



Standard Test Methods for Chemical and Atomic Absorption Analysis of Uranium-Ore Concentrate¹

This standard is issued under the fixed designation C1022; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

^{ε1} NOTE—Sections 1.4 and 7.2 were editorially corrected in August 2010.

1. Scope

1.1 These test methods cover procedures for the chemical and atomic absorption analysis of uranium-ore concentrates to determine compliance with the requirements prescribed in Specification C967.

1.2 The analytical procedures appear in the following order:

	Sections
Uranium by Ferrous Sulfate Reduction—Potassium Dichromate Titrimetry	9
Nitric Acid-Insoluble Uranium	10 to 18
Extractable Organic Material	19 to 26
Determination of Arsenic	27
Carbonate by CO ₂ Gravimetry	28 to 34
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Moisture by Loss of Weight at 110°C	51 to 57
Phosphorus by Spectrophotometry	58 to 66
Determination of Silicon	67
Determination of Thorium	68
Calcium, Iron, Magnesium, Molybdenum, Titanium, and Vanadium by Atomic Absorption Spectrophotometry	69 to 78
Potassium and Sodium by Atomic Absorption Spectrophotometry	79 to 88
Boron by Spectrophotometry	89 to 98

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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 applica-*

bility of regulatory limitations prior to use. A specific precautionary statement is given in Section 7.

2. Referenced Documents

2.1 ASTM Standards:²

- C761 Test Methods for Chemical, Mass Spectrometric, Spectrochemical, Nuclear, and Radiochemical Analysis of Uranium Hexafluoride
- C859 Terminology Relating to Nuclear Materials
- C967 Specification for Uranium Ore Concentrate
- C1110 Test Method for Determining Elements in Waste Streams by Inductively Coupled Plasma-Atomic Emission Spectroscopy (Withdrawn 2014)³
- C1219 Test Methods for Arsenic in Uranium Hexafluoride (Withdrawn 2015)³
- C1254 Test Method for Determination of Uranium in Mineral Acids by X-Ray Fluorescence
- C1267 Test Method for Uranium by Iron (II) Reduction in Phosphoric Acid Followed by Chromium (VI) Titration in the Presence of Vanadium
- C1287 Test Method for Determination of Impurities in Nuclear Grade Uranium Compounds by Inductively Coupled Plasma Mass Spectrometry
- C1347 Practice for Preparation and Dissolution of Uranium Materials for Analysis
- D1193 Specification for Reagent Water
- E60 Practice for Analysis of Metals, Ores, and Related Materials by Spectrophotometry

¹ These test methods are under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and are the direct responsibility of Subcommittee C26.05 on Methods of Test.

Current edition approved June 1, 2010. Published June 2010. Originally approved in 1984. Last previous edition approved in 2005 as C1022 – 05. DOI: 10.1520/C1022-05R10E1.

² 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.

³ The last approved version of this historical standard is referenced on www.astm.org.



3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, refer to Terminology C859.

4. Significance and Use

4.1 The test methods in this standard are designed to show whether a given material meets the specifications prescribed in Specification C967.

4.2 Because of the variability of matrices of uranium-ore concentrate and the lack of suitable reference or calibration materials, the precision and bias of these test methods should be established by each individual laboratory that will use them. The precision and bias statements given for each test method are those reported by various laboratories and can be used as a guideline.

4.3 Instrumental test methods such as X-ray fluorescence and emission spectroscopy can be used for the determination of some impurities where such equipment is available.

5. Interferences

5.1 Interferences are identified in the individual test methods.

5.2 Ore concentrates are of a very variable nature; therefore, all interferences are very difficult to predict. The individual user should verify the applicability of each procedure for specific ore concentrates.

6. Reagents

6.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.⁴ 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.

6.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Specification D1193.

7. Precautions

7.1 Proper precautions should be taken to prevent inhalation or ingestion of uranium during sample preparation and any subsequent sample analysis.

7.2 Hydrofluoric acid is a highly corrosive acid that can severely burn skin, eyes, and mucous membranes. Hydrofluoric acid is similar to other acids in that the initial extent of a burn depends on the concentration, the temperature, and the duration of contact with the acid. Hydrofluoric acid differs from other acids because the fluoride ion readily penetrates the

skin, causing destruction of deep tissue layers. Unlike other acids that are rapidly neutralized, hydrofluoric acid reactions with tissue may continue for days if left untreated. Due to serious consequences of hydrofluoric acid burns, prevention of exposure or injury of personnel is the primary goal. Utilization of appropriate laboratory controls (hoods) and wearing adequate personal protective equipment to protect from skin and eye contact is essential.

8. Sampling

8.1 Collect samples in accordance with Specification C967.

8.2 Special requirements for subsampling are given in the individual test methods.

URANIUM BY FERROUS SULFATE REDUCTION—POTASSIUM DICHROMATE TITRIMETRY

9. Scope

9.1 This test method covers the determination of uranium in uranium-ore concentrates. This test method was discontinued in January 2002 and replaced with Test Method C1267.

9.2 The uranium content of the sample may also be determined using Test Method C1254. The user's laboratory must establish and document method performance.

NOTE 1—Dissolution of UOC samples may be achieved using the techniques or combination of techniques described in C1347. The laboratory must validate the performance of C1347 using characterized UOC samples. If C1347 methods are not suitable for UOC sample dissolution, the user may establish and document applicable dissolution methods.

NITRIC ACID-INSOLUBLE URANIUM

10. Scope

10.1 This test method covers the determination of that quantity of uranium in uranium-ore concentrate that is not soluble in nitric acid.

11. Summary of Test Method

11.1 A sample of ore concentrate is digested in 10 M nitric acid at 95 to 100°C for 1 h. The slurry is filtered and the residue washed with 1 M nitric acid until the filtrate gives a negative test for uranium. The washed residue is then dried and ignited at 1000 ± 25°C for 1 h. The uranium content is determined on the ignited residue by spectrophotometry.

12. Interference

12.1 At the specification limit for nitric acid insoluble uranium usually established for uranium-ore concentrates, interference effects are insignificant.

13. Apparatus

13.1 *Digestion Flask*, 500-mL, with side entry tube and attached reservoir.

13.2 *Stirring Apparatus*, with sleeve-type stirrer.

13.3 *Heating Mantle*, 250-W, controlled by a variable transformer.

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

13.4 *Büchner Funnel*.

13.5 *Porcelain Crucibles*, 40-mL.

13.6 *Muffle Furnace*.

13.7 *Filter Paper*, ⁵ of medium porosity.

13.8 *Spectrophotometer*, with 1-cm cells that are in accordance with Practice E60.

14. Reagents

14.1 *Nitric Acid* (10 *M*)—Dilute 62.5 mL of HNO₃ (sp gr 1.42) to 100 mL with distilled water.

14.2 *Nitric Acid* (1 *M*)—Dilute 62.5 mL of HNO₃ (sp gr 1.42) to 1 L with distilled water.

14.3 *Sodium Hydroxide* (100 g/L)—Dissolve 10 g of NaOH in 100 mL of water.

14.4 *Hydrogen Peroxide* (H₂O₂, 30 %).

14.5 *Hydrochloric Acid* (HCl, sp gr 1.19).

14.6 *Hydrofluoric Acid* (HF, 48 %).

14.7 *Sulfuric Acid* (9 *M*)—Add 500 mL H₂SO₄ (sp gr 1.84) to 500 mL of iced water with constant stirring. Cool and dilute to 1 L with water.

15. Procedure

15.1 Weigh a 50.0 ± 0.1-g sample directly into the digestion flask.

15.2 Place the flask in the heating mantle and adjust the support ring so that the joints of the flask and sleeve stirrer are engaged, and the stirrer blades turn freely but just clear the bottom of the flask.

15.3 Transfer 95 mL of 10 *M* nitric acid to a 250-mL beaker and heat between 95 to 100°C.

15.4 Slowly transfer the heated nitric acid solution to the digestion flask through the entry side tube with the stirrer turning.

NOTE 2—The stirrer is started before the acid is added to prevent material from sticking to the flask.

15.5 Align a thermometer in such a manner that the mercury chamber of the thermometer is immersed in the stirring slurry, but adequately clears the turning stirrer blades.

15.6 Quickly bring the sample to 97°C and digest between 95 to 100°C for 1 h while stirring. (Measure the 1-h digestion time after the temperature of the slurry has reached 97°C.)

15.7 Turn off the variable transformer, but allow the stirrer to continue turning.

15.8 Remove the thermometer and carefully rinse with water all slurry that adheres to it.

15.9 Wipe the immersed portion of the thermometer with one fourth of a circle of filter paper and transfer the paper to a prepared Büchner funnel fitted with a filter paper.

15.10 Add 10 mL of paper pulp to the slurry and continue stirring for about 5 min.

15.11 Turn off the stirrer, then lower the flask and mantle.

15.12 Carefully wash the slurry that adheres to the stirrer shaft and blades into the flask with water.

15.13 Wipe the shaft and blades with one fourth of a circle of filter paper and transfer the filter paper to the Büchner funnel.

15.14 Filter the slurry through the Büchner funnel and wash contents of the flask into the funnel.

15.15 Wash the residue with 1 *M* nitric acid until a 10-mL portion of the filtrate shows no detectable yellow color when made basic with sodium hydroxide and after a few drops of H₂O₂ (30 %) have been added as a color developer.

15.16 Wash the residue several times with water after a negative test is obtained.

15.17 Draw air through the filter until the residue and filter pad are dry.

15.18 Scrape the residue and paper into a preignited (1000°C) tared 40-mL crucible, place on a hot plate and slowly char off the organic material.

