



Standard Test Method for Preparation and Elemental Analysis of Liquid Hazardous Waste by Energy-Dispersive X-Ray Fluorescence¹

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1. Scope

1.1 This test method covers the determination of trace and major element concentrations by energy-dispersive X-ray fluorescence spectrometry (EDXRF) in liquid hazardous waste (LHW).

1.2 This test method has been used successfully on numerous samples of aqueous and organic-based LHW for the determination of the following elements: Ag, As, Ba, Br, Cd, Cl, Cr, Cu, Fe, Hg, I, K, Ni, P, Pb, S, Sb, Se, Sn, Tl, V, and Zn.

1.3 This test method is applicable for other elements (Si-U) not listed in 1.2.

1.4 *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:

C 982 Guide for Selecting Components for Energy-Dispersive X-ray Fluorescence (XRF) Systems²

D 1193 Specification for Reagent Water³

2.2 Other ASTM Documents:

ASTM Data Series DS 46 X-Ray Emission Wavelengths and KeV Tables for Nondiffractive Analysis⁴

3. Summary of Test Method

3.1 A weighed portion of activated alumina and sample are combined in a mixing vessel and shaken until well mixed. The sample mixture is transferred into a disposable sample cup and placed in the spectrometer for analysis.

3.2 The *K* spectral emission lines are used for elements Si-Ba.

3.3 The *L* spectral emission lines are used for elements with atomic numbers greater than Ba.

4. Significance and Use

4.1 The elemental analysis of liquid hazardous waste is often important for regulatory and process specific requirements. This test method provides the user an accurate, rapid method for trace and major element determinations.

5. Interferences

5.1 Spectral Overlaps (Deconvolution):

5.1.1 Samples containing a mixture of elements often exhibit X-ray emission line overlap. Modern Si (Li) detectors generally provide adequate resolution to minimize the effects of spectral overlap. In cases where emission line overlap exists, techniques of peak fitting exist for extracting corrected analyte emission line intensities. For example, the $PbL\alpha$ “line overlaps with the $AsK\alpha$.” The $PbL\beta$ line can be used to avoid this overlap and the AsK lines can then be resolved from the $PbL\alpha$ overlap. The actual lines used for any particular element should be such that overlaps are minimized. Follow the EDXRF manufacturer’s recommendation concerning spectral deconvolution. Reference should be made to ASTM Data Series DS 46 for detailed information on potential line overlaps.

5.2 Matrix Interferences (Regression):

5.2.1 Matrix interference in the measurement of “as received” LHW samples using EDXRF has been the principle limitation in the development and expanding use of this instrumental technique. Using well understood XRF principles for controlling matrix effects, for example, dilution and matrix modification using lithium borate fusion and addition of heavy absorbers, a matrix can be stabilized. Using calcined alumina and the above principles matrices are stabilized for quantitative EDXRF analysis.

5.2.2 The response range of this test method should be linear with respect to the elements of interest and their regulatory or process control, or both, action thresholds. Large concentration variations of element or matrix, or both, components in LHW samples can result in non-linear X-ray intensity response at increasing element concentrations.

6. Apparatus

6.1 *Energy-dispersive X-ray Fluorescence Spectrometer*, capable of measuring the wavelengths of the elements listed in 1.2. Refer to Guide C 982 for system specifications.

¹ This test method is under the jurisdiction of ASTM Committee D34 on Waste Management and is the direct responsibility of Subcommittee D34.01.06 on Analytical Methods.

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² *Annual Book of ASTM Standards*, Vol 12.01.

³ *Annual Book of ASTM Standards*, Vol 11.01.

⁴ Available from ASTM Headquarters, Customer Service.

6.2 *Analytical Balance*, capable of weighing to 0.001 g.

7. Reagents and Materials

7.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.⁵ Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean meeting the numerical requirements of Type II water as defined by Specification D 1193.

7.3 *Aluminum Oxide, Al₂O₃*—pre-calcined at 1500°C, approximately 100 to 125 mesh.

7.4 *Aqueous or organic-based Atomic Absorption Standards (AAS)*, 1000 mg/L for the elements Ag, As, Ba, Cd, Cr, Cu, Fe, Hg, K, Ni, Pb, Sb, Se, Sn, Tl, V, and Zn. Standard solutions for elements not listed are also available.

NOTE 1—AAS standards are typically presented in mass/vol units. The density of these solutions can be considered as unity (that is, 1) thus they can be considered as % mass/mass (m/m).

7.5 *1-bromonaphthalene, trichlorobenzene, iodobenzoic acid, triethyl phosphate and dithiodiglycol* are the recommended standards for the elements Br, Cl, I, P and S, respectively.

