| ³⁷ ClO ⁺ | 53 | Cr |
| ³⁷ ClOH ⁺ | 54 | Cr |
| Ar ³⁵ Cl ⁺ | 75 | As |
| Ar ³⁷ Cl ⁺ | 77 | Se |
| Sulphate | | |
| ³² SO ⁺ | 48 | ... |
| ³² SOH ⁺ | 49 | ... |
| ³⁴ SO ⁺ | 50 | V, Cr |
| ³⁴ SOH ⁺ | 51 | V |
| SO ₂ ⁺ , S ₂ ⁺ | 64 | Zn |
| Ar ³² S ⁺ | 72 | ... |
| Ar ³⁴ S ⁺ | 74 | ... |
| Phosphate | | |
| PO ⁺ | 47 | ... |
| POH ⁺ | 48 | ... |
| PO ₂ ⁺ | 63 | Cu |
| ArP ⁺ | 71 | ... |
| Group I, II Metals | | |
| ArNa ⁺ | 63 | Cu |
| ArK ⁺ | 79 | ... |
| ArCa ⁺ | 80 | ... |
| Matrix Oxides ^B | | |
| TiO | 62 to 66 | Ni, Cu, Zn |
| ZrO | 106 to 112 | Ag, Cd |
| MoO | 108 to 116 | Cd |

^AMethod elements or internal standards affected by molecular ions.

^BOxide interferences will normally be very small and will only impact the method elements when present at relatively high concentrations. Some examples of matrix oxides are listed of which the analyst should be aware. It is recommended that Ti and Zr isotopes be monitored if samples are likely to contain high levels of these elements. Mo is monitored as a method analyte.

the plasma or interface system from support gases or sample components. Most of the common interferences have been identified, and these are listed in Table 3 together with the method elements affected. Such interferences must be recognized, and when they cannot be avoided by the selection of an alternative analytical isotope, appropriate corrections must be made to the data. Equations for the correction of data should be established at the time of the analytical run sequence as the

polyatomic ion interferences will be highly dependent on the sample matrix and chosen instrument conditions.

6.1.4 Physical Interferences—Physical interferences are associated with the physical processes that govern the transport of the sample into the plasma, sample conversion processes in the plasma, and the transmission of ions through the plasma—mass spectrometer interface. These interferences may result in differences between instrument responses for the sample and the calibration standards. Physical interferences may occur in the transfer of solution to the nebulizer (for example, viscosity effects), at the point of aerosol formation and transport to the plasma (for example, surface tension), or during excitation and ionization processes within the plasma itself. High levels of dissolved solids in the sample may contribute deposits of material on the extraction, or skimmer cones, or both, reducing the effective diameter of the orifices and, therefore, ion transmission. Dissolved solids levels not exceeding 0.2 % (w/v) have been recommended to reduce such effects. Internal standardization may be effectively used to compensate for many physical interference effects. Internal standards should have similar analytical behavior to the elements being determined.

6.1.5 Memory Interferences—Memory interferences result when isotopes of elements in a previous sample contribute to the signals measured in a new sample. Memory effects can result from sample deposition on the sampler and skimmer cones, and from the buildup of sample material in the plasma torch and spray chamber. The site where these effects occur is dependent on the element and can be minimized by flushing the system with a rinse blank consisting of HNO₃(1+49) in water between samples. The possibility of memory interferences should be recognized within an analytical run and suitable rinse times should be used to reduce them. The rinse times necessary for a particular element should be estimated prior to analysis. This may be achieved by aspirating a standard containing elements corresponding to ten times the upper end of the linear range for a normal sample analysis period, followed by analysis of the rinse blank at designated intervals. The length of time required to reduce analyte signals to within a factor of ten of the method detection limit should be noted. Memory interferences may also be assessed within an analytical run by using a minimum of three replicate integrations for data acquisition. If the integrated signal values drop consecutively, the analyst should be alerted to the possibility of a memory effect, and should examine the analyte concentration in the previous sample to identify if this was high. If a memory interference is suspected, the sample should be re-analyzed after a long rinse period.

7. Apparatus

7.1 Inductively Coupled Plasma–Mass Spectrometer—Instrument capable of scanning the mass range 5 to 250 amu with a minimum resolution capability of 1 amu peak width at 5 % peak height. Instrument may be fitted with a conventional or extended dynamic range detection system. See manufacturers instruction manual for installation and operation.