15.19 Ignite the residue for 1 h at 1000°C in a muffle furnace.

15.20 Cool the crucible in a desiccator and weigh.

15.21 Calculate the percentage of solids in accordance with 17.1.

NOTE 3—If the percentage of solids (insoluble residue) is greater than 0.1 %, grind and mix the residue and determine the total milligrams of uranium in the residue by the photometric procedure in 16.1 – 16.10.

16. Photometric Procedure for Uranium

16.1 Transfer the ground, blended residue from 15.20 to a 100-mL beaker.

16.2 Add 10 mL of water and 10 mL of HCl (sp gr 1.19), cover, and boil for 10 min.

16.3 Add 5 mL of HNO₃ (sp gr 1.42) and boil until fuming of NO₂ ceases. Remove cover glass.

16.4 Add 5 mL of 9*M* H₂SO₄ and 2 mL of HF (48 %), then heat to dryness on the hotplate. Bake to fume off remaining H₂SO₄ and cool.

16.5 Wash down sides of beaker with water and add 5 mL of HNO₃.

16.6 Cover with a watchglass and digest for approximately 10 min near the boiling point.

16.7 Quantitatively transfer the solution to a 250-mL volumetric flask. Add 25 mL of NaOH solution and a few drops of H₂O₂. Make up to mark with water and mix.

NOTE 4—The solution must be basic for yellow sodium peruranate color to develop.

16.8 Measure the absorbance of the solution in a spectrophotometer at 425 nm in a 1-cm cell using a blank as reference. The blank is prepared by diluting 25 mL of NaOH, plus a few drops of H₂O₂, to 250 mL with water.

⁵ Whatman brand No. 40 or its equivalent has been found suitable.

16.9 Prepare a calibration curve covering the range from 0 to 50 mg of uranium from aliquots of a standard uranium solution. Proceed as in 16.5 – 16.8. Plot the milligrams of uranium against absorbance readings.

16.10 Determine the total milligrams of uranium in the sample solution from the calibration curve.

NOTE 5—If the sample solution falls outside the calibration range, dilute a portion with the reference-blank solution and read again.

17. Calculation

17.1 Calculate the percentage of insoluble residue, R , present as follows:

$$R = \frac{R_w \times 100}{S_w} \quad (1)$$

where:

R_w = weight of residue (see 15.20), g, and

S_w = weight of samples, g.

17.2 If the insoluble residue exceeds 0.1 %, calculate the percentage of nitric acid-insoluble uranium, U_N , and present as follows:

$$U_N = \frac{U}{S_w \times 10} \quad (2)$$

where:

U = uranium content calculated in 16.10, mg, and

S_w = weight of sample, g.

17.3 Calculate the percentage of nitric acid-insoluble uranium, U_u , on a uranium basis as follows:

$$U_u = \frac{U_N \times 100}{U_s} \quad (3)$$

where:

U_N = nitric acid-insoluble residue present (see 17.2), %, and

U_s = uranium in sample, %.

18. Precision and Bias

18.1 *Precision*—A relative standard deviation for this test method has been reported as 10 % at the 0.2 % HNO_3 insoluble uranium level (see 4.2).

18.2 *Bias*—For information on the bias of this test method see 4.2.

EXTRACTABLE ORGANIC MATERIAL

19. Scope

19.1 This test method is used to determine the extractable organic material in uranium-ore concentrates. It is recognized that certain water-soluble organic materials, such as flocculating agents, are not measured by this test method.

20. Summary of Test Method

20.1 This test method consists of a dual extraction using n -hexane on the solid uranium-ore concentrate sample and chloroform on a subsequent nitric acid solution of the sample. Each of the extractants is evaporated to measure the amount of organic material extracted.

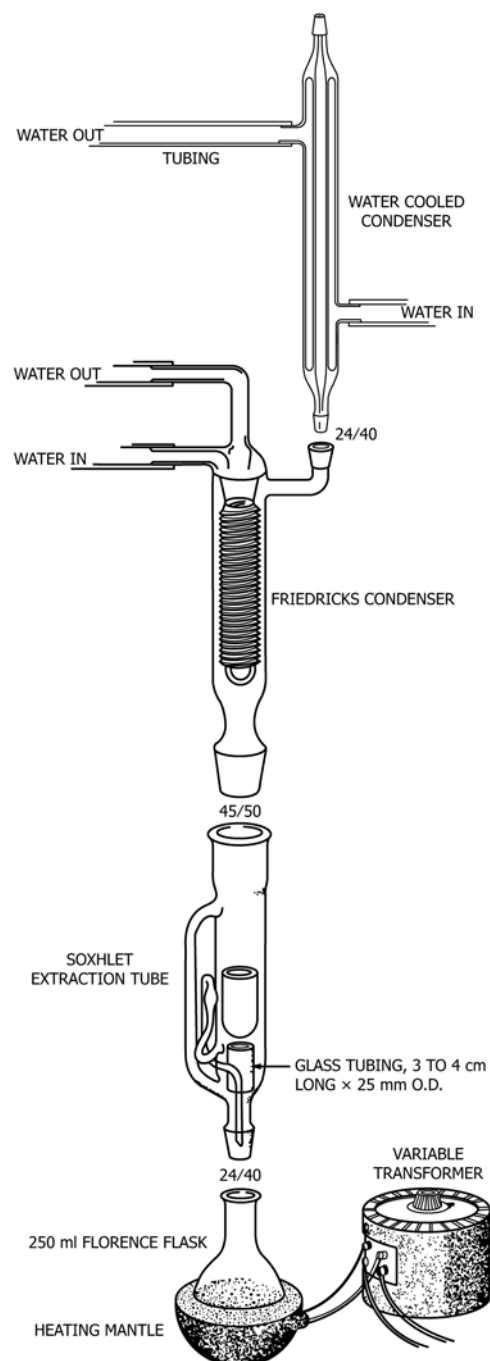


FIG. 1 Hexane Extraction Unit

21. Interferences

21.1 At the specification limit for extractable organic material established for uranium-ore concentrations, and within the scope of this test method, interferences are insignificant.

22. Apparatus

22.1 *Soxhlet Extraction Apparatus*—The n -hexane extraction is done in a Soxhlet extraction apparatus. Construct as follows (see Fig. 1):

22.1.1 Modify a medium Soxhlet extraction tube so that the sidearm siphon is about 2 cm high, therefore, reducing the volume of solvent needed. Insert a 3 to 4-cm long, 25-mm outside diameter glass tube upright into the extraction tube in such a manner that an extraction thimble may be placed on it.

22.1.2 Connect a 250-mL Florence flask, that has a 24/40 ground-glass joint on the lower end to the top of the extraction tube. A 250-mL heating mantle connected to a 7.5-A variable transformer shall be used to heat this.

22.1.3 Connect a Friedrichs condenser, that has a 45/50 ground-glass joint on the lower end, to the top of the extraction tube. Turn this side of the condenser upward, and fuse the outer member of a 24/40 ground-glass joint to it.

22.1.4 Connect a Graham condenser, that has a 24/40 ground-glass joint on the lower end, to the modified sidearm of the Friedrichs condenser. Unless the relative humidity is low, insulate the Graham condenser to prevent the condensation of water on the outside surface that might seep through the joint to the Friedrichs condenser. Foam insulation 1 cm thick may be used for this purpose. The Graham condenser is cooled with cold water from a water bath cooler, and may be required when *n*-hexane is used for the extraction.

22.2 *Heat gun* (hot-air electric dryer), may be used to evaporate the solvent in procedure 24.6 or 24.15.

22.3 *Extraction Thimbles*.

22.4 *Filter Paper*.⁶

22.5 *Phase Separator Paper*.⁷

23. Reagents

23.1 *n*-hexane—Whenever a new supply is used, it should be checked for nonvolatile residue. Evaporate 100.0 mL just to dryness in a weighted platinum dish, cool to room temperature, and reweigh the dish. If there is any residue, either make the appropriate blank correction or distill the solvent before use to remove the nonvolatile impurities.

23.2 *Nitric Acid (1 + 1)*—Mix equal volumes of concentrated (sp gr 1.42) reagent grade HNO₃ and distilled water.

23.3 *Chloroform*—Whenever a new supply of chloroform is to be used, it should be checked for nonvolatile residue as described in 23.1.

24. Procedure

24.1 Weigh 50.0 g of well-mixed, undried uranium-concentrate sample and transfer to an extraction thimble while tapping the thimble on a table top to compact and level the sample.

24.2 Place a plug of glass wool in the thimble above the sample. Support the thimble on the glass tube in the Soxhlet extraction tube so that when solvent condenses on the lower tip of the Friedrichs condenser, it will drop into the thimble.

24.3 Connect the extraction tube to the bottom of the Friedrichs condenser that is in series with the Graham condenser. Turn on the tap water coolant to the condensers.

NOTE 6—Tap water may be used in cooling both condensers if the amount of reagent lost during the refluxing (see 24.5) is not greater than 10 % of the volume added in 24.4. If the tap water is too warm, then the Graham condenser must be cooled by the refrigerated water cooler, or an ice-cooled condenser may be used in place of the Graham condenser.

24.4 Add a piece of sintered glass or several glass boiling beads and then 120 to 125 mL *n*-hexane to the 250-mL Florence flask. Attach the flask to the Soxhlet extraction tube.