7.6 *Low Molecular Weight Polyethylene Glycol (PEG 400, or equivalent) or Water* is used for producing method blank.

7.7 *High-Density Polyethylene (HDPE) Wide-mouth, Round, Screw-Cap Bottles*, 50 to 60 mL capacity.

7.8 *Mixing Balls*, approximately 1 cm diameter, stainless steel or equivalent.

NOTE 2—Potential low level Cr, Fe or Ni (<20 mg/kg¹) contamination due to the use of stainless steel may exist. Other suitable materials would be tungsten carbide, Zr or Ta.

7.9 *Thin-film Support*.

NOTE 3—The user should select a thin-film support that provides for maximum transmittance and is resistant to typical components in LHW. The thin-film supports used in the development of this test method were a polypropylene base and a high-purity, 4 µm polyester film.

7.10 *Sample Cups*, vented.

7.11 *Helium, He*—minimum 99.99 purity for use as a chamber purge gas for the analysis of Cl, P and S. This numerical purity is intended to specify a general grade of helium. Ultra-high purity helium is not required for this test method.

8. Sample

8.1 Because of the potential heterogeneous nature of LHW,

⁵ *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. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

all possible efforts should be made to ensure that representative samples are taken.

9. Preparation of Apparatus

9.1 Follow the manufacturer’s instructions for set-up, conditioning, preparation and maintenance of the XRF spectrometer.

9.2 When required, reference spectra should be obtained from pure element standards for all deconvoluted elements.

9.3 Spectral and matrix interferences as listed in the Interferences section must be addressed per the manufacturer’s recommendations.

10. Calibration and Standardization

10.1 The spectrometer must be calibrated using an appropriate reference element(s) at a minimum frequency as recommended by the manufacturer.

10.2 Analytical standards should be prepared gravimetrically by blending the solution or pure element standards with Al₂O₃ to suitable standard concentrations as determined by the user’s analytical requirements. Table 1 gives recommended concentration ranges for regression. Standards can be single or multi-element mixtures. Standard solutions are generally mixed with Al₂O₃ at a ratio of 3:1.

NOTE 4—More than one standard element(s) solution can be added to a single 15 g Al₂O₃ mass provided the total mass of standard is 5 g. This will maintain the proper 3:1 ratio while allowing mixtures of potentially incompatible elements to be combined in a single standard.

10.2.1 The number of standards required to produce calibrations is dependent on the number of elements to be determined. Generally, two calibrations are produced, the first is to determine potentially major elements such as halogens, S & P. The second is to determine trace elements, typically toxic metals and heavy elements. The minimum number of standards required can be determined from the following equation: minimum standards required = number elements determined plus two. Both of the above calibrations should use a minimum of ten standards each to cover the element concentration ranges shown in Table 1 and to ensure that adequate data is available to assess spectral overlaps as described in 5.1.

10.3 The Al₂O₃ + element(s) specimen is placed into an XRF sample cup supported by a suitable thin-film. The sample is gently tapped on a flat, hard surface to settle the powder against the thin-film support and ensure there are no air gaps.

TABLE 1 Recommended Standards Ranges

Analyte	Low Concentration Range, mg/kg	High Concentration Range, mg/kg	Analyte	Low Concentration Range, mg/kg	High Concentration Range, mg/kg
Ag	5	600	Zn	5	600
Ba	5	600	As	5	600
P	0.1 %	5 %	Se	5	600
S	0.05 %	5 %	Br	10	5000
Cl	0.05 %	5 %	Cd	5	600
K	0.1 %	5 %	Sb	5	600
V	5	600	Sn	5	600
Cr	5	600	I	5	600
Fe	5	600	Hg	5	600
Ni	5	600	Tl	5	600
Cu	5	600	Pb	5	600

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10.3.1 The standard specimen in the sample cups is placed in the spectrometer's sample holder avoiding any contact with the film or rough handling that may disturb the standards.

10.4 Two methods of calibration are available.

10.4.1 *Method A*—Empirical calibration method using a suit of standard concentrations. Standard concentrations are limited to 600 mg/kg for Ag, As, Ba, Br, Cd, Cr, Cu, Fe, Hg, I, K, Ni, Pb, Sb, Se, Sn, Tl, V, and Zn. Standard concentrations are limited to 5 % for Cl, P, S, and other light elements (that is, $z < 22$ and < 0.5 % for Br). The limits ensure staying within the linear range and due to the limited concentration range of available traceable standards. The standards should provide a linear response of element intensity to concentration. Serial dilutions of analyte standards can be used to set up the calibration for each element. Multi-element standards can then be used to assess the deconvolution requirements of the spectrometer and check for calibration linearity.