8. Reagents

8.1 Purity of Reagents—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that reagents shall conform to the specifications of the committee on analytical reagents of the American Chemical Society,⁴ where such specifications are available. The high sensitivity of inductively coupled plasma—mass spectrometry may require reagents of higher purity. Stock standard solutions are prepared from high-purity metals, oxides, or non-hygroscopic reagent grade salts using Type I, II, or III reagent water and ultrapure acids. Other grades may be used provided it is first ascertained that the reagent is of sufficient purity to permit its use without lessening the accuracy of the determination.

8.2 Purity of Water—Unless otherwise indicated, reference to water shall be understood to mean reagent water conforming to ASTM Type I water (Specification D 1193).

8.3 Argon—High purity grade (99.99 %).

8.4 Hydrochloric Acid (sp gr 1.19)—Concentrated hydrochloric acid (HCl), ultrapure or equivalent.

8.5 Hydrochloric Acid (1+1)—Add one volume of hydrochloric acid (sp gr 1.19) to 1 volume of water.

8.6 Nitric Acid (sp gr 1.42)—Concentrated nitric acid (HNO₃), ultrapure or equivalent.

8.7 Nitric Acid (1+1)—Add one volume of nitric acid (sp gr 1.42) to 1 volume of water.

8.8 Nitric Acid (1+49)—Add one volume of nitric acid (sp gr 1.42) to 49 volumes of water.

8.9 Nitric Acid (1+99)—Add one volume of nitric acid (sp gr 1.42) to 99 volumes of water.

8.10 Stock Solutions—Preparation procedures for stock solutions of each element are listed in Table 4.

8.11 Ammonium Hydroxide (sp gr 0.902)—Concentrated ammonium hydroxide (NH₄OH), ultrapure or equivalent.

8.12 Mixed Standard Solutions—Prepare mixed standard solutions by combining appropriate volumes of the stock solutions in volumetric flasks (see Note 1). Prior to preparing mixed standard solutions, each stock solution needs to be analyzed separately to determine possible interferences on the other analytes or the presence of impurities. Care needs to be taken when preparing the mixed standard solutions to ensure that the elements are compatible and stable.

NOTE 1—Mixed calibration standards will vary, depending on the number of elements being determined. Commercially prepared mixed calibration standards of appropriate quality may be used. An example of mixed calibration standards for 20 elements is as follows:

⁴ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

TABLE 4 Preparation of Metal Stock Solutions^A

| Element or Compound | Weight, g | Solvent |
|--|-----------|--|
| Al | 0.1000 | 10 mL of HCl (sp gr 1.19) + 2 mL of HNO ₃ (sp gr 1.42) |
| Sb | 0.1000 | 0.5 mL of HCl (sp gr 1.19) + 2 mL of HNO ₃ (1 + 1) |
| As ₂ O ₃ | 0.1320 | 1 mL of NH ₄ OH (sp gr 0.902) + 50 mL of H ₂ O |
| BaCO ₃ | 0.1437 | 2 mL of HNO ₃ (sp gr 1.42) + 10 mL of H ₂ O |
| BeSO ₄ ·4H ₂ O | 1.9650 | 50 mL of H ₂ O, add 1 mL of HNO ₃ (sp gr 1.42) |
| Bi ₂ O ₃ | 0.1115 | 5 mL of HNO ₃ (sp gr 1.42) |
| Cd | 0.1000 | 5 mL of HNO ₃ (1 + 1) |
| CrO ₃ | 0.1923 | 1 mL of HNO ₃ (sp 1.42) + 10 mL H ₂ O |
| Co | 0.1000 | 5 mL of HNO ₃ (1 + 1) |
| Cu | 0.1000 | 5 mL of HNO ₃ (1 + 1) |
| In | 0.1000 | 10 mL of HNO ₃ (1 + 1) |
| PbNO ₃ | 0.1599 | 5 mL of HNO ₃ (1 + 1) |
| MgO | 0.1658 | 10 mL of HNO ₃ (1 + 1) |
| Mn | 0.1000 | 5 mL of HNO ₃ (1 + 1) |
| MoO ₃ | 0.1500 | 1 mL of NH ₄ OH (sp gr 0.902) + 10 mL of H ₂ O |
| Ni | 0.1000 | 5 mL of HNO ₃ (sp gr 1.42) |
| Sc ₂ O ₃ | 0.1534 | 5 mL of HNO ₃ (1 + 1) |
| SeO ₂ | 0.1405 | 20 mL of H ₂ O |
| Ag | 0.1000 | 5 mL of HNO ₃ (1 + 1) |
| Tb ₄ O ₇ | 0.1176 | 5 mL of HNO ₃ (sp gr 1.42) |
| TiNO ₃ | 0.1303 | 1 mL of HNO ₃ (sp gr 1.42) + 10 mL of H ₂ O |
| Th(NO ₃) ₄ ·4H ₂ O | 0.2380 | 20 mL of H ₂ O |
| UO ₂ (NO ₃) ₂ ·6H ₂ O | 0.2110 | 20 mL of H ₂ O |
| V | 0.1000 | 5 mL of HNO ₃ (1 + 1) |
| Y ₂ O ₃ | 0.1270 | 5 mL of HNO ₃ (1 + 1) |
| Zn | 0.1000 | 5 mL of HNO ₃ (1 + 1) |

