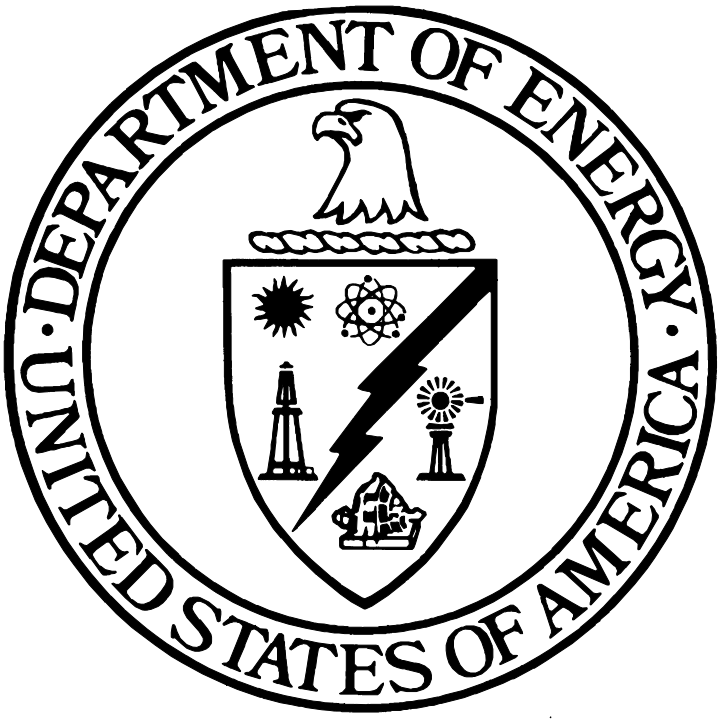
COMPENDIUM OF EPA-APPROVED ANALYTICAL METHODS FOR MEASURING RADIONUCLIDES IN DRINKING WATER



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INTRODUCTION

Purpose

The purpose of this report is to provide a compilation and brief summary of all methods approved by the U.S. Environmental Protection Agency (EPA) for analyzing radionuclides in drinking water. The report also provides references for each approved method. The report is intended to be used by U.S. Department of Energy (DOE) laboratory managers and technicians as a guide for identifying those analytical methods that are acceptable to the EPA for radionuclide analysis. This report provides summary information on each method, to include the methodology, reference, minimum detectable level, sample size, counting time, and noteworthy features. Although this report does not provide detailed discussions of each method, limited comments are provided that may help direct laboratory personnel to the method that is most appropriate for a particular application.

Regulatory Background

The Safe Drinking Water Act directs EPA to publish national primary drinking water regulations that establish either maximum contaminant levels (permissible levels of the contaminant) or treatment techniques for each contaminant of concern. EPA published the maximum contaminant levels for radium-226 , radium-228, and gross alpha particle radioactivity in 40 CFR 141.15 and for beta particle and photon radioactivity from anthropogenic radionuclides in 40 CFR 141.16. The maximum contaminant levels are as follows: combined radium-226 and radium-228 - 5 pCi/L; gross alpha particle activity (including radium-226 but excluding radon and uranium) - 15 pCi/L; beta particle and photon radioactivity - shall not produce an annual dose greater than 4 mrem/year (two specific examples of levels that would not exceed 4 mrem/year are given in 40 CFR 141.16 (b): tritium - 20,000 pCi/L and strontium-90 - 8 pCi/L).

EPA published a list of analytical methods for radionuclides in 40 CFR 141.25 (a) that were approved for determining compliance with the maximum contaminant levels. Until early 1997, Part 141.25 (a) contained only a few approved methods, most of which were approved for use in the 1970s. On March 5, 1997, EPA adopted many new approved methods for analyzing radionuclides in drinking water, which were added to Part 141.25 (a). All approved methods (both old and newly added) are referenced from one of ten documents. The number of approved methods for each radionuclide is indicated in Table 1. Some of the methods are approved for analysis of more than one contaminant. For example, Method 901.1 is approved for analysis of radioactive cesium, radioactive iodine, and gamma emitters.

Table 1 - Number of Methods Approved by the EPA for Analyzing Radionuclides in Drinking Water [from 40 CFR 141.25 (a)]

Radionuclide	Number of Methods
Gross Alpha and Beta	7
Gross Alpha	2
Radium-226	17
Radium-228	8
Uranium	15
Radioactive Cesium	11
Radioactive Iodine	12
Radioactive Strontium-89 and -90	9
Tritium	8
Gamma Emitters	11

Part 141.27 allows for EPA to authorize in writing the use of alternate analytical methods if the alternate method is substantially equivalent to the prescribed test in both precision and accuracy. Part 141.25 (b) directs laboratories to two references (Krieger and Gold 1973; HASL 1973) for identifying and measuring radionuclides other than those specifically listed in Part 141.25(a) (those listed in this report). The Part 141.25 (b) procedure cannot be used in cases where alternate methods have been approved in accordance with Part 141.27.

Part 141.28 requires that for purposes of compliance with Part 141.25, all samples must be analyzed by a state-approved laboratory.

Some of the older methods are no longer included in current editions of reference books (e.g., methods 302-306 in *Standard Methods for the Examination of Water and Wastewater* and method D 2459-72 in the *Annual Book of ASTM Standards*). However, the Agency believes that these older methods still provide acceptable results, and they are used by many laboratories.

Detection Limits

When substances are analyzed for regulatory purposes, such as for ensuring compliance with maximum contaminant levels, regulatory agencies generally specify detection limits. In Part 141.25 (c), EPA states that the detection limit for radionuclides "shall be that concentration which can be counted with a precision of plus or minus 100 percent at the 95 percent confidence level (1.96Φ

where Φis the standard deviation of the net counting rate of the sample)." EPA specifies detection limits for some radionuclides in Parts 141.25 (c) (1) and (2). These are shown in Table 2. *It is important to note that the list of radionuclides for which detection limits are specified in Part 141.25 (c) does not exactly match the list of radionuclides for which maximum contaminant levels are published in Parts 141.15 and .16 or the list of radionuclides for which analytical methods are published in Part 141.25 (a), although there is a great deal of overlap between the lists.*

Table 2 - EPA Detection Limits for Radionuclide Analyses [from 40 CFR 141.25 (c)]

Radionuclide	**Detection Limit (pCi/L)[a]**
Gross alpha (includes radium-226 but excludes radon and uranium)	3
Gross beta	4
Radium-226 and radium-228 combined	1
Cesium-134	10
Iodine-131	1
Strontium-89	10
Strontium-90	2
Tritium	1,000
Other radionuclides	0.1 times the applicable limit

[a] The ability to achieve detection limits depends on proper consideration of the counting geometry, the photon energy, the sample size, and the actual counting time of detection.