24.5 Place the heating mantle below the Florence flask, connect to the variable transformer set at 55 to 60 V, and allow the reagent to reflux rapidly for 3 ½ to 4 h.

24.6 Pour the refluxed reagent into a weighed (*W*₁ in grams) platinum dish, and evaporate in a hood. An infrared lamp or hot air stream from a heat gun may be used.

NOTE 7—Exercise care in this evaporation. If a heat source is used, adjust the rate of heat input and velocity of air across the dish so that no sample will be mechanically lost. If a heat gun is used, the amount and temperature of the air directed against the sample are especially critical because the high rate of evaporation is likely to lower the temperature of the solution to the point where water will condense in the dish.

24.7 Allow the dish to come to room temperature while tilting and rotating it to spread the last few drops of solvent uniformly over the bottom.

NOTE 8—Do not allow the temperature of the dish to go below the dewpoint.

24.8 Weigh in open air at intervals on an analytical balance, recording the weight of the dish 5 min after the rate of loss has decreased to 0.5 mg/min.

NOTE 9—This weight is in grams as *W*₂.

24.9 Add a plastic-covered magnetic stirring bar and 100 mL of (1 + 1) nitric acid to a 400-mL beaker.

24.10 While magnetically stirring the acid, cautiously add the extracted sample from the extraction thimble. Stir until the sample is dissolved or until it is apparent that practically no more sample will dissolve.

24.11 Cool to about room temperature and transfer to a 500-mL separatory funnel. Add 100.0 mL of chloroform, stopper tightly, and shake as vigorously as possible for 60 s.

24.12 Allow the phases to separate.

NOTE 10—If emulsions form, transfer to centrifuge tubes and centrifuge to separate the phases.

24.13 Drain off the lower phase. If the lower phase is the chloroform layer, filter through a phase-separator filter paper into a graduated cylinder or narrow-neck flask. If the lower phase is the aqueous phase, drain and discard. Then filter the upper phase through a phase-separator filter paper into a graduated cylinder or narrow-neck flask.

24.14 Transfer 50.0 mL of the filtered chloroform into an ignited (900°C) platinum dish.

24.15 Place the platinum dish in a hood and evaporate until about 1 mL of chloroform remains. This evaporation may be done as described in 24.6.

24.16 Allow the dish to cool to room temperature while tilting and rotating it to spread the last few drops uniformly over the bottom.

⁶ Whatman brand size 33 by 94 mm has been found suitable.

⁷ Whatman IPS has been found suitable.

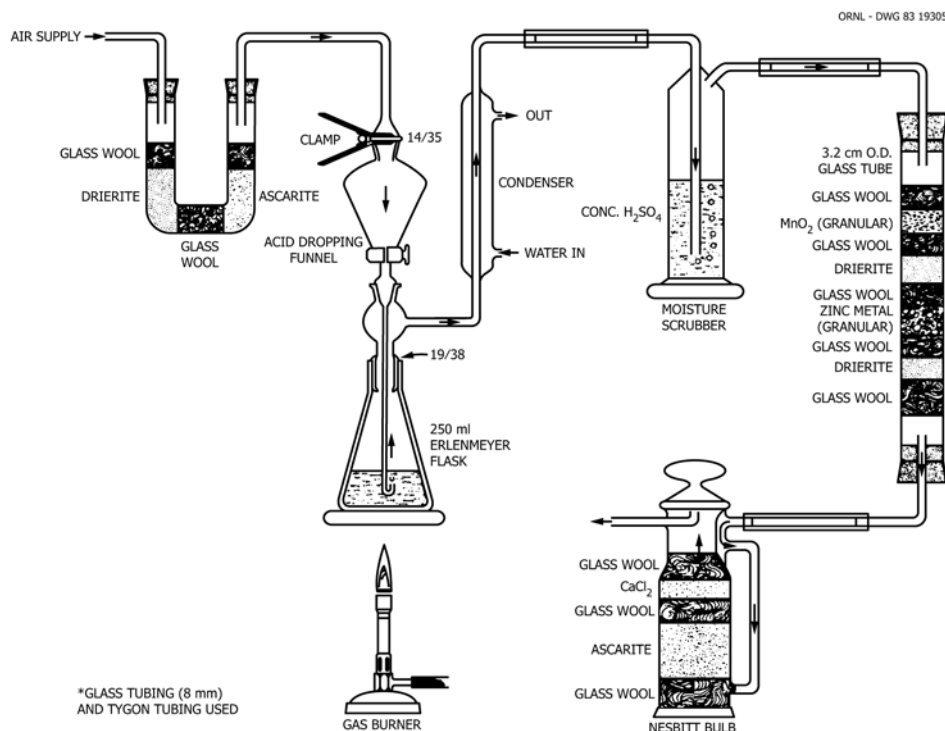


FIG. 2 Carbonate Apparatus

24.17 Weigh in open air on a recording balance or at intervals on an analytical balance, recording the weight of the dish 5 min after the rate of weight loss has decreased to 0.5 mg/min.

NOTE 11—This weight is in grams as W_3 .

24.18 Ignite the platinum dish at 900°C for a minimum of 30 min, cool to room temperature, and weigh.

NOTE 12—This weight is in grams as W_4 .

25. Calculation

25.1 Calculate the percentage of extractable organic material, O_m , as follows:

$$O_m = \frac{100 [(W_2 - W_1) + 2 (W_3 - W_4)]}{S_w} \quad (4)$$

where:

- W_2 = weight of platinum dish in 24.8, g,
- W_1 = weight of platinum dish in 24.6, g,
- W_3 = weight of platinum dish in 24.17, g,
- W_4 = weight of platinum dish in 24.18, g, and
- S_w = weight of sample.

26. Precision and Bias

26.1 *Precision*—A relative standard deviation for this test method has been reported as 18 % at the 0.1 % extractable organic level (see 4.2).

26.2 *Bias*—For information on the bias of this test method see 4.2.

DETERMINATION OF ARSENIC

27. Scope

27.1 The determination of Arsenic by diethyldithiocarbamate photometric method has been discontinued. Interested persons can obtain a copy in the C1022-02 version.

27.2 With appropriate sample preparation, Atomic Absorption Spectrometry as described in Test Methods C1219 may be used for arsenic determination.

27.3 As an alternative and with appropriate sample preparation, ICP-MS as described in Test Method C1287 may be used for arsenic determination.

CARBONATE BY CO₂ GRAVIMETRY

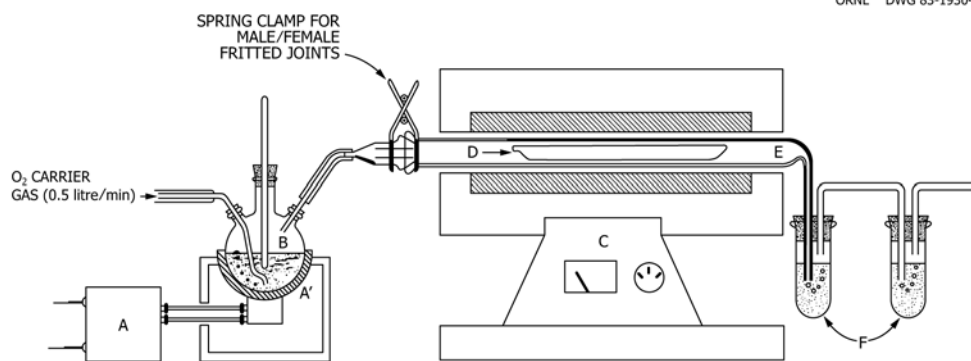
28. Scope

28.1 This test method covers the determination of 0.1 to 3 % carbonate in uranium-ore concentrate.

28.2 The concentration range can be extended by taking smaller sample weights.

29. Summary of Test Method

29.1 The carbonate in the sample is decomposed with hydrochloric acid and evolved as carbon dioxide. The incoming air is dried and the CO₂ is removed by passing it through NaOH and anhydrous calcium sulfate (CaSO₄). The evolved gases are scrubbed in H₂SO₄ to remove moisture and passed through a tower of manganese dioxide and zinc metal to



A, A'—Heating jacket controlled by variable transformer. Nominal temperature 80 to 85°C for water.
 B—One-liter three-necked with gas diffuser and thermometer 0 to 110°C. D.D. water used.
 C—Tube furnace, controlled by variable transformer with thermocouple. Operating temperature 850 ± 25°C.
 D—Sample boat.
 E—Pyrohydrolytic tube.
 F—Collection system; 10 mL of 0.2 N sodium hydroxide in first tube, 10 to 15 mL of water in second tube.

FIG. 3 Pyrohydrolysis Apparatus

remove any SO₂ or H₂S formed. The evolved gas is then absorbed by NaOH in a Nesbitt bulb and determined gravimetrically (1).

30. Apparatus

30.1 Carbonate Apparatus, (see Fig. 2).

31. Reagents

31.1 Sodium Hydroxide Coated Non-Fibrous Silicate, indicating (Ascarite II).⁸

31.2 Anhydrous Calcium Sulfate, indicating (Drierite).⁸

31.3 Glass Wool.

31.4 Manganese Dioxide, granular.

31.5 Zinc Metal, granular.

31.6 Sulfuric Acid (H₂SO₄, sp gr 1.84).

31.7 Hydrochloric Acid (5.5 M)—Dilute 50 mL of HCl (sp gr 1.19) to 100 mL with water.

32. Procedure

32.1 Weigh a sample (maximum of 5 g) to the nearest 0.01 g. The sample should contain approximately 20 mg CO₂. Transfer to an Erlenmeyer flask and add enough water to cover the inlet tube.