^A Metal stock solutions, 1.00 mL = 1000 µg of metal. Dissolve the listed weights of each metal or compound as specified in Table 4, then dilute to 100 mL with water. The metals may require heat to increase rate of dissolution. Commercially available standards may be used. Alternate salts or oxides may also be used.

| Mixed Standard Solution I | | Mixed Standard Solution II |
|---------------------------|------------|----------------------------|
| Aluminum | Manganese | Barium |
| Antimony | Molybdenum | Silver |
| Arsenic | Nickel | |
| Beryllium | Selenium | |
| Cadmium | Thallium | |
| Chromium | Thorium | |
| Cobalt | Uranium | |
| Copper | Vanadium | |
| Lead | Zinc | |

Prepare multi-element mixed standard solutions I and II (1 mL = 10 µg) by pipetting 1.00 mL of each single element stock solution (see Table 4) onto a 100 mL volumetric flask. Add 50 mL of HNO₃(1+99) and dilute to 100 mL with HNO₃(1 + 99).

8.13 Reagent Blank—This solution must contain all the reagents and be the same volume as used in the processing of the samples. Carry reagent blank through the complete procedure. Reagent blank must contain the same acid concentration in the final solution as the sample solution used for analysis.

8.14 Internal Standards—Internal standards are recommended in all analyses to correct for instrument drift and physical interferences. A list of acceptable internal standards is provided in Table 5. For full mass range scans use a minimum of three internal standards with the use of five suggested. Add internal standards to blanks, samples and standards in a like manner. A concentration of 100 µg/L of each internal standard is recommended.

TABLE 5 Internal Standards and Limitations of Use

| Internal Standard | Mass | Possible Limitation |
|-----------------------|------|-----------------------------|
| Lithium | 6 | May be present in samples |
| Scandium ^A | 45 | Polyatomic ion interference |
| Yttrium ^A | 89 | May be present in samples |
| Rhodium | 103 | ... |
| Indium ^A | 115 | Isobaric interference by Sn |
| Tarbitum ^A | 159 | ... |
| Holmium | 165 | ... |
| Lutetium | 175 | ... |
| Bismuth ^A | 209 | May be present in samples |

^AInternal standards recommended for use with this test method. It is also recommended when analyzing a new sample matrix that a scan for the presence of internal standards be performed.

9. Hazards

9.1 The toxicity or carcinogenicity of each reagent used in this test method has not been precisely defined; however, each chemical should be treated as a potential health hazard. Adequate precautions should be taken to minimize exposure of personnel to chemicals used in this test method.

10. Sampling

10.1 Collect the samples in accordance with the applicable standards, Practice D 1066, Specification D 1192, or Practices D 3370.

10.2 Preserve the samples at the time of collection by immediately adding nitric acid (sp gr 1.42) to adjust the pH to 2. Normally, 2 mL of HNO₃(sp gr 1.42) is required per litre of sample. If only dissolved elements are to be determined, filter the sample through a 0.45-μm membrane filter before acidification (see Note 2).