Another related term, "method detection limit," is defined in 40 CFR 136, Appendix B, as "the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte." The requirements of 40 CFR 136 apply to analyses conducted under the National Pollutant Discharge Elimination System (NPDES) or for water quality certifications conducted by states under Section 401 of the Clean Water Act. Part 136 methods or procedures may be used for analyses conducted under other regulatory programs, if not otherwise prohibited, but they are not required for drinking water analyses. The term "method detection limit" is used in various sections of the drinking water regulations dealing with analysis of chemical contaminants and is referenced to 40 CFR 136, Appendix B. The term is not applied to radionuclides, however.

There is a difference between how a laboratory achieves the detection limit for radionuclides and the method detection limit for chemical contaminants. For chemical contaminants, if the laboratory uses the designated instrument and method correctly, the method detection limit can be achieved. For radionuclides, the lowest detectable concentration varies depending upon the counting geometry, the photon energy, the sample size, and the actual counting time of detection. A laboratory analyzing radionuclides must pay attention to these factors in addition to correctly using the designated instrument and method.

Some of the approved radionuclide methods contain different types of functional "detection levels" that are not necessarily the same as the regulatory "detection limit" specified in Part 141.25 (c). These "detection levels" are given varying names in different methods (minimum detection level, minimum detection limit, minimum detectable concentration, minimum detectable amount, minimum detectable level, and method detection levels). Where some version of a "detection level" is reported in the method description, it is included in the summaries below, and the terminology used in the reference is incorporated as well.

Sample Collection and Handling Procedures

The EPA regulations do not specify across-the-board requirements for sample collection, handling, preservation, and storage of radionuclide water samples. Many of the individual approved methods include specifications on these procedures. One EPA reference cited in this report, *Prescribed Procedures for Measurement of Radioactivity in Drinking Water* (August 1980), contains useful guidance in this area.

Summary of Approved Methods

Tables 3-12 provide summary information on all approved methods. The sections that follow the tables provide more detailed information for each method. The method descriptions are intended to serve as an easy reference guide.

Table 3 Approved Methods - Gross Alpha and Beta

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 900.0	EPA 1980	Evaporation; count by gas-flow internal proportional counter or scintillation detector.	1.0 alpha, 0.5 beta	1000	100	Uses Am-241 as alpha and Sr-90 + Y-90 as beta calibration standards.
2	EPA 1976	Evaporation; count for alpha and beta activity.	0.1-1.8 alpha, 0.3-4 beta	500 - 100	60 - 1,000	Uses U-238 as alpha & Cs-137 as beta calibration standards.
3 - Method 00-01	EPA 1984	Evaporation; count for alpha and beta activity in internal gas-flow type proportional counter.	na[b]	na	na	Uses natural uranium and Pu-239 as alpha and Sr-89 and Sr-90 + Y-90 as beta calibration standards.
4	EPA 1979	Evaporation; count by low-background internal gas-flow type proportional counter.	na	na	na	Uses Am-241 as alpha and Cs-137 as beta calibration standard.
5 - Method 302	APHA 1971	Evaporation/filtration; count by internal proportional counter, thin window proportional counter, or Geiger counter.	na	na	na	Uses natural uranium as alpha and Cs-137 as beta calibration standard.
6 - Method 7110B	APHA 1995	Evaporation; count by thin-window heavily shielded, gas-flow type, anticoincidence circuitry proportional counter; internal proportional counter; or Geiger counter.	na	na	na	Uses natural uranium, Th-230, Pu-239, and Am-241 as alpha and Cs-137, Sr-90 + Y-90 as beta calibration standard.
7 - Residue method R-1120-76	GSI 1977	Evaporation; count by low-background proportional counter.	na	na	na	Uses natural uranium as alpha and Sr-90+Y-90 or Cs-137 as beta calibration standard.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

Table 4 Approved Methods - Gross Alpha

Method	Reference	Methodology	Noteworthy Features
1- Method 00-02	EPA 1984	Coprecipitation; count by alpha scintillation or low background proportional counter.	Determine counter efficiency by coprecipitating standardized aliquots of alpha-emitting actinide solutions.
2- Method 7100 C	APHA 1995	Coprecipitation; count by alpha scintillation or low background proportional counter.	This method can be used for drinking water samples with high dissolved solid content, e.g., 500 mg/L or higher. Preferably use thorium-230 (a pure alpha emitter) for gross alpha efficiency calibration. Allow at least 3 hours for decay of radon progeny before beginning the alpha counting.

Table 5 Approved Methods - Radium-226

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 903.1	EPA 1980	Radon emanation; count alpha by scintillation counter.	0.5	1,000	100	There are no radioactive interferences in this method. The calibration constant of each scintillation cell must be determined using a standardized radium-226 solution.
2	EPA 1976	Radon emanation; count alpha by scintillation counter.	0.01-0.04	1,000	1,000-60	The calibration constant is determined using radium-226 standard solution.
3 - Method Ra-04	EPA 1984	Radon emanation; count alpha by scintillation counter.	na[b]	na	na	The calibration constant is determined by sealing a known quantity of radium-226 in a de-emanation tube.
4	EPA 1979	Radon emanation (for radium-226); for radium-226, count alpha by scintillation counter and for radium-228, count beta by low-level proportional counter.	0.3	1,500	na	This method is applicable for the determination of radium-226 and radium-228 in water, soil, air, biological tissues, and biological fluids.
5 - Method 7500-Ra C	APHA 1995	Radon emanation; count alpha by scintillation counter.	0.03-0.05	1,000	na	This method is suitable for the determination of soluble, suspended, and total radium-226.
6 - Method 305	APHA 1971	Radon emanation; count alpha by scintillation counter.	0.03-0.05	1,000	na	This method requires a moderate amount of chemistry coupled with a sensitive alpha scintillation count of radon-222 plus progeny in a small chamber.
7 - Method D 3454-91	ASTM 1994	Radon emanation; count alpha by scintillation counter.	0.1	na	na	This method covers the measurement of soluble, suspended, and total radium-226 in water.
8- Method R-1141-76	GSI 1977	Radon emanation; count alpha by scintillation counter.	0.1	1,000	1,000	This method is applicable to any water sample.

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
9- Method Ra-05	DOE 1990	Radon emanation; count alpha by ionization chamber or scintillation cell.	na	na	na	Only radium-226 yields radon-222 progeny that has suitable characteristics for detection by an emanation technique; therefore, the procedure is specific.
10- Method Ra-02	RSI 1982	Radon emanation (for radium-226); count alpha by scintillation cell for radium-226 and by beta/gamma coincidence counter for radium-228.	na	na	na	This method is applicable to water, soil, and air particulate samples and can be used to measure radium-226 alone or radium-226 in conjunction with radium-228.
11- Method 903.0	EPA 1980	Radiochemical/precipitation; counted by alpha scintillation or gas-flow proportional alpha particle counting.	0.5	1,000	100	The method does not always give an accurate measurement of the radium-226 content of the sample (when other radium alpha emitters are present); it can be used to screen samples. Absolute measurement can be made by calibrating the alpha detector with standard radium-226 in the geometry obtained with the final precipitate
12	EPA 1976	Radiochemical/precipitation; count alpha by internal proportional counter.	0.4-0.15	2,000	1,000-60	None.
13- Method Ra-03	EPA 1984	Radiochemical/precipitation; alpha counting by scintillator counter.	na	na	na	Radium-226 in solution is determined by coprecipitation from the sample with barium sulphate. The sample is then analyzed using the de-emanation procedure
14- Method 7500-Ra B	APHA 1995	Radiochemical/precipitation; alpha counting by gas-flow proportional counter, scintillation counter, or thin end-window gas-flow proportional counter.	na	na	na	This method is suitable for determination of the alpha-emitting isotopes of radium.
15- Method 304	APHA 1971	Radiochemical/precipitation; alpha counting by gas-flow internal proportional counter, scintillation counter, or thin end-window gas-flow proportional counter.	na	na	na	This method is designed to measure radium in clear water. It is applicable to sewage and industrial wastes, provided steps are taken to destroy organic matter and eliminate other interfering ions.