32.2 Attach the Nesbitt bulb, open the stopper and pass air through the apparatus for 10 to 15 min at the rate of 2 to 3 bubbles/s.

NOTE 13—Measure the flow rate at the H₂SO₄ moisture trap.

32.3 Remove the Nesbitt bulb without altering the air flow. Close the stopper and weigh the bulb to nearest 0.1 mg.

32.4 Open the stopper of the bulb and replace it on the apparatus.

32.5 Place 25 mL of 5.5 M HCl in the dropping funnel and force it into the flask by replacing the air inlet tube.

NOTE 14—If the uranium-ore concentrate was produced as a uranium peroxide, replace 25 mL of 5.5 M HCl with 25 mL of 5.5 M H₂SO₄ to prevent the release of chlorine.

32.6 Heat the Erlenmeyer flask with a small burner until the acid boils and adjust the burner to maintain gentle boiling.

32.7 Boil for 15 min, then shut off the flame.

32.8 Continue to pass air through the apparatus for an additional 10 min.

32.9 Remove the Nesbitt bulb and close the stopper immediately.

32.10 Reweigh the Nesbitt bulb to the nearest 0.1 mg.

32.11 Remove the Erlenmeyer flask from the apparatus while air is still flowing.

NOTE 15—Leave the air on until the flask is removed to prevent suck-back of the H₂SO₄.

32.12 Repeat the procedure in 32.1 – 32.10, without a sample, to obtain a blank.

33. Calculation

33.1 Calculate the percentage of carbonate, C_a, for the sample and the blank as follows:

$$C_a = \frac{136.36 (B - C)}{A} \quad (5)$$

where:

A = sample weight, g,

B = weight of Nesbitt bulb after absorption of CO₂, g, and

C = weight of Nesbitt bulb before absorption of CO₂, g.

33.2 Correct the percentage of CO₃ obtained on the sample for a blank.

33.3 Calculate the weight percentage of carbonate, C_u, on a uranium basis as follows:

⁸ Ascarite II and Drierite have been found to be acceptable for this application. They are, respectively, the trademarks of Arthur H. Thomas and W. A. Hammond Drierite Companies.



$$C_u = \frac{C_c \times 100}{U} \quad (6)$$

where:

C_c = corrected percentage of carbonate in the sample (see 33.2), and

U = uranium in the sample, %.

34. Precision and Bias

34.1 *Precision*—A relative standard deviation for this test method has been reported at 5 % at 1.0 % carbonate level (see 4.2).

34.2 *Bias*—For information about the bias of this test method see 4.2.

FLUORIDE BY ION-SELECTIVE ELECTRODE

35. Scope

35.1 This test method covers the determination of fluoride in uranium-ore concentrates.

36. Summary of Test Method

36.1 The fluoride is separated pyrohydrolytically by passing a stream of moist oxygen over a mixture of sample and fluoride-free uranium oxide (U_3O_8) in a reactor tube at 850°C. (The U_3O_8 acts as an accelerator in the presence of high concentrations of sodium, calcium, or magnesium.) The HF formed is absorbed in a dilute solution of sodium hydroxide and the fluoride ion concentration is measured with an ion-selective electrode (2, 3, 4).

37. Interferences

37.1 At the specification limit for fluoride, interference effects are insignificant.

38. Apparatus

38.1 *Pyrohydrolysis Apparatus*, (see Fig. 3).

38.2 *Gas-Flow Regulator and Flowmeter*.

38.3 *Three-Necked 1-L Flask*.

38.4 *Gas Diffuser*.

38.5 *Thermometer*.

38.6 *Male Ball-Joint Connector*.

38.7 *Heating Mantle*, for 1-L flask, controlled by variable transformer.

38.8 *Furnace*—A tube furnace capable of maintaining a temperature of 850°C. The bore of the furnace should be a minimum of 32 mm (1¼ in.) in diameter and 330 mm (13 in.) in length.

38.9 *Reactor Tube*, made from clear silica about 30 mm (1½ in.) in diameter and 460 mm (18 in.) in length having a female ball-joint connector at the entrance end and a delivery tube 9.5 mm (¾ in.) in diameter and 150 mm in length fused at right angles to the exit end.

38.10 *Absorption Vessels*—50-mL glass test tubes.

38.11 *Combustion Boat*—A quartz boat with 10-mL capacity and dimensions (100 mm long, 15 mm wide, and 10 mm deep).

38.12 *Fluoride-Ion Selective Electrode*.

38.13 *Millivolt Meter*, with saturated calomel reference electrode capable of reading to 1 mV.

38.14 *Magnetic Stirrer*.

39. Reagents

39.1 *Accelerator*—Fluoride-free uranium oxide (U_3O_8).

39.2 *Sodium Hydroxide Solution* (NaOH, 0.2 N)—Dissolve 8 g of NaOH in distilled water and dilute to 1 L.

39.3 *Buffer Solution* (0.001 N)—Dissolve 0.1 g of potassium acetate ($KC_2H_3O_2$) in water. Add 0.050 mL of acetic acid (sp gr 1.05) and dilute to 1 L.

39.4 *Fluoride Solution, Standard* (1 mL = 10 µg F)—Dissolve in water 0.221 g of sodium fluoride (NaF) previously dried at 110°C and dilute to 1 L in a volumetric flask. Pipet 10.0 mL of this solution into a 100-mL volumetric flask and dilute to volume with water. Mix and transfer the solution to a plastic container.

40. Procedure

40.1 Adjust the pyrohydrolysis system to operating conditions as follows:

40.1.1 Place the reactor tube in the furnace with the delivery tube as close as possible to the end (5 to 10 mm).

40.1.2 Turn on the furnace and allow it to reach 850°C. Adjust the controls to maintain this temperature within ±25 °C.

40.1.3 Fill the three-necked flask half full with water.

40.1.4 Place the flask on the heating mantle, then connect the gas diffuser to the flowmeter and the female socket to the reactor tube with a spring clamp.

40.1.5 Adjust the control on the heating mantle to bring the temperature of the water to 80 to 85°C.

40.1.6 Turn on the oxygen and adjust the flow to 500 mL/min. Flush the apparatus in this manner for 10 to 15 min.

40.2 Weigh 4 ± 0.01 g of powdered sample, mix thoroughly with 8 g of U_3O_8 accelerator, and place in a sample boat.

NOTE 16—A blank of 8 g U_3O_8 is run in a separate boat.

40.3 Connect the collection system. The collection system consists of two 50-mL test tubes in series. The first tube contains 10 mL of 0.2 N NaOH. The second tube contains 10 to 15 mL of water. The first tube is fitted with a two-holed stopper through which is passed the quartz delivery tube from the pyrohydrolysis apparatus and a glass inverted U-tube leading to the second tube. The gas stream escaping from the first tube during pyrohydrolysis is carried through the inverted U-tube into the water in the second test tube. Sufficient back pressure is created to ensure that all the fluoride is absorbed in the first tube.

NOTE 17—The delivery tube tip should be immersed to a depth of 15 mm below the surface of the NaOH solution.

40.4 Position the sample boat in the middle of the reactor tube and immediately close the tube.

40.5 Pyrohydrolyze for 60 min.

40.6 Remove the first test tube containing NaOH solution and rinse the delivery tube with distilled water into the tube.

40.7 Transfer the contents of the test tube to a 25-mL volumetric flask. Dilute to mark and mix.

40.8 Pipet 1 mL into a 100-mL plastic beaker, add 24 mL of water and 25 mL of buffer solution.

40.9 Place in a magnetic stirrer and insert the electrode pair.

40.10 Set the meter at the millivolt setting and stir the sample solution until a stable reading is reached. Record the millivolt reading.

40.11 Rinse electrodes with water and dry with absorbent tissue.

40.12 Read all samples and blank.

40.13 Prepare a calibration curve by adding, to separate 100-mL plastic beakers, the following amounts of fluoride standard solution (1 mL = 10 µg of fluoride): 0, 0.1, 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 mL. Dilute to 25 mL with distilled water. Add 25 mL of buffer solution just prior to measuring each standard individually as in 56.15 and 56.16. Plot mV readings against micrograms of fluoride using log/linear graph paper.

41. Calculation

41.1 Calculate the percentage of fluoride, F , as follows:

$$F = \frac{(C_s - C_B)}{W \times 400} \quad (7)$$

where:

C_s = fluoride from the calibration curve for the sample, µg,

C_B = fluoride from the calibration curve for the blank, µg, and

W = sample weight, g.

41.2 Calculate the percentage of fluoride, F_u , on a uranium basis as follows:

$$F_u = \frac{F \times 100}{U} \quad (8)$$

where:

F = fluoride (see 41.1), %, and

U = uranium in sample, %.

42. Precision and Bias

42.1 *Precision*—A relative standard deviation has been reported as 7 % at the 0.05 % fluoride level (see 4.2).

42.2 *Bias*—For information on the bias of this test method see 4.2.

HALIDES BY VOLHARD TITRATION

43. Scope

43.1 This test method covers the determination of halides except fluoride in uranium-ore concentrates.

44. Summary of Test Method

44.1 A sample of ore concentrate is digested in dilute HNO_3 without boiling. A known amount of standard silver nitrate solution is added and the silver halide precipitates that are formed are filtered. The excess silver nitrate in the filtrate is titrated with a standard potassium thiocyanate solution using ferric ammonium sulfate as indicator. The halide content of the sample is expressed as a chloride equivalent.