NOTE 2—Depending on the manufacturer, some filters have been found to be contaminated to various degrees with heavy metals. Care should be exercised in selecting a source of these filters. A good practice is to wash the filters first with HNO₃(1+99) and then with 50 mL of the sample before filtering.

11. Calibration and Standardization

11.1 Calibrate the instrument for the elements chosen over a suitable concentration range by atomizing the calibration blank and mixed standard solutions and recording their concentrations and signal intensities. It is recommended that a minimum of three standards and a blank be used for calibration with one of the standards at three to five times the elements' MDL. It is recommended that the calibration blank and standards be matrix matched with the same acid concentration contained in the samples. Analyze appropriate reference solutions to validate the calibration of the instrument before proceeding to the sample analysis.

12. Procedure

12.1 To determine dissolved elements, add 1 mL of concentrated HNO₃(sp gr 1.42) to 100 mL of filtered, acid-preserved sample. Proceed with 12.3.

12.2 When determining total-recoverable elements, use 100 mL of a well mixed, acid-preserved sample appropriate for the expected level of elements containing not more than 0.25 % (w/v) total solids.

12.2.1 Transfer the sample to a 125 mL (or larger) beaker or flask and add 2 mL of HNO₃(1+1) and 1 mL HCl (1+1) and

TABLE 6 Recommended Elemental Equations for Data Calculation

| Element | Elemental Equation ^A | Note |
|---------|---|--------------|
| Al | (1.000) (²⁷ C) | ... |
| Sb | (1.000) (¹²¹ C) | ... |
| As | (1.000) (⁷⁵ C) – (3.127) [(⁷⁷ C) – (0.815) (⁸² C)] | ^B |
| Ba | (1.000) (¹³⁷ C) | ... |
| Be | (1.000) (⁹ C) | ... |
| Cd | (1.000) (¹¹¹ C) – (1.073) [(¹⁰⁸ C) – (0.712) (¹⁰⁶ C)] | ^C |
| Cr | (1.000) (⁵² C) | ^D |
| Co | (1.000) (⁵⁹ C) | ... |
| Cu | (1.000) (⁶³ C) | ... |
| Pb | (1.000) (²⁰⁶ C) + (1.000) (²⁰⁷ C) + (1.000) (²⁰⁸ C) | ^E |
| Mn | (1.000) (⁵⁵ C) | ... |
| Mo | (1.000) (⁹⁸ C) – (0.146) (⁹⁹ C) | ^F |
| Ni | (1.000) (⁶⁰ C) | ... |
| Se | (1.000) (⁸² C) | ^G |
| Ag | (1.000) (¹⁰⁷ C) | ... |
| Tl | (1.000) (²⁰⁵ C) | ... |
| Th | (1.000) (²³² C) | ... |
| U | (1.000) (²³⁸ C) | ... |
| V | (1.000) (⁵¹ C) – (3.127) [(⁵³ C) – (0.113) (⁵² C)] | ^H |
| Zn | (1.000) (⁶⁶ C) | ... |
| Kr | (1.000) (⁸³ C) | ... |
| Pd | (1.000) (¹⁰⁵ C) | ... |
| Ru | (1.000) (⁹⁹ C) | ... |
| Sn | (1.000) (¹¹⁸ C) | ... |
| Bi | (1.000) (²⁰⁹ C) | ^I |
| In | (1.000) (¹¹⁵ C) – (0.016) (¹¹⁸ C) | ^J |
| Sc | (1.0000) (⁴⁵ C) | ^K |
| Tb | (1.000) (¹⁵⁹ C) | ... |
| Y | (1.000) (⁸⁹ C) | ^I |

^A C = calibration blank subtracted counts at specified mass.

^B Correction for chloride interference with adjustment for Se77. ArCl 75/77 ratio may be determined from the reagent blank.

^C Correction for MoO interference. An additional isobaric elemental correction should be made if palladium is present.

^D In 0.4 % v/v HCl, the background from ClOH will normally be small. However the contribution may be estimated from the reagent blank.

^E Allowance for isotopic variability of lead isotopes.

^F Isobaric elemental correction for ruthenium.

^G Some argon supplies contain krypton as an impurity. Selenium is corrected for Kr82 by background subtraction.

^H Correction for chloride interference with adjustment for Cr53. ClO 51/53 ratio may be determined from the reagent blank.