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
16- Method D 2460-90	ASTM 1994	Radiochemical/precipitation; alpha counting by gas-flow counter or scintillation counter.	1.0	na	na	This method covers the separation of dissolved radium from water for the purpose of measuring its radioactivity.
[1] 17- Method R-1140-76	GSI 1977	Radiochemical/precipitation; alpha counting by low-background, anticoincidence, thin window, gas proportional counter.	1.0	1,000	100	This method is satisfactory for applications that do not require high precision or radium isotope identification.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

Table 6 Approved Methods - Radium-228

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 904.0	EPA 1980	Radiochemical/precipitation; count by gas-flow proportional beta counter.	1.0	1,000	100	This technique is devised so that the beta activity from actinium-228, which is produced by decay of radium-228, can be determined and related to the radium-228 that is present in the sample.
2	EPA 1976	Radiochemical/precipitation; beta counting for actinium-228 to get radium-228 reading and alpha internal proportional counting for radium-226.	0.06-0.3	2,000	1,000-60	In this method, if after sufficient beta decay of the actinium fraction, it is determined that there is no radium-228 in the sample, then the radium-226 fraction may be alpha counted directly. If radium-228 is present, then the radium-226 must be determined by radon emanation.
3 - Method Ra-05	EPA 1984	Radiochemical precipitation; count for beta in a low background proportional counter.	na[b]	na	na	The sample may be taken from the stored solution following radium-226 de-emanation or from a water sample.
4	EPA 1979	Radon emanation (for radium-226) followed by radiochemical/precipitation (for radium-228); for radium-226, count alpha by scintillation counter and for radium-228, count beta by low-level proportional counter.	0.3	1,500	na	This method is applicable for the determination of radium-226 and radium-228 in water, soil, air, biological tissues, and biological fluids.
5 - Method 7500 Ra D	APHA 1995	Radiochemical/precipitation; count for radium-228 by gas-flow internal proportional counter or thin end-window gas-flow proportional counter. For radium-226, count by scintillation counter.	na	na	na	This method can be used to determine soluble radium-228 alone or soluble radium-228 plus radium-226.
6 - Method R-1142-76	GSI 1977	Radiochemical/precipitation; beta counting by low-background, anticoincidence, thin window, gas proportional counter.	1.0	4,000-1,000	300-500	This method is applicable to all natural water samples. No chemical interferences have been detected.

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
7- Method Ra-02	RSI 1982	Radon emanation (for radium-226) followed by radiochemical/precipitation (for radium-228); count alpha by scintillation cell for radium-226 and by beta/gamma coincidence counter for radium-228.	na	na	na	This method is applicable to water, soil, and air particulate samples and can be used to measure radium-226 alone or radium-226 in conjunction with radium-228.
8	DEP 1980	Radiochemical/precipitation; count by low-background beta counter.	0.4	1,000	100	Each laboratory that uses this method is required to operate a formal quality control program.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

Table 7 Approved Methods - Uranium

Method	Reference	Methodology	Minimum Detectable Level [a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 908.0	EPA 1980	Radiochemical/precipitation; count for alpha particle activity by gas-flow proportional or scintillation counting.	1.0	1,000	100	This method covers the measurement of total uranium alpha particle activity in drinking water.
2- Method 7500-U B	APHA 1995	Radiochemical/precipitation; count by gas-flow proportional counter or alpha scintillation counting.	na[b]	na	na	This method determines total alpha activity without making an isotopic uranium analysis.
3- Method 908.1	EPA 1980	Direct fusion or fusion after extraction; count by fluorometer.	1.0	1,000	100	This method covers the determination of soluble uranium in waters at concentrations greater than 0.1 µg/L.
4- Method 7500-U C	APHA 1989	Direct fusion or fusion after extraction; count by fluorometer.	na	na	na	For samples containing > 20 µg/L U, uranium is determined directly. For samples containing < 20 µg/L U, uranium is first separated from quenching elements and excessive salt concentrations.
5- Method D 2907-91	ASTM 1994	Direct fusion or fusion after extraction; count by fluorometer.	5 µg/L	na	na	This test method is applicable to the determination of micro quantities of uranium in water.
6- Method R-1180-76	GSI 1977	Direct fusion; count by fluorometer.	0.3 µg/L	na	na	This method is suitable for determination of uranium in nonsaline water in which uranium fluorescence is quenched less than 30%.
7 - Method R-1181-76	GSI 1977	Extraction and fusion; count by fluorometer.	0.01 µ g/L	na	na	This method is applied to water samples where the reduction of uranium fluorescence by quenching exceeds 30%.
8- Method U-04	DOE 1990	Extraction and fusion; count by fluorometer.	na	na	na	This procedure has been used to analyze bone, soil, food, tissue, air filter, and water samples.

Method	Reference	Methodology	Minimum Detectable Level [a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
9- Method 00-07	EPA 1984	Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.	na	na	na	None.
10	EPA 1979	Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.	0.02	na	na	This method is appropriate for the analysis of isotopic plutonium, uranium, and thorium, collectively or individually.
11- Method 7500-U C	APHA 1995	Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.	0.1	na	na	This method determines the isotopic content of the uranium activity; it is consistent with determining the differences among naturally occurring, depleted, and enriched uranium.
12- Method D 3972-90	ASTM 1994	Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.	na	na	na	This method applies to soluble uranium as well as to any uranium that might be present in suspended matter in the water sample.
13- Method R-1182-76	GSI 1977	Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.	na	na	na	This method is applicable to most fresh water and saline waters.
14- Method U-02	DOE 1990	Radiochemical separation, micro precipitation; count by alpha spectrometer.	na	na	na	This procedure has been used to analyze soft tissue, vegetation, water, and air filter samples.
15- Method D 5174-91	ASTM 1994	An aliquot of the sample pipetted directly (for screening purposes) or after chemical treatment into the phosphorimeter cell; count by laser phosphorimeter.	0.05 ppb	na	na	This method covers the determination of total uranium in water.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

