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Standard Test Method for Isotopic Uranium in Water by Radiochemistry¹

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1. Scope

1.1 This test method covers the determination of alpha-particle-emitting isotopes of uranium in water by means of chemical separations and alpha pulse-height analysis (also known as alpha-particle spectrometry). Uranium is chemically separated from a water sample by coprecipitation with ferrous hydroxide, anion exchange, and electrodeposition. The test method applies to soluble uranium as well as to any uranium that might be present in suspended matter in the water sample. This test method is applicable for uranium processing effluents as well as substitute ocean water. When suspended matter is present, an acid dissolution step is added to assure that all of the uranium dissolves. It is the user's responsibility to ensure the validity of this test method for waters of untested matrices.

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

1.3 *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.* Specific warning statements are given in Section 9.

2. Referenced Documents

2.1 ASTM Standards:²

- C859 Terminology Relating to Nuclear Materials
- C1163 Practice for Mounting Actinides for Alpha Spectrometry Using Neodymium Fluoride
- D1066 Practice for Sampling Steam
- D1129 Terminology Relating to Water
- D1192 Guide for Equipment for Sampling Water and Steam

¹ This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.04 on Methods of Radiochemical Analysis.

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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.

in Closed Conduits (Withdrawn 2003)³

- D1193 Specification for Reagent Water
- D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water
- D3084 Practice for Alpha-Particle Spectrometry of Water
- D3370 Practices for Sampling Water from Closed Conduits
- D3648 Practices for the Measurement of Radioactivity
- D5847 Practice for Writing Quality Control Specifications for Standard Test Methods for Water Analysis
- D7282 Practice for Set-up, Calibration, and Quality Control of Instruments Used for Radioactivity Measurements

3. Terminology

3.1 Definitions:

3.1.1 For definitions of terms used in this test method, refer to Terminologies C859 and D1129. For terms not included in these reference may be made to other published glossaries.^{4,5}

4. Summary of Test Method

4.1 The water sample to be analyzed is acidified and ²³²U is added to serve as an isotopic tracer before any additional operations are performed. If the sample is a seawater sample, or if it contains carbonate or bicarbonate ions, the sample must be boiled under acidic conditions to convert these ions to carbon dioxide gas which is then expelled from the solution. Carbonate ions must not be present during the precipitation step because they complex the uranium and prevent its coprecipitation. The uranium is coprecipitated from the sample with ferrous hydroxide. This precipitate is dissolved in concentrated hydrochloric acid, or is subjected to an acid dissolution with concentrated nitric and hydrofluoric acids if the hydrochloric acid fails to dissolve the precipitate.

4.2 The uranium is separated from other radionuclides by adsorption on anion-exchange resin from 8 M hydrochloric acid, followed by elution with 0.1 M hydrochloric acid. The uranium is electrodeposited onto a stainless steel disk. Isotopic uranium radioactivities are measured by alpha pulse-height

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

⁴ Parker, S. P., ed., *Dictionary of Chemical Terms*, McGraw-Hill Book Co., New York, NY, 1985.

⁵ IUPAC, "Glossary of Terms Used in Nuclear Analytical Chemistry," *Pure and Applied Chemistry*, Vol 54, 1982, pp. 1533–1554.

TABLE 1 Relevant Properties of Uranium Isotopes of Interest in Environmental Waters^A

Isotope	Half Life	Principal Alpha Energies in MeV	
	Years	(Abundance)	
²³² U	68.9	5.320(68.6)	5.262(31.4)
²³³ U	1.592 × 10 ⁵	4.824(83.3)	4.782(14.1)
²³⁴ U	2.455 × 10 ⁵	4.774(72.5)	4.722(27.5)
²³⁵ U	7.038 × 10 ⁸	4.596(5.6)	4.307 (57)
		4.366 (17)	4.214(6.4)
²³⁶ U	2.342 × 10 ⁷	4.493 (74)	4.445 (26)
²³⁸ U	4.468 × 10 ⁹	4.198 (77)	4.151 (23)

^ATable of Isotopes, Eighth Edition, Vol. 11, Richard B. Firestone, Lawrence Berkeley National Laboratory, University of California, 1996.

analysis with a silicon surface-barrier or ion-implanted detector and a multichannel analyzer.

4.3 When ²³²U is used as the tracer, the other isotopes of uranium listed in **Table 1** can be detected in the alpha-particle spectrum of an unknown sample. From the alpha energies given in the table, it can be seen that the alpha energy of ²³²U is more than 0.40 MeV higher than the energy of any other uranium isotope. Thus, there should be little interference from tailing of the ²³²U into the lower energy alpha peaks. ²³³U and ²³⁴U usually cannot be resolved because their principal alpha energies differ by only 0.04 MeV. ²³⁵U and ²³⁶U peaks can be resolved only with difficulty. The alpha peaks from other combinations of uranium isotopes can be resolved unless the quality of the finally prepared sample is poor.