^I May be present in environmental samples.

^J Isobaric elemental correction for tin.

^K Polyatomic ion interference.

heat on a steam bath or hot plate until the volume has been reduced to near 25 mL, making certain the sample does not boil. Cool the sample, and if necessary, filter or let insoluble material settle to avoid clogging of the nebulizer. Adjust to original sample volume. To determine total-recoverable elements, proceed with 12.3. This method is suitable for the determination of silver in aqueous samples containing concentrations up to 0.1 mg/L. For the analysis of samples containing higher concentrations of silver, succeeding smaller volume, well mixed sample aliquots must be prepared until the analysis solution contains < 0.1 mg/L silver.

12.3 Atomize each solution and record signal's intensity or calculated concentration for each mass of interest. Atomize a rinse blank consisting of HNO₃(1+49) in water between samples.

12.4 Minimum quality control requirements for this method include (see Section 15):

12.4.1 Monitoring of internal standard area counts in each sample,

12.4.2 Analysis of one reagent blank with each set of samples as continuing check on sample contamination,

TABLE 7 Regression Equations for Bias and Precision, µg/L, Reagent Water

| Element | Applicable Range | Bias | Overall Precision | Single Analyst Precision |
|------------|------------------|---------------------|-----------------------|--------------------------|
| Antimony | 2.80 to 100 | $X = 0.999C + 0.04$ | $S_i = 0.013X + 0.61$ | $S_o = 0.022X + 0.20$ |
| Arsenic | 8.00 to 200 | $X = 1.013C + 0.50$ | $S_i = 0.031X + 2.74$ | $S_o = 0.007X + 2.95$ |
| Barium | 8.01 to 200 | $X = 1.001C - 0.36$ | $S_i = 0.039X + 0.31$ | $S_o = 0.024X + 0.25$ |
| Beryllium | 2.80 to 100 | $X = 1.056C + 0.32$ | $S_i = 0.067X + 0.55$ | $S_o = 0.038X + 0.11$ |
| Cadmium | 4.00 to 100 | $X = 1.007C + 0.07$ | $S_i = 0.041X + 0.19$ | $S_o = 0.022X + 0.10$ |
| Chromium | 8.00 to 200 | $X = 1.017C + 0.62$ | $S_i = 0.066X + 0.48$ | $S_o = 0.026X + 1.25$ |
| Cobalt | 0.80 to 101 | $X = 0.977C + 0.01$ | $S_i = 0.28X + 0.06$ | $S_o = 0.027X + 0.02$ |
| Copper | 4.01 to 100 | $X = 1.003C - 0.05$ | $S_i = 0.037X + 0.64$ | $S_o = 0.016X + 0.51$ |
| Lead | 4.00 to 100 | $X = 1.043C - 0.31$ | $S_i = 0.064X + 1.43$ | $S_o = 3.42$ |
| Manganese | 8.00 to 200 | $X = 0.983C + 0.02$ | $S_i = 0.026X + 0.11$ | $S_o = 0.027X + 0.06$ |
| Molybdenum | 2.80 to 100 | $X = 1.012C + 0.20$ | $S_i = 0.032X + 0.22$ | $S_o = 0.021X + 0.09$ |
| Nickel | 4.00 to 100 | $X = 1.000C + 0.12$ | $S_i = 0.051X + 0.31$ | $S_o = 0.017X + 0.40$ |
| Selenium | 32.00 to 200 | $X = 1.036C - 0.06$ | $S_i = 0.051X + 3.24$ | $S_o = 0.061X - 0.64$ |
| Silver | 0.80 to 200 | $X = 0.917C + 0.26$ | $S_i = 0.196X + 0.09$ | $S_o = 0.053X + 0.08$ |
| Thallium | 2.80 to 100 | $X = 0.984C + 0.08$ | $S_i = 0.035X + 0.09$ | $S_o = 0.027X + 0.13$ |
| Thorium | 0.80 to 100 | $X = 1.0913 + 0.08$ | $S_i = 0.036X + 0.13$ | $S_o = 0.025X + 0.07$ |
| Uranium | 0.80 to 100 | $X = 1.026C - 0.02$ | $S_i = 0.048X + 0.02$ | $S_o = 0.027X + 0.05$ |
| Zinc | 8.00 to 200 | $X = 1.042C + 0.87$ | $S_i = 0.041X + 2.60$ | $S_o = 0.030X + 1.42$ |