Table 8 Approved Methods - Radioactive Cesium

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 901.0	EPA 1980	Radiochemical separation; gamma ray spectrometry or gas-flow proportional beta counting (when cesium-134 is present alone).	1.0	1,000	100	This method covers the measurement of cesium-134 and cesium-137 in the same sample of drinking water.
2	EPA 1976	Radiochemical separation; beta counting.	0.2-0.6	1,000	100	None.
3 - Method 7500-Cs B	APHA 1995	Radiochemical separation; count by low-background beta counter or gamma spectrometer.	na[b]	na	na	None.
4- Method R-1111-76	GSI 1977	Radiochemical separation; beta counting by low-background, anticoincidence, thin window, gas proportional counter.	1	500	150	This method determines total dissolved radiocesium concentrations but does not measure individual isotopes. This method can be used when identification of individual cesium isotopes is not required and interfering beta-emitting isotopes are in low concentrations.
5 - Method R-1110-76	GSI 1977	Radiochemical separation through a column of inorganic ion-exchanger; count dried ion-exchanger by a well-type NaI gamma detector/gamma spectrometer.	na	na	na	None.
6 - Method D 2459-72	ASTM 1973	A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge(Li) or NaI(Tl) detectors.	na	na	na	This method is applicable to radionuclides emitting gamma rays with energies greater than 100 keV.
7- Method 901.1	EPA 1980	A homogeneous water sample is put into a standard geometry; count using a Ge(Li) detector (preferred) or a NaI(Tl) detector.	na	na	na	This method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 2,000 keV.

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
8	EPA 1979	A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using a Ge(Li) detector.	5	200	1,000	This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from nearly 60 keV to approximately 2 MeV.
9- Method 7120 B	APHA 1995	A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge or Ge(Li) detectors.	na	na	na	This method is applicable to samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 2,000 keV.
10- Method D 3649-91	ASTM 1994	A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.	na	na	na	This method is applicable to radionuclides emitting gamma rays with energies greater than 20 keV.
11- Method 4.5.2.3	DOE 1990	A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge(Li), high purity germanium, or NaI(Tl) detectors.	na	na	na	This method is applicable to radionuclides emitting gamma rays with energies > 20 keV for germanium detectors and 50 keV for NaI(Tl) detectors.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

Table 9 Approved Methods - Radioactive Iodine

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 902.0	EPA 1980	Radiochemical separation; count by gamma ray spectrometer, gas-flow proportional beta counter, or beta/gamma coincidence scintillation counter.	1.0	1,000	100	This method provides for the separation and concentration of iodine from sufficiently large samples.
2	EPA 1976	Radiochemical separation; beta counting.	0.1-0.3	2,000	1,000-60	None.
3	EPA 1976	Radiochemical separation; beta counting.	0.1-0.3	2,000	1,000-60	None.
4 - Method 7500-I B	APHA 1995	Radiochemical separation; count by low-background beta counter or beta-gamma coincidence counter.	na[b]	na	na	This is a simple method and involves the least time.
5- Method 7500-I C	APHA 1995	Radiochemical separation; count by low-background beta counter or beta-gamma coincidence counter.	na	na	na	In this method, iodide is concentrated by absorption on an anion resin, purified, and counted in a beta-gamma coincidence system. This method is sensitive and accurate.
6 - Method 7500-I D	APHA 1995	Radiochemical separation; beta counting.	na	na	na	This method uses distillation.
7 - Method D 4785-88	ASTM 1992	Radiochemical separation; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.	1	4,000	na	This method determines low levels of iodine-131 in water by means of chemical separation and counting with a high-resolution gamma ray detector.
8- Method 901.1	EPA 1980	A homogeneous water sample is directly put into a standard geometry; count using a Ge(Li) detector (preferred) or a NaI(Tl) detector.	na	na	na	This method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 2,000 keV.

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
9	EPA 1979	A homogeneous water sample is directly put into a standard geometry; count by gamma ray spectrometer using a Ge(Li) detector.	na	na	na	This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from nearly 60 keV to approximately 2 MeV.
10 - Method 7120 B	APHA 1995	A homogeneous water sample is directly put into a standard geometry; count by gamma ray spectrometer using Ge or Ge(Li) detectors.	na	na	na	This method is applicable to samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 2,000 keV.
11- Method D 3649-91	ASTM 1994	A homogeneous water sample is directly put into a standard geometry; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.	na	na	na	This method is applicable to radionuclides emitting gamma rays with energies greater than 20 keV.
12- Method 4.5.2.3	DOE 1990	A homogeneous water sample is directly put into a standard geometry; count by gamma ray spectrometer using Ge(Li), high purity germanium, or NaI(Tl) detectors.	na	na	na	This method is applicable to radionuclides emitting gamma rays with energies > 20 keV for germanium detectors and 50 keV for NaI(Tl) detectors.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

Table 10 Approved Methods - Radioactive Strontium-89 and -90

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 905.0	EPA 1980	Radiochemical separation; beta counting.	0.5	1,000	100	This method covers the measurement of total strontium and soluble strontium-89 and strontium-90 in drinking water samples.
2	EPA 1976	Radiochemical separation; beta counting.	0.3-0.9 Sr-89 0.1-0.5 Sr-90	1,000	1,000-60	None.
3 - Method Sr-04	EPA 1984	Radiochemical separation; low background beta counting.	na[b]	na	na	This method can determine strontium-90 as well as strontium-89.
4	EPA 1979	Radiochemical separation; low background beta counting.	3.0	na	na	This method is applicable for the determination of strontium-89 and strontium-90 in freshwater, seawater, soil, vegetation, and animal tissue.
5 - Method 303	APHA 1971	Radiochemical separation; beta counting by gas-flow internal proportional counter or thin end-window low-background proportional counter.	na	na	na	This method is designed to measure total radioactive strontium (strontium-89 and strontium-90) or strontium-90 alone in drinking water or in filtered raw water.
6 - Method 7500-Sr	APHA 1995	Radiochemical separation; beta counting by gas-flow internal proportional counter or thin end-window low-background proportional counter.	na	na	na	This method is designed to measure total radioactive strontium (strontium-89 and strontium-90) or strontium-90 alone in drinking water or in filtered raw water.
7 - Method R-1160-76	GSI 1977	Radiochemical separation; beta counting by low-background, anticoincidence, thin window, gas proportional counter.	0.5	1,000	100	This method is applicable to all natural freshwater and saltwater. Interferences from both fission products and natural radioactivity are negligible.