45. Apparatus

45.1 *Filter Paper*.⁹

46. Reagents

46.1 *Silver Nitrate Solution, Standard* (0.0500 N)—Weigh exactly 8.494 g of finely powdered silver nitrate (AgNO_3), dried at 110°C, into a 250-mL beaker. Dissolve the salt in water and dilute to exactly 1 L. Store the reagent in an amber-colored bottle.

46.2 *Potassium Thiocyanate Solution, Standard* (0.025 N)—Dissolve 2.43 g of potassium thiocyanate (KSCN) in 1 L of water.

46.3 *Nitric Acid* (HNO_3 , sp gr 1.42).

46.4 *Nitric Acid Solution* (1 + 4)—Add 200 mL of HNO_3 (sp gr 1.42) to 500 mL of water and boil to remove oxides of nitrogen. Dilute the cooled solution to 1 L with water.

46.5 *Ferric Ammonium Sulfate Indicator Solution*—Add 50 g of ferric ammonium sulfate to 200 mL of water and heat gently to dissolve. Add HNO_3 (sp gr 1.42) dropwise, while stirring, until the color of the solution changes from brown to pale yellow.

47. Standardization of Potassium Thiocyanate Solution

47.1 Pipet individual 10-mL aliquots of the 0.0500 N silver nitrate solution into two 250-mL beakers.

47.2 Add 25 mL of HNO_3 (1 + 4) solution and 10 mL of ferric ammonium sulfate indicator solution to each beaker.

47.3 Titrate with the potassium thiocyanate solution to the first permanent reddish-brown end point.

$$\text{Normality of KSCN} = \frac{0.5}{\text{mean titre (mL)}} \quad (9)$$

48. Procedure

48.1 Add 25 mL of boiled nitric acid solution to a 2.00 ± 0.01 -g sample and heat for 20 min at low heat. Do not boil. (If insoluble residue is evident, filter through filter paper using a small amount of paper pulp.)

48.2 Add 5.0 mL of the AgNO_3 standard solution by pipet and stir thoroughly. Heat at low heat until the precipitate coagulates.

48.3 Filter off the precipitated silver halides using filter paper.⁹ Wash the beaker and filter paper with water.

⁹ Whatman No. 42 has been found suitable.

48.4 Add 10 mL of ferric ammonium sulfate indicator solution to the filtrate and titrate the excess AgNO₃ with the KSCN standard solution to the first permanent ferric thiocyanate color.

49. Calculation

49.1 Calculate the percentage of halides (expressed as chloride), *H*, as follows:

$$\frac{H = 0.177 [A - (B \times C)]}{S} \quad (10)$$

where:

A = 0.0500 *N* AgNO₃ added, mL,
B = 0.025 *N* KSCN added, mL,
C = KSCN factor, the actual normality of KSCN (see 47.3) divided by 0.0500,
 0.177 = mg chloride/mL (0.0500 *N*) AgNO₃, and
S = sample weight, g.

49.2 Calculate the percentage of halides, *H_u*, on a uranium basis as follows:

$$H_u = \frac{H \times 100}{U} \quad (11)$$

where:

H = halide from 49.1, %, and
U = uranium in the sample, %.

50. Precision and Bias

50.1 *Precision*—A relative standard deviation for this test method has been reported as 25 % at 0.10 % chloride level (see 4.2).

50.2 *Bias*—For information on the bias of this test method see 4.2.

MOISTURE BY LOSS OF WEIGHT

51. Scope

51.1 This test method provides a means of process control used to estimate the moisture content of the material before shipment; and a means of determining the moisture content of a sample for the purpose of correcting impurity analyses where necessary.

51.2 Moisture, for contractual purposes, is usually determined during the course of ore-concentrate sampling as part of the procedure agreed upon between the supplier and the purchaser.

52. Summary of Test Method

52.1 A weighed portion of the sample is placed into a well-sealed oven that is fitted with an entry and exit port for the passage and circulation of dry air. The oven atmosphere is composed of dry air under a slight positive pressure. The sample is heated, then removed, cooled, weighed, and the loss in weight observed.

52.2 This procedure is repeated until the weight becomes constant or the loss in weight becomes insignificant.

53. Apparatus

53.1 *Drying Oven*, with inlet and outlet ports.

53.2 *Desiccator*.

53.3 *Vacuum Pump*.

53.4 *Wide-Mouth Weighing Bottles*, with covers, bottle size 40 by 50 mm.

53.5 *Drying Tube*.

54. Reagents

54.1 *Anhydrous Calcium Sulfate*, (Drierite).

55. Procedure

55.1 Transfer a 5-g sample of the ore concentrate to a tared weighing bottle.

55.2 Weigh the sample and weighing bottle and record the weight to the nearest 0.1 mg.

55.3 Place the sample bottle with the cover removed into the dry-air oven which has been heated to and thermostatically controlled at 110°C.

55.4 Open the oven after 24 h, replace the cover on the bottle, and quickly transfer the sample to a desiccator.

55.5 Allow the sample to cool to room temperature. After approximately 40 min, allow air to enter the desiccator.

55.6 Remove the sample weighing bottle from the desiccator and weigh immediately to the nearest 0.1 mg.

55.7 Return the sample to the oven and repeat 55.3 – 55.6 until no further loss in weight is noted or the change in weight for a 24-h period is less than 0.1 mg or a difference that is specified by user's QA requirement.

NOTE 18—Complete drying often requires several days.

NOTE 19—For UOC made of peroxides, the temperature for drying should be raised to 160°C.

56. Calculation

56.1 Calculate the percentage of moisture, *M*, as follows:

$$M = \frac{(W_2 - W_3) \times 100}{(W_2 - W_1)} \quad (12)$$

where:

*W*₁ = weight of weighing bottle, g,
*W*₂ = weight of weighing bottle plus sample, g, and
*W*₃ = weight of weighing bottle plus dried sample, g.

57. Precision and Bias

57.1 *Precision*—A standard deviation has been reported as 0.01 % absolute (see 4.2), using a 5 g sample and a weight change of 0.1 mg.

57.2 *Bias*—For information on the bias of this test method see 4.2.

PHOSPHORUS BY SPECTROPHOTOMETRY

58. Scope

58.1 This test method covers the determination of phosphorus in uranium-ore concentrates.

59. Summary of Test Method

59.1 The phosphorus compounds present in the sample are oxidized by potassium permanganate to orthophosphates in dilute nitric acid solution. Addition of ammonium vanadate and ammonium molybdate produces the colored phosphovanadomolybdate complex. This complex is extracted from the sample matrix with isoamyl alcohol. The absorbance of the extract is then measured spectrophotometrically at 400 nm (5 and 6).

60. Interferences

60.1 There are no known interferences. A blank is run to compensate for any possible absorbance due to the uranyl ion.

61. Apparatus

61.1 *Spectrophotometer*, with 1-cm cells in accordance with Practice E60.

61.2 *Laboratory Shaker*, with clamps to hold 250-mL separatory funnels.

61.3 *Centrifuge*, equipped to handle 15-mL centrifuge tubes.

62. Reagents

62.1 *Potassium Permanganate Solution (1 %)*—Dissolve 10 g of potassium permanganate (KMnO₄) in distilled water and dilute to 1 L.

62.2 *Sulfurous Acid (H₂SO₃)*—Saturate distilled water with SO₂.

62.3 *Ammonium Vanadate Solution (0.25 %)*—Dissolve 2.5 g of ammonium metavanadate (NH₄VO₃) in 500 mL of warm water, cool, add 20 mL of HNO₃ (sp gr 1.42) and dilute to 1 L with water.

62.4 *Ammonium Molybdate Solution (10 %)*—Dissolve 100 g of ammonium molybdate ((NH₄)₆Mo₇O₂₄·4H₂O) in about 800 mL of hot water, cool, and dilute to 1 L. Filter if necessary.

62.5 *Isoamyl Alcohol*.

62.6 *Phosphorus Solution, Standard (1 mL = 100 µg P)*—Weigh 4.2638 g of ammonium hydrogen phosphate ((NH₄)₂HPO₄). Dissolve in water and dilute to 1 L to produce a solution containing 1 mg phosphorus/mL. Dilute 10 mL of 1 mg of phosphorus/mL solution to 100 mL to produce a solution containing 100 µg phosphorus/mL.

63. Calibration

63.1 Prepare a calibration curve by adding 0, 10, 20, 30, 40, and 50 mL of phosphorus standard solution (100 µg of phosphorus/mL) to separate 250-mL beakers, each containing 0.5 g of pure U₃O₈.

63.2 Follow 64.2 – 64.19 of the procedure.

63.3 Plot absorbancies corrected for the blank against milligrams of phosphorus.

64. Procedure

64.1 Weigh a 0.5 to 1-g sample to the nearest 1 mg into a 250-mL beaker.

NOTE 20—A blank containing the same weight of uranium as the sample should be carried through the procedure. Nuclear grade UO₂ or U₃O₈ is suitable for this purpose.

64.2 Dissolve the sample in 10 mL of HNO₃ (sp gr 1.42) by digesting on a hot plate until dissolution is complete.

64.3 Dilute the solution to approximately 50 to 75 mL with water.

NOTE 21—Some uranium-ore concentrates may produce an insoluble residue of silica, in which case the solution should be filtered through a Whatman No. 541 filter paper or equivalent, and the residue washed well with hot water. The washings should be added to the main filtrate.

64.4 Transfer the solution to a 500-mL volumetric flask and dilute to volume with water. Pipet a 50-mL aliquot into a 250-mL Erlenmeyer flask.