12.4.3 Analysis of a quality control sample (3.2.8) with each set of samples as a continuing check on method reference sample recovery,

12.4.4 Analysis of mid-range calibration check standard (3.2.3) every ten analyses as a continuing check on calibration curve, and

12.4.5 Analysis of calibration blank every ten analyses as a continuing check on contamination.

13. Calculation

13.1 Elemental equations recommended for sample data calculations are listed in Table 6.

13.2 Reagent blanks should be subtracted as appropriate (see section 9.13) from the samples. This subtraction is particularly important for digested samples requiring large quantities of acids to complete the digestion (see Note 3).

NOTE 3—High reagent blank concentrations will negatively influence the sample results.

13.3 If dilutions were required, apply the appropriate dilution factor to sample values.

13.4 Report results in the calibration concentration units.

14. Precision and Bias ⁵

14.1 The precision and bias data for this test method are based on a joint interlaboratory method validation study conducted by the U.S. Environmental Protection Agency and the Association of Official Analytical Chemists.⁶

14.2 The test design of the study meets the requirements of Practice D 2777 for elements listed in this test method with the following exceptions. Thorium in drinking water and vanadium in ground and reagent water did not meet the requirements of 10.3 in Practice D 2777 and are deleted in the test method. In addition, the following elements did not meet the requirements of 10.5 of Practice D 2777 for the concentration

levels (in µg/L) tested: Aluminum in reagent (8) and drinking water (12), antimony in ground water (2.0 and 100), manganese in ground (0.8 and 1.2) and drinking water (1.2), molybdenum in ground water (2.8), silver, in ground (0.8 and 2.2) and drinking water (0.8 and 1.2), and zinc in drinking water (8).

14.2.1 The regression equations are based on the results of 13 laboratories for 20 elements tested at six levels, they are outlined in Table 7, Table 8, and Table 9 for reagent water, drinking water, and ground water, respectively.

14.2.2 Type I water was specified for this round robin.

14.2.3 These data may not apply to waters of other matrices; therefore, it is the responsibility of the analyst to ensure the validity of the test method in a particular matrix.

14.2.4 It is the user's responsibility to ensure the validity of precision and bias outside the joint interlaboratory method validation study ranges.

14.3 Precision and bias for this test method conforms to Practice D 2777-77, which was in place at the time of collaborative testing. Under the allowances made in 1.4 of D 2777-98, these precision and bias data do meet existing requirements for interlaboratory studies of Committee D19 test methods.

15. Quality Control (QC)

15.1 The following quality control information is recommended for measuring elements in water by Inductively-Coupled Argon Plasma Mass Spectrometry.

15.2 The instrument shall be calibrated using a minimum of three calibration standards and a calibration blank. The calibration correlation coefficient shall be equal to or greater than 0.990.

15.3 An instrument check standard shall be analyzed at a minimum frequency of 10 % and at the end of the batch run throughout the batch analysis. The value of the instrument check standard shall fall between 90 % and 110 % of the true value.

15.4 A calibration blank shall be analyzed at a minimum frequency of 10% and at the end of the batch run to ensure contamination was not a problem during the batch analysis, the measured values should be less than 2.2 times the MDL.

⁵ Supporting data are available from ASTM Headquarters. Request RR:D19-1157.

⁶ Longbottom, J. E., et al., "Determination of Trace Elements in Water by Inductively Coupled Plasma-Mass Spectrometry: Collaborative Study," *Journal of AOAC, International* 77, 1994, pp. 1004-1023.