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
8- Method Sr-01	DOE 1990	Radiochemical separation; count by low-level beta scintillation counter.	na	na	na	This method determines strontium-89 at the same time as strontium-90
9- Method Sr-02	DOE 1990	Radiochemical separation; counting by low-level beta scintillation counter.	na	na	na	This method measures strontium-90.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available

Table 11 Approved Methods - Tritium

Method	Reference	Methodology	Minimum Detectable Level[a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 906.0	EPA 1980	Distillation, portion of distillate mixed with scintillator solution; beta counting by coincidence-type liquid scintillation spectrometer.	300	8	100	None.
2	EPA 1976	Distillation, portion of distillate mixed with scintillator solution; beta counting by liquid scintillation spectrometer.	150-500 70-300	4 8	1,000-60 1,000-60	None.
3 - Method H-02	EPA 1984	Distillation, portion of distillate mixed with scintillator solution; beta counting by liquid scintillation spectrometer.	na[b]	na	na	None.
4	EPA 1979	Distillation, portion of distillate mixed with scintillator solution; beta counting by liquid scintillation spectrometer.	na	na	na	This method is applicable for the determination of tritium at low levels for all distilled waters.
5 - Method 306	APHA 1971	Distillation, portion of distillate mixed with scintillator solution; beta counting by liquid scintillation spectrometer.	200-500	4	100	A sample of water or waste is distilled to remove quenching materials and nonvolatile radioactivity.
6 - Method 7500-^{3}H	APHA 1995	Distillation, portion of distillate mixed with scintillator solution; beta counting by coincidence-type liquid scintillation spectrometer.	1,000	4	100	A sample of water is treated by alkaline permanganate distillation to hold back most quenching materials as well as radioiodine and radiocarbon.
7 - Method D 4107-91	ASTM 1994	Distillation, portion of distillate mixed with scintillator solution; beta counting by coincidence-type liquid scintillation spectrometer.	1,000	4	na	This method is used successfully with drinking water
8- Method R-1171-76	GSI 1977	Distillation, portion of distillate mixed with scintillator solution; beta counting by liquid scintillation spectrometer.	190		500	This method is not sufficiently sensitive to be applicable to the determination of very low natural tritium levels.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

Table 12 Approved Methods - Gamma Emitters

Method	Reference	Methodology	Minimum Detectable Level [a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
1- Method 901.0	EPA 1980	Radiochemical separation; gamma ray spectrometry or gas-flow proportional beta counting (when cesium-134 is present alone).	1.0	1,000	100	This method covers the measurement of cesium-134 and cesium-137 in the same sample of drinking water.
2- Method 902.0	EPA 1980	Radiochemical separation; count by gamma ray spectrometer, gas-flow proportional beta counting, or beta/gamma coincidence scintillation counting.	1.0	1,000	100	This method provides for the separation and concentration of iodine from sufficiently large samples.
3- Method 7500-Cs B	APHA 1995	Radiochemical separation; count by low-background beta counter or gamma spectrometer.	na[b]	na	na	None.
4- Method 7500-I B	APHA 1995	Radiochemical separation; count by low-background beta counter or beta-gamma coincidence counter.	na	na	na	This is a simple method and involves the least time.
5- Method D 4785-88	ASTM 1992	Radiochemical separation; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.	1.0	4,000	na	This method determines low levels of iodine-131 in water by means of chemical separation and counting with a high-resolution gamma ray detector.
6- Method R-1110-76	GSI 1977	Radiochemical separation through a column of inorganic ion-exchanger; count dried ion-exchanger by a well-type NaI(Tl) gamma detector/gamma ray spectrometer.	na	na	na	None.
7- Method 901.1	EPA 1980	A homogeneous water sample is put into a standard geometry; count by a Ge(Li) detector (preferred) or a NaI(Tl) detector.	na	na	na	This method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 2,000 keV.
8	EPA 1979	A homogeneous water sample is put into a standard geometry; count by a gamma ray spectrometer using a Ge(Li) detector.	5	200	1,000	This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from nearly 60 keV to approximately 2 MeV.

Method	Reference	Methodology	Minimum Detectable Level [a] (pCi/L)	Sample Size (mL)	Counting Time (min)	Noteworthy Features
9- Method 7120 B	APHA 1995	A homogeneous water sample is put into a standard geometry; count by a gamma ray spectrometer using Ge or Ge(Li) detectors.	na	na	na	This method is applicable to samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 2,000 keV.
10- Method D 3649-91	ASTM 1994	A homogeneous water sample is put into a standard geometry; count by a gamma ray spectrometer using Ge(Li) or high purity germanium detectors.	na	na	na	This method is applicable to nuclides emitting gamma rays with energies greater than 20 keV.
11-Method 4.5.2.3	DOE 1990	A homogeneous water sample is put into a standard geometry; count by a gamma ray spectrometer using a Ge(Li), high purity germanium, or NaI(Tl) detectors.	na	na	na	This method is applicable to nuclides emitting gamma rays with energies > 20 keV for germanium detectors and 50 keV for NaI(Tl) detectors.

[a] Minimum detectable level is defined as the minimum detectable concentration reported for the method at the 99% confidence level (EPA 1980) or at the 95% confidence level (EPA 1976).

[b] na - information not available.

APPROVED METHODS - GROSS ALPHA AND BETA

EPA has approved seven methods for gross alpha and beta analysis in drinking water (see Table 3). All approved methods use an evaporation methodology.

1. Method 900.0 - Gross Alpha and Gross Beta Radioactivity in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032 , prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Evaporation; count by gas-flow internal proportional or scintillation detector counter.

Comments: This method provides a rapid screening measurement to indicate whether specific analyses are necessary. This method is applicable to measuring alpha emitters having energies above 3.9 MeV and beta emitters having maximum energies above 0.1 MeV. The method will not measure radionuclides that are volatile under the sample preparation conditions. For a given water sample, sensitivity of the method depends on the solids concentration. This method is not recommended for drinking waters with extremely high solids contents (>500 ppm). This method has a minimum detectable level of 1.0 pCi/L for gross alpha and 0.5 pCi/L for gross beta for a 1,000-mL sample and 100-minute counting time.

2. Gross Alpha and Gross Beta Radioactivity in Drinking Water

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 1. Available from NTIS, document no. PB 253258.

Methodology: Evaporation; count for alpha and beta particle activity - no specific procedure noted.

Comments: In this method, the specified volume (range 100 - 500 mL) of drinking water to be evaporated will be a function of its hardness and solids concentration. Self-absorption factors for the solids present in these volumes have to be determined to correct for losses due to self-absorption. In any event, the maximum sample thickness should be less than 5 mg/cm^2. This method can achieve a minimum detection level of 0.1-1.8 pCi/L for gross alpha activity and 0.3-4 pCi/L for gross beta activity, for sample volumes from 100-500 mL and 60 to 1,000 minute counting times. The procedure description estimates that eight samples can be run in one to two hours.

3. Method 00-01 - Radiochemical Determination of Gross Alpha and Gross Beta Particle Activity in Water

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from NTIS, document no. PB 84-215581.

Methodology: Evaporation; count for gross alpha and beta particle activity - no specific procedure noted.

Comments: This procedure provides a rapid screening measurement to indicate whether specific analyses are necessary. Flaming the planchet will result in the loss of polonium-210, if present.

4. Determination of Gross Alpha and Beta in Water

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 1. Available from NTIS.

Methodology: Evaporation; count by low-background internal proportional counter.

Comments: This is a screening technique used to determine quantities of alpha- or beta- emitting radionuclides present. A known volume of sample is concentrated, dried in a planchet, and counted in a low-background internal proportional counter. Tritium and other volatile radionuclides cannot be determined by this method.