64.5 Add 5 mL of 1 % KMnO₄ solution and boil for 3 min.

64.6 Add H₂SO₃ dropwise until the solution clears.

64.7 Boil off the excess sulfur dioxide and evaporate the solution to a volume of about 10 mL.

64.8 Cool the solution and transfer it to a 50-mL stoppered graduated cylinder keeping the volume to about 30 mL after three water washings.

NOTE 22—At this point, ensure that the separatory funnels are clean and ready for use on the shaker. Proceed from this point as rapidly as possible.

64.9 Add 5 ± 0.5 mL of HNO₃ (sp gr 1.42) from a graduated cylinder.

64.10 Add 5 mL of ammonium vanadate solution and mix.

64.11 Add 5 mL of ammonium molybdate solution, dilute to 50 mL, stopper the cylinder, and shake.

64.12 Transfer to a 250-mL separatory funnel without washing.

64.13 Add 50 ± 0.5 mL of isoamyl alcohol.

64.14 Shake for 5 min.

64.15 Discard the lower aqueous layer, and let a little solvent run through the spout of the funnel to clean it.

64.16 Transfer a portion of the organic layer to a 15-mL centrifuge tube.

64.17 Centrifuge for about 1 min.

64.18 Measure the absorbance of the organic layer in a 1-cm cell at 400 nm using isoamyl alcohol as the reference.

64.19 Measure the absorbance of the blank solution and subtract the absorbance from all the sample readings.

64.20 Using either the calibration curve (see 63.3) or a factor, obtain the phosphorus content in milligrams of the 50-mL aliquot (see 64.4).

65. Calculation

65.1 Calculate the percentage of phosphorus, *P*, as follows:

$$P = \frac{C}{W} \quad (13)$$

where:

C = phosphorus in the aliquot (see 64.20), mg, and

TABLE 1 Instrumental Conditions

Element	Wavelength, nm	Flame	Determination Range in Solution Aspirated, µg/mL
Calcium	422.7	N ₂ O/C ₂ H ₂	0.02–2
Iron	248.3	N ₂ O/C ₂ H ₂	0.05–2
Magnesium	285.2	N ₂ O/C ₂ H ₂	0.05–2
Molybdenum	313.3	N ₂ O/C ₂ H ₂	0.2–2
Titanium	365.3	N ₂ O/C ₂ H ₂	0.2–2
Vanadium	318.4	N ₂ O/C ₂ H ₂	0.1–2

W = weight of sample, g.

65.2 Calculate percentage of phosphorus, P_u , on a uranium basis as follows:

$$P_u = \frac{100 C}{W \times U} \quad (14)$$

where:

C = phosphorus in the aliquot, mg,

W = weight of sample, g, and

U = uranium in the sample, %.

66. Precision and Bias

66.1 *Precision*—A relative standard deviation has been reported as 6 % at 0.5 % phosphorus level, and 25 % at 0.05 % phosphorus level (see 4.2).

66.2 *Bias*—For information on the bias of this test method see 4.2.

DETERMINATION OF SILICON

67. Scope

67.1 The determination of Silicon by gravimetric method has been discontinued. Interested persons can obtain a copy in the C1022-02 version.

67.2 Silicon may be determined by X-Ray Fluorescence analysis following preparation as described in Practice C1110.

DETERMINATION OF THORIUM

68. Scope

68.1 The determination of Thorium by the thorin photometric method has been discontinued. Interested persons can obtain a copy in the C1022-02 version.

68.2 With appropriate sample preparation, ICP-MS as described in Test Method C1287 may be used for thorium determination.

CALCIUM, IRON, MAGNESIUM, MOLYBDENUM, TITANIUM, AND VANADIUM BY ATOMIC ABSORPTION SPECTROPHOTOMETRY

69. Scope

69.1 This test method is suitable for the determination of calcium, iron, magnesium, molybdenum, titanium, and vanadium in uranium-ore concentrates. The nominal determination ranges of the elements are given in Table 1. The range of

concentrations measured can be varied considerably by appropriate dilution of the sample solution (7).

69.2 For simultaneous determination of metals by plasma emission spectroscopy refer to Test Methods C761, Sections 251 to 270.

70. Summary of Test Method

70.1 A portion of homogenized ore-concentrate sample is dissolved in nitric acid and any silica is removed by evaporation with hydrofluoric acid. The residue is fused with potassium bisulfate, redissolved in nitric acid, and diluted to standard volume.

70.2 The sample solution, together with a blank and a series of calibration standard solutions that all contain 10 g of potassium bisulfate and 50 mL of nitric acid/L are aspirated into a nitrous oxide-acetylene flame of an atomic absorption spectrophotometer. The absorbances due to the various elements are measured and the impurity concentrations in the samples are calculated from calibration curves.

70.3 The concentration of uranium in the sample solution being analyzed is less than 2 g/L and, at this concentration, it is not necessary to make a corresponding addition to the calibration standards.

70.4 In addition to providing a fusion medium to ensure complete dissolution of the ore concentrate, the potassium bisulfate acts as an ionization suppressor in the flame.

71. Interferences

71.1 Atomic absorption spectrophotometry is a specific analytical technique. However, because uranium-ore concentrates vary widely in both the nature and concentration of impurities, the performance of this test method should be checked in accordance with Section 74.

72. Apparatus

72.1 *Atomic Absorption Spectrophotometer*.

72.2 *Pressure-Reducing Valve*, suitable for use with nitrous oxide.

72.3 *Platinum Dishes*, (7.6-cm diameter).

73. Reagents

73.1 *Nitric Acid* (1 + 1)—Add a volume of high-purity HNO₃ (sp gr 1.42) to an equal volume of water and mix.

73.2 *Hydrofluoric Acid* (48 %).

73.3 *Potassium Bisulfate* (KHSO₄).

73.4 *Potassium Bisulfate-Nitric Acid Solution*—Dissolve 20 ± 0.5 g of high-purity KHSO₄ in about 50 mL of water. Add 100 mL HNO₃ (sp gr 1.42), dilute to 1 L, and mix.

73.5 *Sulfuric Acid* (sp gr 1.84).

73.6 *Calcium Solution, Standard* (1 mg/mL)—Dissolve 1250 ± 2 mg of calcium carbonate (CaCO₃), previously dried at 110°C for 1 h, in 50 mL of HNO₃ (1 + 1). Boil for 5 min, allow to cool, and dilute with water to 500 mL in a volumetric flask.

73.7 Iron Solution, Standard (1 mg/mL)—Dissolve 500 ± 1 mg of pure iron (Fe) in 50 mL of HNO_3 (1 + 1). Cool and dilute with water to 500 mL in a volumetric flask.

73.8 Magnesium Solution, Standard (1 mg/mL)—Dissolve 500 ± 1 mg of pure magnesium (Mg) in 50 mL of HNO_3 (1 + 1). Cool and dilute to 500 mL in a volumetric flask.

73.9 Molybdenum Solution, Standard (1 mg/mL)—Dissolve 750 ± 1 mg of molybdenum trioxide (MoO_3), previously dried at 350°C for 2 h, in 25 mL of ammonia solution (sp gr 0.88) and 100 mL of water. Boil to remove excess ammonia. Cool and dilute to 500 mL in a volumetric flask.

73.10 Titanium Solution, Standard (1 mg/mL)—Dissolve 834 ± 1 mg of titanium dioxide (TiO_2) in 10 mL of sulfuric acid (sp gr 1.84) and 0.8 g of ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$). Heat until the TiO_2 dissolves and allow the solution to cool to room temperature. Dilute to 500 mL with water in a volumetric flask.

73.11 Vanadium Solution, Standard (1 mg/mL)—Dissolve 1148 ± 2 mg of ammonium metavanadate NH_4VO_3 , previously dried at 120°C for 1 h, in 50 mL of HNO_3 (1 + 1). Heat to assist dissolution. Cool and dilute to 500 mL in a volumetric flask.

73.12 General Metals Solution, Standard Combined (100 $\mu\text{g}/\text{mL}$)—Pipet 100 mL of each standard solution (1 mg/mL) of aluminum, calcium, iron, magnesium, molybdenum, vanadium, and zinc into a 1-L volumetric flask. Dilute to volume with water and mix.

73.13 General Metals Solution, Standard Combined (10 $\mu\text{g}/\text{mL}$)—Pipet 10 mL of the combined standard (100 $\mu\text{g}/\text{mL}$) into a 100-mL standard flask. Add 5 mL of nitric acid (sp gr 1.42) and dilute to volume with water.

74. Check on Method Performance

74.1 Whenever a new type of ore concentrate is analyzed, the performance of the method shall be checked by measuring the recovery of known concentrations of added impurities.

74.2 Dissolve two separate 1.000 ± 0.005 -g portions of the same homogenized sample following the procedure detailed in **76.1 – 76.4**, but adding 5.0 mL of combined general-metal standard solution (100 $\mu\text{g}/\text{mL}$) to one of the two samples before dissolution.

74.3 Measure the absorbances of the two solutions for the elements of interest using the conditions employed in **76.5** and **76.6**.

74.4 Obtain the micrograms of metal per millilitre for each of the two solutions from the calibration curves and calculate the percentage recovery of the added elements.

75. Calibration

75.1 Into a series of six 500-mL volumetric flasks, add by pipet 0, 5, 10, and 25 mL of combined general-metals standard (10 $\mu\text{g}/\text{mL}$) and 5 and 10 mL of combined general-metals standard (100 $\mu\text{g}/\text{mL}$).