5. Significance and Use

5.1 This test method was developed to measure the radioactivity of uranium isotopes in environmental waters or waters released to the environment, and to determine whether the uranium-isotope concentrations are below the maximum amounts allowable by any regulatory statute.

6. Interferences

6.1 Thorium, polonium, plutonium, and americium were found not to interfere in this uranium determination.⁶ The only possible alpha-emitting isotopes that might interfere, based on the chemistry of this test method, are ²³¹Pa (3.28 × 10⁴ y half-life) and ²³⁷Np (2.16 × 10⁶ y half-life). These isotopes, however, are not likely to be present in environmental water samples. Protactinium-231 has the following alpha energies in MeV, the abundance being given in parentheses: 5.013

(25.4 %), 5.03 (23 %), 4.951 (22.5 %), 5.059 (11 %), and 4.734 (8.4 %). Thus, from **Table 1**, it is seen that ²³¹Pa can interfere with the determination of ²³³U or ²³⁴U. However, when the 4.951 to 5.059 MeV ²³¹Pa peaks can be resolved from the uranium peaks, a correction can be made. Neptunium-237 has alpha emission energies ranging from 4.639 to 4.873 MeV, with 72 % found between 4.771 and 4.788 MeV. Conventional analytical equipment would not be able to resolve these peaks from normal ²³⁴U emissions. If Np-237 is suspected to be present in the sample, a separate ²³⁷Np analysis would be required to make the appropriate correction to the ²³⁴U result.

6.2 When measuring very low concentrations of uranium isotopes in environmental samples, detector backgrounds and laboratory blanks must be well known. Blank determinations are made to ascertain that any contamination from reagents, glassware and other laboratory apparatus is small compared to the activity in the sample that is being analyzed. A blank determination should be made in exactly the same way as the sample determination.

7. Apparatus

7.1 *Centrifuge*, 250-mL centrifuge bottle or tube capacity.

7.2 *Ion Exchange Column*, glass or plastic, approximately 13-mm inside diameter and 150 mm long with a glass-wool plug or plastic frit and a 100- to 150-mL reservoir.

7.3 *Electrodeposition Apparatus*, consisting of a 0 to 12-V, 0 to 2-A power supply (preferably constant current) and an electrodeposition cell. The cathode is an approximately 20-mm diameter stainless steel disk polished to a mirror finish. The anode is approximately 1-mm diameter platinum wire with an approximately 8-mm diameter loop at the end of the wire parallel to the cathode disk. Cooling of the electrolyte during electrodeposition to at least 50°C is recommended. See references in Section 8 of Practice **D3084** for more details.

7.4 *Alpha Pulse-Height Analysis System*, consisting of a silicon surface-barrier or ion-implanted detector, supporting electronics, and pulse-height analyzer. A system capable of giving a resolution of 30 keV FWHM or better, when measured with a high-quality source, is recommended. The counting efficiency of the system should be greater than 15 %, and the background in the energy region of each peak should be less than ten counts in 60 000 s.

8. Reagents and Materials

8.1 *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.⁷ Other grades may be used provided it is first ascertained that

⁶ Bishop, C. T., Casella, V. R., and Glosby, A. A., "Radiometric Method for the Determination of Uranium in Water: Single-Laboratory Evaluation and Interlaboratory Collaborative Study," *U.S. Environmental Protection Agency Report*, EPA 600/7-79-093, April 1979.

⁷ *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 *Annual 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.

the reagent is of sufficiently high purity to permit its use without reducing the precision, or increasing the bias, of the determination.

8.2 *Purity of Water*—Unless otherwise indicated, reference to water shall be understood to mean reagent water conforming to Specifications **D1193**, Type III, as a minimum.

8.3 *Radioactive Purity of Reagent*—Radioactive purity shall be such that the measured results of blank samples do not exceed the calculated probable error of the measurement or are within the desired precision.

8.4 *Ammonium Hydroxide* (sp gr 0.90)—Concentrated ammonium hydroxide (NH_4OH).

8.5 *Ammonium Hydroxide Solution 0.15 M (1+99)*—Mix 1 volume of concentrated NH_4OH (sp gr 0.90) with 99 volumes of water. This solution is 0.15 M.

8.6 *Anion-Exchange Resin*—Strongly basic, styrene, quaternary ammonium salt, 4 % crosslinked, 100 to 200 mesh, chloride form.

8.7 *Electrolyte*—Dissolve 132 g of ammonium sulfate in water and dilute to 1 L. Slowly add concentrated NH_4OH or concentrated H_2SO_4 while stirring to adjust the pH of the solution to 3.5. The solution is 1 M in $(\text{NH}_4)_2\text{SO}_4$.