NOTE 5—Standards may be diluted into the linear range using low molecular weight polyethylene glycol (PEG) or water. The choice of diluent is dependent upon whether the original standard solution is aqueous- or organic-based. For example, a 5000 mg/kg organic-based Pb standard solution can be diluted into the 0–600 mg/kg range by combining and mixing 15 g of Al_2O_3 + 0.5 g of 5000 mg/kg Pb standard solution + 4.5 g PEG. This yields a ten-fold dilution yielding a prepared standard concentration of 500 mg/kg.

10.4.1.1 *Drift Correction Monitors*—To correct for instrumental drift, use physically stable, solid disks or pressed pellets containing at least one element measured under each instrumental condition used.⁶ At least two disks are necessary to correct both sensitivity and base-line drifts. One should provide a high net count-rate similar to standards from the upper end of the calibration range and the other should provide a low net count-rate similar to the blank. Measure the net count-rate for each element in the high concentration disk in such a way that the counting statistical error due to random fluctuation of the X-ray flux is less than 0.5 % relative to the net count-rate. Counting times must be long enough to collect 40 000 net counts for each element in the high-concentration disk. Use the same counting times when measuring the low concentration or blank disk.

10.4.2 *Method B*—Fundamental Parameters method. Most EDXRF manufacturers provide software capable of estimating the composition of materials without the use of a suite of standards. The setup of a particular manufacturer's fundamental parameters method may require a high and low concentration or mid-range concentration for each element present to determine the initial sensitivity for the elements in the alumina matrix. Other manufacturers provide the initial sensitivity with the added option to align the sensitivity to a specific matrix type for more accurate determinations using a single similar standard containing the elements of interest. By measuring the X-ray intensity (cps) for each element and using the above determined sensitivity factor for each element plus various equations to account for X-ray absorption and enhancement

effects, the concentration of all elements present can be estimated. The exact equations used will differ for each manufacturer.

10.4.2.1 Follow the manufacturer's fundamental parameters set-up recommendations. The stoichiometric set-up of the fundamental parameters method for the analysis of the LHW mixed with alumina should allow for the manual input of a fixed 75 % Al_2O_3 concentration and the use of carbon as a balance estimate of the solvent/aqueous phase with the elements of interest determined directly according to the principles of 10.4.2.

10.4.3 Two control samples are needed for monitoring instrument stability. One control sample is a blank preparation using PEG or the low concentration drift correction monitor used in 10.4.1.1. The other sample is a stable mixture containing a suitable range and number of elements (for example, S, V, Zn, Pb, and Ba) at concentrations near the middle of the calibration ranges. A mixture of leftover samples/standards, spiked with element concentrations as needed and carefully mixed may be used.

10.4.4 Restandardization should be carried out whenever quality control results defined in Section 14 are outside data quality objectives as determined by the user. Method A: The initial linear regressions are performed only once as per 10.4.1. A day zero measurement of the drift correction monitors, 10.4.1.1 during the set-up of the initial regression allows for subsequent re-calibration to be performed using the two standards defined in 10.4.1.1, via a restandardization procedure in order to check the values of the slope and intercept for each regressed element. NOTE: Restandardization using drift correction monitors is often part of instrumental software. Follow the manufacturer's recommendations for the set-up of restandardization using two standards. Method B: Follow the manufacturer's recommendations for the set-up of initial element sensitivities and the appropriate fundamental parameters methods using the principles outlined in 10.4.2.

11. Procedure

11.1 Thoroughly mix the LHW sample before withdrawing a portion with a pipet, or equivalent device for preparation. See the Sample section.

11.2 Weigh 15.00 g $\text{Al}_2\text{O}_3 \pm 0.05$ g directly into the HDPE bottle.

11.3 Weigh a 5.00 g ± 0.05 g portion of the sample directly into the blending vial/vessel containing the Al_2O_3 from 11.1.

11.4 Add two mixing balls to the HDPE bottle from 11.3 and seal.

11.5 Shake vigorously for approximately 30 s. Tapping the bottle on a hard surface will aid in proper mixing. The user may feel a mild exothermic reaction.

11.6 Empty the Al_2O_3 /sample mixture from the bottle to an XRF sample cup as described in 10.3.

11.7 Place the sample cup into the spectrometer sample holder and initiate data acquisition. If re-analysis of the sample is required, the user should obtain a new portion from the HDPE bottle following the instructions in 11.6.

11.8 After analysis is completed by the instrument, process analytical results according to Section 12.

⁶ Pressed aluminum powder doped with the elements of interest has been found to be satisfactory. Preparation guidelines can be found in: Forte, M., "Fabrication and Use of Permanent Monitors and Standards," *X-ray Spectrometry*, 1983, Vol 3, pp. 115.