75.2 To each flask, add 250 mL of potassium bisulfate-nitric acid solution and dilute to volume with water. The six flasks

contain respectively 0, 0.1, 0.2, 0.5, 1, and 2 $\mu\text{g}/\text{mL}$ of each of the metals of interest. If these solutions are to be stored, they should be transferred to polyethylene bottles.

75.3 Aspirate the standards and blank under the same instrumental conditions as used for the sample (see **76.5** and **76.6**).

76. Procedure

76.1 Dissolve 1.000 ± 0.005 g of homogenized sample in 10 mL of HNO_3 (sp gr 1.42) in a platinum dish. Add 10 mL HNO_3 (sp gr 1.42) to a second platinum dish as a blank and treat it in the same way as a sample.

76.2 Add 2 mL of HF (48 %) and evaporate the solution to dryness. Add 5 ± 0.05 g KHSO_4 to the residues and heat gently over a burner increasing the temperature gradually until a clear melt is obtained.

76.3 Allow the dish and contents to cool. Add 25 mL of HNO_3 (sp gr 1.42) and about 20 mL water. Heat gently until dissolution is complete.

76.4 Allow the solution to cool and transfer it to a 500-mL volumetric flask washing the dish with two 20-mL volumes of water. Dilute to 500 mL with water and mix.

76.5 Set up the atomic-absorption spectrophotometer in accordance with to the manufacturer's instructions using a nitrous oxide-acetylene flame and the relevant conditions given in **Table 1**.

NOTE 23—The burner head is aligned parallel to the light path except for the determination of magnesium when it is set at an angle of 45° .

76.6 Following the manufacturer's operating instructions, obtain absorbance readings for the impurity elements of interest in the sample and corresponding blank, and for the calibration standards as described in **Section 75**.

76.7 Correct the absorbances of the calibration standards for the calibration blank and construct calibration curves by plotting corrected absorbance against micrograms of element per millilitre.

76.8 Correct the absorbance of the impurity elements in the sample for the reagent blank and obtain their concentration in micrograms per millilitre from the appropriate calibration curves.

76.9 If the absorbance of the sample is greater than that of the highest calibration standard, pipet a 10-mL aliquot of the sample and the blank solution prepared in **76.4** into 100-mL volumetric flasks. Add 45 mL of potassium bisulfate-nitric acid solution and dilute to volume with water. Repeat the procedure detailed in **76.6 – 76.8**.

77. Calculation

77.1 Calculate the percentage of impurity element concentration, E , in the sample as follows:

$$E = \frac{C \times D \times 0.05}{W} \quad (15)$$

where:

C = concentration of element in the solution aspirated, $\mu\text{g/mL}$,
 D = dilution factor (10) if applicable (see 76.9), and
 W = weight of sample taken, g.

77.2 Calculate the percentage of impurity element concentration, E_u , on a uranium basis as follows:

$$E_u = \frac{C \times D \times 5}{W \times U} \quad (16)$$

where:

C = concentration of element in the solution aspirated, $\mu\text{g/mL}$,
 D = dilution factor (10) if applicable (see 76.9),
 W = weight of sample taken, g, and
 U = uranium in original sample, %.

78. Precision and Bias

78.1 *Precision*—The relative standard deviation, based on 74 determinations at various impurity levels in a range of different ore concentrates, varies between 5 and 10 % (see 4.2).

78.2 *Bias*—For information about the bias of this test method see 4.2.

POTASSIUM AND SODIUM BY ATOMIC ABSORPTION SPECTROPHOTOMETRY

79. Scope

79.1 This test method is suitable for the determination of sodium and potassium in uranium-ore concentrates in the range from 0.05 to 10 % on a uranium basis.

80. Summary of Test Method

80.1 A portion of the sample is dissolved in nitric acid. The silica is volatilized or solubilized by evaporation with hydrofluoric acid. Cesium is added as an ionization suppressant and the solution is diluted to contain 0.1 % sample, 0.05 % cesium, and 5 % nitric acid.

80.2 The prepared sample solutions, together with standard calibration solutions, are aspirated into an air-acetylene flame of an atomic-absorption spectrophotometer. The absorbance readings of the samples are compared to those of the standard solutions. Because the uranium concentration in the sample solutions is below the level required to produce nonspecific absorption, the standards do not need to be prepared in a uranium-based matrix solution.

81. Interferences

81.1 Because of the variation in the nature and concentration of impurities in uranium-ore concentrates, a check must be kept on the potential interference in the atomic absorption flame process by following the procedure in Section 84.

82. Apparatus

82.1 *Atomic Absorption Spectrophotometer*.

82.2 *Platinum Dishes* (7.6-cm diameter).

83. Reagents

83.1 *Nitric Acid (1 + 1)*—Add a volume of HNO_3 (sp gr 1.42) to an equal volume of deionized water and mix.

83.2 *Hydrofluoric Acid* (48 %).

83.3 *Cesium Solution, Stock (1 %)*—Dissolve 14.66 ± 0.05 g of anhydrous cesium nitrate (CsNO_3) in 20 mL HNO_3 (1 + 1) and 200 mL of water. Dilute to 1 L with water.

83.4 *Cesium Solution (0.1 %)*—Add 100 mL HNO_3 (sp gr 1.42) to 100 mL cesium solution (1 %) and dilute to 1 L with water.

83.5 *Sodium Solution, Standard (1 g/L)*—Dry some anhydrous sodium nitrate (NaNO_3) at 140°C for 1 h. Dissolve 1.848 g of dried NaNO_3 in 50 mL HNO_3 (1 + 1) and dilute to 500 mL with water in a volumetric flask.

83.6 *Potassium Solution, Standard (1 g/L)*—Dry some anhydrous potassium nitrate (KNO_3) at 140°C for 1 h. Dissolve 1.293 g of dried KNO_3 in 50 mL HNO_3 (1 + 1) and dilute to 500 mL with water in a volumetric flask.

83.7 *Sodium-Potassium Solution, Standard (100 $\mu\text{g/mL}$)*—Pipet 10 mL of sodium solution (1 g/L) and 10 mL of potassium solution (1 g/L) into a 100-mL volumetric flask and dilute to volume with water.

83.8 *Sodium-Potassium Solution, Standard (10 $\mu\text{g/mL}$)*—Pipet 10 mL of sodium-potassium solution (100 $\mu\text{g/mL}$) into a 100-mL volumetric flask and dilute to volume with water.

83.9 *Sodium-Potassium Solution, Standard (1 $\mu\text{g/mL}$)*—Pipet 10 mL of sodium-potassium solution (10 $\mu\text{g/mL}$) into a 100-mL volumetric flask and dilute to volume with water.

84. Check on Method Performance

84.1 In order to confirm the satisfactory operation of the test method, prepare duplicate weights of an ore-concentrate sample for analysis following the procedure in 86.1 – 86.6, but adding 2.0 mL of sodium-potassium solution (100 $\mu\text{g/mL}$) to one portion of sample before dissolution.

84.2 Calculate the percentage recovery of the added sodium-potassium standard.

85. Calibration

85.1 Pipet appropriate volumes of the 1, 10, and 100- $\mu\text{g/mL}$ sodium-potassium standard solutions into 100-mL volumetric flasks containing 50 mL of cesium solution (0.1 %) to give a range of standards containing 0, 0.2, 0.5, 1.0, 2.0, 5.0, and 10 $\mu\text{g/mL}$ of sodium and potassium when diluted to volume. Transfer to polyethylene bottles.

85.2 Aspirate the standards into the air-acetylene flame under the same conditions as those used for the samples (see 86.6) and record the absorbance for both sodium and potassium.

85.3 Correct the absorbances for the blank and plot micrograms of sodium per millilitre and micrograms of potassium per millilitre against corrected absorbances.

86. Procedure

86.1 Weigh 0.100 ± 0.001 g of homogenized sample into a platinum dish, and add 5 mL of NO_3 (sp gr 1.42) and 2 mL of HF (48 %). Add the same volume of acids to a second platinum dish in order to determine the reagent blank and process this in the same way as the sample.

86.2 Heat both platinum dishes and evaporate the solutions to dryness. Allow the dishes to cool, add 5 mL of water and 2 mL of HNO_3 (1 + 1), and evaporate to near dryness. Add 20 mL of water and heat to redissolve.

86.3 Allow the solutions to cool, then transfer them to 100-mL polypropylene volumetric flasks, rinsing the dishes with water. Add 50 mL of cesium solution (0.1 %), dilute to volume with water, mix, and transfer to a polyethylene bottle. The solution now contains sample (0.1 %), cesium (0.05 %), and HNO_3 (5 %).

86.4 Pipet 5 mL of the 0.1 % sample solution into a volumetric flask, add 22.5 mL of cesium solution (0.1 %), and dilute to 50 mL with water. This solution contains sample (0.01 %), cesium (0.05 %), and HNO_3 (5 %). Dilute a 5-mL aliquot of the blank solution following exactly the same procedure. Transfer the prepared solutions to polyethylene bottles.

86.5 Set up the atomic absorption spectrophotometer in accordance with the manufacturer's instructions for determining sodium and potassium using an air-acetylene flame and wavelength settings of 589.0 nm for sodium and 766.5 nm for potassium.

86.6 Aspirate the sample and blank solutions and the calibration standards into the flame and record the absorbances at both wavelengths. If the absorbance value for the sample exceed that of the 10- $\mu\text{g/mL}$ calibration standard solution, nebulize the diluted sample and blank prepared in 86.4.