8.8 *Ethyl Alcohol* ($\text{C}_2\text{H}_5\text{OH}$)—Make slightly basic with a few drops of concentrated NH_4OH per 100 mL of alcohol. Anhydrous denatured ethanol is acceptable.

8.9 *Ferric Chloride Carrier Solution* (20 mg Fe/mL)—Dissolve 9.6 g of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ in 100 mL of 0.5 M HCl.

8.10 *Filter paper*, ashless, medium porosity.

8.11 *Hydrochloric Acid* (sp gr 1.19)—Concentrated hydrochloric acid (HCl).

8.12 *Hydrochloric Acid 8 M (2+1)*—Mix 2 volumes of concentrated HCl (sp gr 1.19) with 1 volume of water. This solution is 8 M.

8.13 *Hydrochloric Acid 0.5 M (1+23)*—Mix 1 volume of concentrated HCl (sp gr 1.19) with 23 volumes of water.

8.14 *Hydrochloric Acid 0.1 M (1+119)*—Mix 1 volume of concentrated HCl (sp gr 1.19) with 99 volumes of water. This solution is 0.1 M.

8.15 *Hydrofluoric Acid* (sp gr 1.2)—Concentrated hydrofluoric acid (HF).

8.16 *Hydroiodic Acid* (sp gr 1.5)—Concentrated hydroiodic acid (HI).

8.17 *Nitric Acid* (sp gr 1.42)—Concentrated nitric acid (HNO_3).

8.18 *Sodium Hydrogen Sulfate—Sulfuric Acid*—Dissolve 10 g of sodium hydrogen sulfate in 100 mL of water and then carefully add 100 mL of concentrated H_2SO_4 (sp gr 1.84) while stirring. This solution contains about 5 g of NaHSO_4 per 100 mL of 9 M H_2SO_4 .

8.19 *Sodium Hydrogen Sulfite* (NaHSO_3).

8.20 *Sulfuric Acid* (sp gr 1.84)—Concentrated sulfuric acid (H_2SO_4).

8.21 *Sulfuric Acid 1.8 M (1+9)*—Cautiously add with stirring 1 volume of concentrated sulfuric acid (sp gr 1.84) to 9 volumes of water. This solution is 1.8 M.

8.22 *Thymol Blue Indicator Solution*—Dissolve 0.04 g of the sodium salt of thymol blue in 100 mL of water.

8.23 *Uranium-232 Solution, Standard* (about 0.2 Bq/mL).

9. Precautions

9.1 Hydrofluoric acid (HF) is very hazardous and should be used in a well-ventilated hood. Wear rubber gloves, safety glasses or goggles, and a laboratory coat. Avoid breathing any HF fumes. Clean up all spills promptly and wash thoroughly after using HF. Ready availability of a topical fluoride binding agent, such as calcium gluconate gel, is strongly recommended in the event of skin contact with HF.

10. Sampling

10.1 Collect the sample in accordance with Practices **D1066**, **D3370**, and Specification **D1192** as applicable. Preserve the sample by adjusting the pH to 1 with concentrated HCl if the sample is not to be analyzed within 24 h. Record the volume of the sample and the volume of acid added.

11. Calibration and Standardization

11.1 Standardized ^{232}U is required as a tracer. Before standardization, this isotope must be separated from its radioactive descendants by anion exchange or some other means of chemical separation. See Practices **D3084** and **D3648** for general guidance concerning the standardization of tracers, and the energy and efficiency calibrations of the detector. The pulse-height analyzer should be set to accept pulses from alpha particles of approximately 3.5 to approximately 9.0 MeV in energy.

12. Procedure

12.1 Coprecipitation:

12.1.1 Measure the volume of approximately 1 L of the water sample to be analyzed and transfer to a 2-L beaker.

12.1.2 If the sample has not been acidified, add 5 mL of concentrated HCl.

12.1.3 Add a magnetic stirring bar, mix the sample completely, and check the acidity with pH-indicating paper or strip. If the pH is greater than 1, add concentrated HCl with mixing until it reaches this value.

12.1.4 Add approximately 0.2 Bq of standardized ^{232}U tracer with a calibrated pipet or by weight.

12.1.5 If the sample is a seawater or if it may contain carbonate ions, it must be boiled for approximately 5 min. Check the pH again after boiling and if it is greater than 1, add concentrated HCl with mixing to bring the pH back to 1.

12.1.6 Add approximately 500 mg of NaHSO_3 and 2 mL of ferric chloride carrier solution.

12.1.7 Cover the sample with a watch glass and heat the sample to boiling for 10 min.

12.1.8 Without removing the watch glass, add concentrated NH_4OH from a polyethylene squeeze bottle with the delivery tube inserted under the watch glass at the beaker pouring lip.