The evaporated sample residue, by acting as an absorber for the alpha and beta particle, is the largest interference. Moisture absorbed or trapped also serves as an interference. The counting efficiency of the low-background beta counter is determined by three factors: geometry, back scatter, and self-absorption. For quality control, every tenth sample is reprocessed as a blind duplicate, and bi-monthly cross-check samples are obtained from the Quality Assurance Branch, EMSL-LV.

5. Method 302 - Gross Alpha and Gross Beta Radioactivity in Water (Total, Suspended and Dissolved)

Reference: Standard Methods for the Examination of Water and Wastewater, 13th edition, 1971. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Evaporation; count by internal proportional counter, thin-window proportional counter, or Geiger counter.

Comments: In counting water samples for gross beta activity, a solid thickness of 10 mg/cm^2 or less at the bottom area of the counting pan is recommended. For more accurate results, the self-absorption factor should be determined. Sample residues having particulates that tend to be airborne, which are to be counted in internal counters, should be treated with a few drops of Lucite solution, then air- and oven-dried and weighed.

This method was deleted from all editions of *Standard Methods for the Examination of Water and Wastewater* following the 13th edition, and, therefore, it may be difficult to obtain a copy of the method. Nevertheless, it is still an approved EPA method.

6. Method 7110 B - Evaporation Method for Gross Alpha-Beta

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Evaporation; count by thin-window gas-flow proportional counter, internal proportional counter, or Geiger counter.

Comments: For drinking water samples with high dissolved solids content (e.g., 500 mg/L or higher), this method is severely limited because of the small sample size possible and the very long counting times necessary to meet the required sensitivity of 3 pCi/L.

7. Residue Method R-1120-76 - Gross Alpha and Beta Radioactivity, Dissolved and Suspended

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Evaporation; count low-background proportional counter.

Comments: The sensitivity of this method falls off with increasing concentrations of dissolved solids. This method is a rapid, semiquantitative measure of gross sample activity. The accuracy of this method varies with the nature of the alpha and beta emitters, chemical composition of the sample, and uniformity of planchet preparation.

APPROVED METHODS - GROSS ALPHA

EPA has approved two methods for gross alpha analysis in drinking water (see Table 4). Both methods use a coprecipitation methodology.

1. Method 00-02 - Radiochemical Determination of Gross Alpha Activity in Drinking Water by Coprecipitation

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 84-215581.

Methodology: Coprecipitation; count by alpha scintillation counter or low background proportional counter.

Comments: None.

2. Method 7110 C - Coprecipitation Method for Gross Alpha Radioactivity in Drinking Water (proposed)

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Coprecipitation; count by alpha scintillation counter or low-background proportional counter.

Comments: This procedure eliminates the problem of high dissolved solids and provides increased sensitivity compared with Method 7110 B for gross alpha and beta.

APPROVED METHODS - RADIUM-226

EPA has approved 17 methods for radium-226 analysis in drinking water (see Table 5). Seven of the approved methods use a radiochemical/precipitation methodology to measure the total soluble alpha-emitting radioisotopes of radium, namely, radium-223, radium-224, and radium-226; ten of the methods use a radon-emanation methodology that is specific to radium-226. The radiochemical methods do not always give an accurate measurement of the radium-226 content when other radium emitters are present, but they can be used to screen samples. When the total radium activity of a sample approaches 3-5 pCi/L, a radon-emanation method should be used. Because of their greater specificity, the radon-emanation methods are presented first.

1. Method 903.1 - Radium in Drinking Water, Radon Emanation Technique

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Radon-emanation; count alpha by scintillation counter.

Comments: This method is specific for radium-226. This method has a minimum detectable level of 0.5 pCi/L for a 100-minute counting time.

2. Radon-226 in Drinking Water - Radon Emanation Technique

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 16. Available from NTIS, document no. PB 253258.

Methodology: Radon-emanation; count alpha by scintillation counter.

Comments: This method can achieve a minimum detection level of 0.01-0.04 pCi/L for a 1-L sample volume and 60- to 1,000-minute counting times. The procedure description estimates that four samples can be run in eight hours.

3. Method Ra-04 - Radiochemical Determination of Radium-226, De-emanation Procedure

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from NTIS, document no. PB 84-215581.

Methodology: Radon-emanation; count alpha by scintillation counting.

Comments: None.

4. Determination of Radium-226 and Radium-228 in Water, Soil, Air, and Biological Tissue

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 19. Available from NTIS.

Methodology: Radon-emanation (for radium-226); for radium-226, count alpha by scintillation counter and for radium-228, count beta by low-level proportional counter.

Comments: This method allows for measurement of both radium-226 and radium-228. The radium solution from the radium-226 determination is saved, and the radium is reprecipitated for radium-228 analysis.

5. Method 7500-Ra C - Emanation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radon emanation; count alpha by scintillation counter.

Comments: This method utilizes a moderate amount of chemistry coupled with a sensitive alpha scintillation count of radon-222 plus progeny. An estimated minimum detectable amount (not necessarily equal to a regulatory minimum detection level) should be between 0.03 and 0.05 pCi/L.

6. Method 305 - Radium 226 by Radon in Water (Soluble, Suspended, and Total)

Reference: Standard Methods for the Examination of Water and Wastewater, 13th edition, 1971. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005 .

Methodology: Radon emanation; count alpha by scintillation counter.

Comments: This method was deleted from all editions of *Standard Methods for the Examination of Water and Wastewater* subsequent to the 13th edition, and, therefore, it may be difficult to obtain a copy of the method. Nevertheless, it is still an approved EPA method. An estimated minimum detectable amount (not necessarily equal to a regulatory minimum detection level) should be between 0.03 and 0.05 pCi/L.

7. Method D 3454-91 - Standard Test Method for Radium-226 in Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: Radon emanation; count alpha by scintillation counter.

Comments: This method covers the measurement of radium-226 in concentrations above 3.7 Bq/L.

8. Method R-1141-76 - Radium-226, Dissolved - Radon Emanation Method

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radon emanation; count alpha by scintillation counter.

Comments: None.

9. Method Ra-05 - Radium-226 in Tap Water, Urine, and Feces

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: Radon emanation; count alpha by ionization chamber or scintillation cell.

Comments: None.

10. Method Ra-02 - Determination of ^{226}Ra and ^{228}Ra

Reference: Determination of Ra-226 and Ra-228 (Ra-02), January 1980, Revised June 1982. Available from Radiological Sciences Institute Center for Laboratories and Research, New York State Department of Health, Empire State Plaza, Albany, NY 12201.

Methodology: Radon emanation (for radium-226); count alpha by scintillation cell for radium-226 and by beta/gamma coincidence counter for radium-228.

Comments: This method can measure radium-226 alone or radium-226 in conjunction with radium-228. The radium solution from the radium-226 determination is saved and the radium is reprecipitated for radium-228 analysis.