87. Calculation

87.1 Correct the absorbances of the samples for the reagent blank and, from the calibration curves, obtain the micrograms of sodium per millilitre and micrograms of potassium per millilitre.

87.2 When the 0.1 % sample solution is nebulized (see 117.4), calculate the percentage of sodium and potassium concentrations, S_u or P_u respectively, on a uranium basis as follows:

$$S_u \text{ or } P_u = \frac{C \times 10}{U} \quad (17)$$

where:

C = sodium or potassium, $\mu\text{g/mL}$, and
 U = uranium in the sample, %.

87.3 When the 0.01 % sample solution is nebulized (see 117.5), calculate the percentage of sodium and potassium concentrations using the same equation in 87.2.

88. Precision and Bias

88.1 *Precision*—The relative standard deviations, measured at varying levels and on a variety of different ore concentrates, has been reported as sodium 9.5 % and potassium 8.0 % (see 4.2).

88.2 *Bias*—For information on the bias of this test method see 4.2.

BORON BY SPECTROPHOTOMETRY

89. Scope

89.1 This test method covers the determination of boron in uranium-ore concentrates when present in concentrations of more than 0.001 % by weight (10 $\mu\text{g/g}$).

90. Summary of Test Method

90.1 The sample of ore concentrate is dissolved in 12 M HCl , with the addition of HNO_3 if necessary. An aliquot is treated with HCl and H_2SO_4 and fumed. The resulting solution is diluted and an aliquot is mixed with concentrated H_2SO_4 and carminic acid ($\text{C}_{22}\text{H}_{20}\text{O}_{13}$) to form the bluish-red carmine-boron complex. This solution is measured spectrophotometrically at 610 nm (8).

91. Interferences

91.1 Nitrate ion is removed by fuming with H_2SO_4 .

91.2 Vanadium is reduced to the tetravalent state; in this form it does not interfere.

91.3 Titanium and zirconium do not interfere at levels normally found in uranium-ore concentrate (below 0.10 % titanium and 5 % zirconium).

91.4 Uranium forms a carmine-uranium complex which has an absorbance at 610 nm. This interference can be corrected for by running a uranium blank. Each gram of uranium in the sample produces an interference equivalent to approximately 5 μg of boron.

91.5 Fluoride ion can cause loss of boron by volatilization during the H_2SO_4 fuming stage.

92. Apparatus

92.1 *Spectrophotometer*, with 1-cm cells in accordance with Practice E60.

92.2 *Platinum Dishes*, 50-mL.

92.3 *Micropipet*, 100- μL .

92.4 *TFE-Fluorocarbon Beakers and Covers*, 250-mL.

92.5 *Plastic Volumetric Flasks*, 25 and 50-mL.

92.6 *Plastic Pipets*, 25-mL.

93. Reagents

93.1 *Hydrochloric Acid* (HCl) (sp gr 1.19).

93.2 *Nitric Acid* (HNO_3) (sp gr 1.42).

93.3 *Sulfuric Acid* (H_2SO_4) (sp gr 1.84).

93.4 *Sulfuric Acid (9 M)*—Carefully add, while stirring, 500 mL sulfuric acid (H₂SO₄) (sp gr 1.84) to 500 mL of distilled water, mix, cool, and dilute to 1 L.

93.5 *Carminic Acid Solution (0.25 g/L)*—Dissolve 0.250 g of carminic acid (1,3,4-(HO)₃-2CO(CHOH)₄CH₃-C₆ COC₆H₅-5-COOH-6-OH8CH₃CO) in 1 L of sulfuric acid (H₂SO₄) (sp gr 1.84). Store in a plastic container and keep closed.

93.6 *Boron Solution, Standard (100 µg/mL)*—Dissolve 0.5716 g of boric acid (H₃BO₃), previously dried at 110°C, in distilled water and dilute to 1 L.

93.7 *Sodium Carbonate (Na₂CO₃), boron-free.*

93.8 *Uranium Solution, Standard (100 g/L)*—Dissolve 11.79 g of high-purity U₃O₈ (<1 µg boron/g) in HNO₃ (1 + 1) and dilute to 100 mL with water.

94. Calibration

94.1 Prepare a series of standards by pipetting 2, 4, 6, 8, and 10 mL of the standard boron solution (100 µg of boron/mL) into 100-mL plastic volumetric flasks. Distilled water is used as a blank.

94.2 Dilute standards to volume with distilled water and mix.

94.3 Follow 95.9 – 95.11 of the procedure.

94.4 Prepare a calibration curve by plotting micrograms of boron in the standards against the corresponding absorbance.

95. Procedure

95.1 Weigh a uranium-ore concentrate sample of up to 5 g (±0.001 g) into a 250-mL TFE-fluorocarbon beaker. Carry a reagent blank throughout the procedure.

NOTE 24—The sample should contain 100 to 500 µg of boron.

95.2 Wet the sample with 5 mL of distilled water and add 20 mL of HCl (sp gr 1.19).

95.3 Cover the TFE-fluorocarbon beaker and heat the sample gently until it dissolves.

NOTE 25—Add 0.5 mL HNO₃ (sp gr 1.42) or more to complete the sample dissolution if necessary.

95.4 Cool the sample solution and transfer to a 50-mL plastic volumetric flask. Dilute to volume with distilled water and mix.

NOTE 26—If the solution is cloudy, filter or centrifuge before diluting to volume and fuse the residue with 2 to 4 g Na₂CO₃. Dissolve the fusion with HCl (sp gr 1.19) and add the solution to the 50-mL plastic volumetric flask containing the sample.

95.5 Transfer 25 mL of the sample solution using a plastic pipet into a 250-mL TFE-fluorocarbon baker.

95.6 Add 5 mL of HCl (sp gr 1.19) and 10 mL of 9 M H₂SO₄. Heat the solution until the sample just begins to fume.

NOTE 27—Excessive fuming may volatilize boron; therefore, control of the fuming step is critical.

95.7 Cool and transfer the solution into a 25-mL plastic volumetric flask with distilled water. Dilute to volume with water and mix.

95.8 Using a micropipet, transfer a 1-mL aliquot into a dry 50-mL plastic vial.

95.9 Add 5 mL H₂SO₄ (sp gr 1.84) and 5 mL of carminic acid solution. Immediately cap the vial and mix.

NOTE 28—The solution must be capped immediately since sulfuric acid tends to pick up water which adversely affects the condensation reaction resulting in incomplete color development.

95.10 After 30 min, measure the absorbance at 610 nm in a 1-cm cell using a reagent blank as a reference.

95.11 Using either the calibration curve (see 94.4) or a calibration factor, obtain the boron content in micrograms for the 1-mL aliquot (see 95.8).

96. Determination of Uranium Blank

96.1 Pipet 5, 10, and 20-mL aliquots of the standard uranium solution into separate 250-mL TFE-fluorocarbon beakers. These aliquots are equivalent to 1, 2, and 4 g of uranium in the sample.

96.2 Carry through the procedure in 95.6 – 95.11.

96.3 Plot apparent boron content against grams of uranium and calculate the slope in micrograms of boron per gram of uranium and use this for the blank correction in 97.2.

97. Calculation

97.1 Calculate the concentration of boron, B_u , on a uranium basis (uncorrected) as follows:

$$B_u = \frac{50 C \times 100}{W \times U} \quad (18)$$

where:

C = boron in the 1-mL aliquot, mg,
 W = weight of sample, g, and
 U = uranium in the sample, %.

97.2 Calculate the percentage of boron B_c on a uranium basis as follows; correcting for the apparent boron due to uranium interference:

$$B_c = (B_u - D)10^{-4} \quad (19)$$

where:

B_u = boron per gram of uranium, µg, and
 D = uranium blank calculated in 96.3.

98. Precision and Bias

98.1 *Precision*—A relative standard deviation has been reported as 5 % at 0.005 % boron level and 2 % at 0.040 % boron level (see 4.2).

98.2 *Bias*—based on spiked samples show 94 to 106 % recoveries (see 4.2).

99. Keywords

99.1 concentrates; uranium ore



REFERENCES

- (1) Furman, N. H., (Editor), *Scott's Standard Methods of Chemical Analysis*, Joseph D. Van Nostrand Co., Inc., 1962, Vol 1, pp. 298–299.
- (2) De Boer, J. H., “The Determination of Fluoride in Uranium Oxide,” *Chemisch Weekblad*, Vol 21, 1924, p. 404.
- (3) Lamar, W. L., and Seigmiller, E. G., *Industrial and Engineering Chemistry, Analytical Edition*, Vol 13, 1941, p. 901.
- (4) Powell, R. H., and Menis, O., *Analytical Chemistry*, Vol 30, 1958, p. 1546.
- (5) Snell, F. D., and Snell, C. T., “Colorimetric Methods of Analysis,” Vol IIA, Joseph D. Van Nostrand Co., 1959, pp. 561–562.
- (6) Elwell, W. T., and Wilson, H. N., “The Colorimetric Determination of Phosphorus in Steel and Copper—Base Alloys,” *Analyst*, Vol 81, 1956, pp. 136–143.
- (7) Scarborough, J. M., “Determination by Atomic Absorption of Molybdenum, Ruthenium, Palladium, and Rhodium in Uranium Alloys,” *Analytical Chemistry*, Vol 41, 1969, p. 250.
- (8) Day, G. T., and Dunlop, G. A., “Development of an Analytical Method to Determine Boron in Yellowcake and Related Materials,” *Eldorado Nuclear Ltd., Report AR82-2*, 1981.

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