TABLE 8 Regression Equations for Bias and Precision, µg/L, Drinking Water

| Element | Applicable Range | Bias | Overall Precision | Single Analyst Precision |
|------------|------------------|---------------------|-----------------------|--------------------------|
| Antimony | 2.80 to 100 | $X = 0.983C + 0.03$ | $S_t = 0.049X + 0.19$ | $S_o = 0.026X + 0.08$ |
| Arsenic | 8.00 to 200 | $X = 0.993C + 0.57$ | $S_t = 0.018X + 2.55$ | $S_o = 0.031X + 1.65$ |
| Barium | 8.01 to 200 | $X = 0.995C - 0.37$ | $S_t = 0.045X + 0.97$ | $S_o = 0.040X + 0.72$ |
| Beryllium | 2.80 to 100 | $X = 1.055C + 0.20$ | $S_t = 0.057X + 0.28$ | $S_o = 0.016X + 0.25$ |
| Cadmium | 4.00 to 100 | $X = 0.985C + 0.10$ | $S_t = 0.031X + 0.65$ | $S_o = 0.021X + 0.61$ |
| Chromium | 8.00 to 200 | $X = 0.990C + 1.45$ | $S_t = 0.015X + 2.19$ | $S_o = 2.18$ |
| Cobalt | 0.80 to 101 | $X = 0.964C + 0.06$ | $S_t = 0.19X + 0.32$ | $S_o = 0.014X + 0.30$ |
| Copper | 4.01 to 100 | $X = 0.976C - 0.38$ | $S_t = 0.063X + 0.86$ | $S_o = 0.029X + 0.86$ |
| Lead | 4.00 to 100 | $X = 1.032C - 0.30$ | $S_t = 0.015X + 1.06$ | $S_o = 0.011X + 1.13$ |
| Molybdenum | 2.80 to 100 | $X = 1.013C + 0.07$ | $S_t = 0.037X + 0.17$ | $S_o = 0.035X + 0.20$ |
| Nickel | 4.00 to 100 | $X = 0.953C - 0.19$ | $S_t = 0.046X + 0.56$ | $S_o = 0.023X + 0.91$ |
| Selenium | 32.00 to 200 | $X = 1.022C + 0.14$ | $S_t = 0.056X + 2.10$ | $S_o = 0.040X + 2.15$ |
| Thallium | 2.80 to 100 | $X = 1.010C + 0.01$ | $S_t = 0.040X + 0.21$ | $S_o = 0.039X + 0.02$ |
| Uranium | 0.80 to 100 | $X = 1.026C - 0.04$ | $S_t = 0.044X + 0.11$ | $S_o = 0.022X + 0.07$ |
| Vanadium | 32.00 to 200 | $X = 1.022C + 0.30$ | $S_t = 0.023X + 1.45$ | $S_o = 0.023X + 1.38$ |

TABLE 9 Regression Equations for Bias and Precision, µg/L, Ground Water

| Element | Applicable Range | Bias | Overall Precision | Single Analyst Precision |
|-----------|------------------|---------------------|-----------------------|--------------------------|
| Aluminum | 8.00 to 200 | $X = 0.946C + 2.20$ | $S_t = 0.169X + 6.22$ | $S_o = 0.172X + 0.75$ |
| Arsenic | 8.00 to 200 | $X = 0.949C + 0.91$ | $S_t = 0.048X + 4.52$ | $S_o = 0.059X + 4.29$ |
| Barium | 8.01 to 200 | $X = 1.055C - 0.21$ | $S_t = 0.020X + 2.05$ | $S_o = 0.014X + 2.08$ |
| Beryllium | 2.80 to 100 | $X = 1.049C + 0.08$ | $S_t = 0.084X + 0.16$ | $S_o = 0.043X + 0.06$ |
| Cadmium | 4.00 to 100 | $X = 0.944C + 0.11$ | $S_t = 0.017X + 1.09$ | $S_o = 0.029X + 0.01$ |
| Chromium | 8.00 to 200 | $X = 1.026C + 0.89$ | $S_t = 0.067X + 0.68$ | $S_o = 0.068X - 0.37$ |
| Cobalt | 0.80 to 101 | $X = 0.989C - 0.01$ | $S_t = 0.057X + 0.09$ | $S_o = 0.012X + 0.40$ |
| Copper | 4.01 to 100 | $X = 0.977C - 0.01$ | $S_t = 0.073X + 0.92$ | $S_o = 0.077X + 0.35$ |
| Lead | 4.00 to 100 | $X = 1.012C + 0.15$ | $S_t = 0.048X + 1.27$ | $S_o = 1.78$ |
| Nickel | 4.00 to 100 | $X = 1.022C - 0.66$ | $S_t = 0.091X + 2.03$ | $S_o = 0.008X + 2.75$ |
| Selenium | 32.00 to 200 | $X = 1.045C - 0.83$ | $S_t = 0.037X + 2.97$ | $S_o = 0.058X + 1.02$ |
| Thallium | 2.80 to 100 | $X = 1.023C - 0.06$ | $S_t = 0.056X + 0.04$ | $S_o = 0.049X - 0.06$ |
| Thorium | 0.80 to 100 | $X = 1.019C - 0.03$ | $S_t = 0.041X + 0.13$ | $S_o = 0.027X + 0.04$ |
| Uranium | 0.80 to 100 | $X = 1.058C - 0.06$ | $S_t = 0.039X + 0.17$ | $S_o = 0.028X + 0.16$ |
| Zinc | 8.00 to 200 | $X = 0.962C + 0.07$ | $S_t = 0.093X + 0.92$ | $S_o = 0.069X + 1.55$ |