11. Method 903.0 - Alpha-Emitting Radium Isotopes in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from NTIS, document no. PB 80-224744.

Methodology: Radiochemical/precipitation; counted by alpha scintillation or gas-flow proportional alpha particle counting.

Comments: This method has a minimum detectable level of 0.5 pCi/L for a 100-minute counting time.

12. Alpha-Emitting Radium Isotopes in Drinking Water - Precipitation Method

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 13. Available from NTIS, document no. PB 253258.

Methodology: Radiochemical/precipitation; count alpha by internal proportional counter.

Comments: This method can achieve a minimum detection level of 0.04-0.15 pCi/L for a 2-L sample volume and 60- to 1,000-minute counting times. The procedure description estimates that one sample can be run in six hours and four samples can be run in eight hours.

13. Method Ra-03 - Radiochemical Determination of Radium-226 in Water Samples

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from NTIS, document no. PB 84-215581.

Methodology: Radiochemical/precipitation; alpha counting by scintillation counter.

Comments: None.

14. Method 7500-Ra B - Precipitation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical/precipitation; alpha counting by gas-flow internal proportional counter, scintillation counter, or thin end-window gas-flow proportional counter.

Comments: None.

15. Method 304 - Radium in Water by Precipitation

Reference: Standard Methods for the Examination of Water and Wastewater, 13th edition, 1971. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical/precipitation; alpha counting by gas-flow internal proportional counter, scintillation counter, or thin end-window gas-flow proportional counter.

Comments: This method was deleted from all editions of *Standard Methods for the Examination of Water and Wastewater* subsequent to the 13th edition, and, therefore, it may be difficult to obtain a copy of the method. Nevertheless, it is still an approved EPA method.

16. Method D 2460-90 - Standard Test Method for Radionuclides of Radium in Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: Radiochemical/precipitation; alpha counting by gas-flow counter or scintillation counter.

Comments: The lower limit of concentration for which this test is applicable is 1 pCi/L.

17. Method R-1140-76 - Radium, Dissolved as Radium-226 - Precipitation Method

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radiochemical/precipitation; alpha counting by low-background, anticoincidence, thin window, gas proportional counter.

Comments: None.

APPROVED METHODS - RADIUM-228

EPA has approved eight methods for radium-228 analysis in drinking water (see Table 6). All of the approved methods use a radiochemical/precipitation methodology.

1. Method 904.0 - Radium-228 in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Radiochemical/precipitation; count by gas-flow proportional beta counter.

Comments: This method can measure radium-228 alone or radium-228 in conjunction with radium-226. The radium solution from the radium-228 determination is saved, and the radium is reprecipitated for radium-226 analysis. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

2. Radium-228 in Drinking Water - Sequential Method Radium-228/Radium-226

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 24. Available from NTIS, document no. PB 253258.

Methodology: Radiochemical/precipitation; beta counting for actinium-228 to get radium-228 reading and alpha internal proportional counting for radium-226.

Comments: This method can measure radium-228 alone or radium-228 in conjunction with radium-226. The radium solution from the radium-228 determination is saved and the radium is reprecipitated for radium-226 analysis. This method can achieve a minimum detection level of 0.06-0.3 pCi/L for a 2-L sample volume and 60- to 1,000-minute counting times. The procedure description estimates that two samples can be run in 12 hours.

3. Method Ra-05 - Radiochemical Determination of Radium-228 in Water Samples

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from NTIS, document no. PB 84-215581.

Methodology: Radiochemical/precipitation; count for beta in a low background proportional counter.

Comments: This method can measure radium-228 from a fresh sample of drinking water or from a stored sample following radium-226 measurement using radon emanation.

4. Determination of Radium-226 and Radium-228 in Water, Soil, Air, and Biological Tissue

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 19. Available from NTIS.

Methodology: Radon emanation (for radium-226) followed by radiochemical/precipitation (for radium-228); for radium-226, count alpha by scintillation counter and for radium-228, count beta by low-level proportional counter.

Comments: This method allows for measurement of both radium-226 and radium-228. The radium solution from the radium-226 determination is saved, and the radium is reprecipitated for radium-228 analysis.

5. Method 7500-Ra D - Sequential Precipitation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical/precipitation; count by gas-flow internal proportional counter or thin end-window gas-flow proportional counter. For radium-226, count by scintillation counter.

Comments: This method can measure radium-228 alone or radium-228 in conjunction with radium-226. The radium solution from the radium-228 determination is saved, and the radium is reprecipitated for radium-226 analysis.

6. Method R-1142-76 - Radium-228, Dissolved - Determination by Separation and Counting of Actinium-228

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radiochemical/precipitation; beta counting by low-background, anticoincidence, thin window, gas proportional counter.

Comments: None.

7. Method Ra-02 - Determination of ^{226}Ra and ^{228}Ra

Reference: Determination of Ra-226 and Ra-228 (Ra-02), January 1980, Revised June 1982. Available from Radiological Sciences Institute Center for Laboratories and Research, New York State Department of Health, Empire State Plaza, Albany, NY 12201.

Methodology: Radon emanation (for radium-226) followed by radiochemical/precipitation (for radium-228); count alpha by scintillation cell for radium-226 and by beta/gamma coincidence counter for radium-228.

Comments: This method can measure radium-226 alone or radium-226 in conjunction with radium-228. The radium solution from the radium-226 determination is saved, and the radium is reprecipitated for radium-228 analysis.

8. Determination of Ra-228 in Drinking Water

Reference: Determination of Radium 228 in Drinking Water, August 1980. Available from State of New Jersey, Department of Environmental Protection, Division of Environmental Quality, Bureau of Radiation and Inorganic Analytical Services, Trenton, NJ 08625.

Methodology: Radiochemical/precipitation; count by low-background beta counter.

Comments: The beta counters used by the authors of this method achieved a minimum detectable concentration of 0.41 pCi/L.

APPROVED METHODS - URANIUM

EPA has approved 15 methods for uranium analysis in drinking water (see Table 7). Two methods employ radiochemical methodologies that measure total uranium alpha particle activity. Six methods employ fluorometric methodologies to measure the mass of uranium but not its alpha particle activity. Six other methods employ alpha spectrometry methodologies that can provide isotopic ratios for uranium. One additional method employs laser phosphorimetry.

1. Method 908.0 - Uranium in Drinking Water - Radiochemical Method

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Radiochemical/precipitation; count for alpha particle activity by gas-flow proportional or scintillation counting.

Comments: This method measures the total uranium alpha particle activity in drinking water and is not affected by the relative abundance of different uranium isotopes. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

2. Method 7500-U B - Radiochemical Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical/precipitation; count by gas-flow proportional counter or alpha scintillation counting.

Comments: This method measures the total uranium alpha particle activity in drinking water and is not affected by the relative abundance of different uranium isotopes.

3. Method 908.1 - Uranium in Drinking Water - Fluorometric Method

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from NTIS, document no. PB 80-224744.

Methodology: Direct fusion or fusion after extraction; count by fluorometer.