15.5 A QCS shall be analyzed with each batch of samples to verify the instrument's calibration and be within 10 % of the certified value.

15.6 The internal standard area counts in each sample should be within 60–125 % of area in calibration blank.

15.7 If the QC for the sample batch is not within the established control limits, reanalyze the samples or qualify the results with the appropriate flags, or both (Practice D 5847).

15.8 Blind control samples should be submitted by an outside agency in order to determine the laboratory performance capabilities.

15.9 Method Performance:

15.9.1 Demonstrate initial, and continuing, method performance every six months by digesting seven spiked reagent water samples at two through five times estimated detection limit to determine method detection limits (MDL) (Guide D 5810).

15.9.2 Determine detection limits annually or whenever a significant change in background or instrument response is expected.

$$MDL = (t) \times (s)$$

where:

t = students' t value for a 99 % confidence level and with $n-1$ degrees of freedom ($t = 3.14$ for seven replicates), and

s = standard deviation of the replicate analyses.

16. Keywords

16.1 elements; mass spectrometry; water

APPENDIX

(Nonmandatory Information)

X1. PRECISION AND BIAS

TABLE X1.1 Regression Equations for Bias and Precision, µg/L

| Element | Applicable Range | Bias | Overall Precision | Single Analyst Precision |
|-----------------------|------------------|---------------------|-----------------------|--------------------------|
| <i>Reagent Water</i> | | | | |
| Aluminum | (8.00–200) | $X = 0.992C + 1.19$ | $S_t = 0.056X + 2.59$ | $S_o = 0.042X + 1.27$ |
| <i>Drinking Water</i> | | | | |
| Aluminum | (8.00–200) | $X = 0.954C + 2.38$ | $S_t = 7.70$ | $S_o = 0.013X + 6.17$ |
| Manganese | (8.00–200) | $X = 0.989C + 0.10$ | $S_t = 0.047X + 0.29$ | $S_o = 0.021X + 0.40$ |
| Silver | (0.80–200) | $X = 0.888C + 0.09$ | $S_t = 0.186X + 0.17$ | $S_o = 0.164X + 0.18$ |
| Zinc | (8.00–200) | $X = 0.943C + 2.54$ | $S_t = 0.048X + 5.27$ | $S_o = 0.004X + 5.66$ |
| <i>Ground Water</i> | | | | |
| Antimony | (2.80–100) | $X = 1.003C + 0.01$ | $S_t = 0.059X + 0.04$ | $S_o = 0.058X + 0.02$ |
| Manganese | (8.00–200) | $X = 0.954C - 0.16$ | $S_t = 0.103X + 0.14$ | $S_o = 0.025X + 0.09$ |
| Molybdenum | (2.80–100) | $X = 1.032C - 0.09$ | $S_t = 0.55X + 0.43$ | $S_o = 0.042X + 0.27$ |
| Silver | (0.80–200) | $X = 0.858C - 0.00$ | $S_t = 0.169X + 0.14$ | $S_o = 0.120X - 0.01$ |

X1.1 The following regression expressions in Table X1.1 are based on the measured values, X , S_p , and S_o that were derived from data of the joint interlaboratory method validation study conducted by the U.S. Environmental Protection Agency

and the Association of Official Analytical Chemists,⁶ some of which do not meet the requirements of 10.5 of Practice D 2777, as noted in 14.2 of this test method and were therefore are not included in Tables 7-9 in this test method.

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