Comments: This method measures the mass of soluble uranium in water at concentrations greater than 0.1 µg/L. Different uranium isotopes have different alpha particle activity, and this method is unable to distinguish between isotopes. Therefore, unless isotopic concentration is known, radiation effects can not be assessed. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

4. Method 7500-U C Fluorometric Method (PROPOSED) [17th edition]

Reference: Standard Methods for the Examination of Water and Wastewater, 17th edition, 1989. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Direct fusion or fusion after extraction; count by fluorometer.

Comments: This method was discontinued after the 17th edition but is still an EPA-approved method. Later editions of *Standard Methods for the Examination of Water and Wastewater* include another method known as 7500-U C, but that method uses alpha spectrometry rather than fluorometry.

5. Method D 2907-91 - Standard Test Methods for Microquantities of Uranium in Water by Fluorometry

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: Direct fusion or fusion after extraction; count by fluorometer.

Comments: This method provides two different test methods depending on the concentration range of the uranium in the water sample. Test Method A - Direct Fluorometric should be used for uranium concentrations in the range of 0.005 to 2 mg/L, whereas Test Method B - Extraction should be used for concentrations in the range of 0.04 to 50 mg/L. Uranium fluorescence is quenched by many cations and some anions in the sample; it is enhanced by a few cations. If interfering ions are present, a direct fluorometric measurement is not suitable, and an extraction method should be used to provide accurate results. This method should not be used to determine the uranium alpha activity of water.

6. Method R-1180-76 - Uranium, Dissolved - Fluorometric Method - Direct

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Direct fusion; count by fluorometer.

Comments: This method is used when the quenching of uranium fluorescence by cations is less than 30%. When the quenching exceeds 30%, a companion method, R-1181-76, is used to purify the uranium by extraction. Under normal conditions, the minimum detection limit is 0.3 µg/L.

7. Method R-1181-76 - Uranium, Dissolved - Fluorometric Method - Extraction Procedure

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Extraction and fusion; count by fluorometer.

Comments: This method is used when (a) the quenching of uranium fluorescence by cations is greater than 30%, (b) the concentration of dissolved solids exceeds 10,000 mg/L, or (c) a minimum detection level lower than 0.3 µg/L is desired. Under less restrictive circumstances, a more direct companion method, R-1180-76, is used. The minimum detectable concentration is 0.01 µg/L.

8. Method U-04 - Uranium in Biological and Environmental Materials

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: Extraction and fusion; count by fluorometer.

Comments: None.

9. Method 00-07 - Radiochemical Determination of Thorium and Uranium in Water

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from NTIS, document no. PB 84-215581.

Methodology: Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.

Comments: None.

10. Isotopic Determination of Plutonium, Uranium, and Thorium in Water, Soil, Air, and Biological Tissue

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 33. Available from NTIS.

Methodology: Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.

Comments: This method allows for the measurement of isotopic plutonium, uranium, and thorium, collectively or individually. This method is designed to measure levels of activity in the range of 0.02 to 25 pCi.

11. Method 7500-U C Isotopic Method (PROPOSED) [19th edition]

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.

Comments: This method was not present in editions prior to the 18th edition, although a fluorometric method was listed with the same method number. Although *Standard Methods* considers this method to be proposed, EPA has accepted it as an approved methods. According to EPA, if the method is eventually made final, EPA will revise its list of approved methods. Until EPA updates its list of approved methods, labs should use the proposed method.

12. Method D 3972-90 - Standard Test Method for Isotopic Uranium in Water by Radiochemistry

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.

Comments: This method measures both soluble and suspended uranium.

13. Method R-1182-76 - Uranium, Dissolved, Isotopic Ratios - Alpha Spectrometry-Chemical Separation

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey*, 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radiochemical separation, electrodeposition on stainless steel disk; count by alpha spectrometer.

Comments: This method is designed to follow other companion methods R-1180-76 or R-1181-76. This method provides isotopic ratios for uranium.

14. Method U-02 - Isotopic Uranium in Biological and Environmental Materials

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: Radiochemical separation, micro precipitation; count by alpha spectrometer.

Comments: None.

15. Method D 5174-91 - Standard Test Method for Trace Uranium in Water by Pulsed-Laser Phosphorimetry

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: An aliquot of the sample is pipetted directly (for screening purposes) or after chemical treatment into the phosphorimeter cell; count by laser phosphometer.

Comments: This method covers measurement of uranium in water at levels greater than 0.05 ppb. According to the test procedures, this method may only be used directly for screening purposes.

APPROVED METHODS - RADIOACTIVE CESIUM

EPA has approved 11 methods for radioactive cesium analysis in drinking water (see Table 8). Five of the methods employ radiochemical methodologies, and six of the methods employ [direct] gamma ray spectrometry. Some of the radiochemical methods use gamma ray spectrometry for counting.

1. Method 901.0 - Radioactive Cesium in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Radiochemical separation; gamma ray spectrometry or gas-flow proportional beta counting (when Cs-134 is present alone).

Comments: This method covers measurement of cesium-134 and cesium-137 in the same sample of drinking water. This method makes it possible to determine whether an undesirable concentration of a specific nuclide is present when a gross beta screening analysis exceeds 15 pCi/L. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

2. Radioactive Cesium in Drinking Water

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 4. Available from NTIS, document no. PB 253258.

Methodology: Radiochemical separation; beta counting - no specific procedure noted.

Comments: This method can achieve a minimum detection level of 0.2-0.6 pCi/L for a 1-L sample volume and 60- to 1,000-minute counting times. The procedure description estimates that four samples can be run in five hours.

3. Method 7500-Cs B - Precipitation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical separation; count by low-background beta counter or gamma spectrometer.

Comments: None.

4. Method R-1111-76 - Radiocesium, Dissolved, as Cesium-137 - Inorganic Ion-Exchange Method - Beta Counting

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey*, 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radiochemical separation; beta counting by low-background, anticoincidence, thin window, gas proportional counter.

Comments: This method determines total dissolved radiocesium concentrations but does not measure individual isotopes. This method can be used when identification of individual cesium isotopes is not required and interfering beta-emitting isotopes are in low concentrations.

5. Method R-1110-76 - Cesium-137 and Cesium-134, Dissolved - Inorganic Ion-Exchange Method - Gamma Counting

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey*, 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radiochemical separation through a column of inorganic ion-exchanger; count dried ion-exchanger by a well-type NaI gamma detector /gamma ray spectrometer.

Comments: None.

6. Method D 2459-72 - Standard Method of Test for Gamma Spectrometry of Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1973. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge(Li) or NaI(Tl) detectors.

Comments: This method is not included in current versions of the *Annual Book of ASTM Standards*, but it still remains an EPA-approved method. This method measures nuclides emitting gamma rays with energies greater than 0.1 MeV.

7. Method 901.1 - Gamma Emitting Radionuclides in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from NTIS, document no. PB 80-224744.

Methodology: A homogeneous water sample is put into a standard geometry; count using a Ge(Li) detector (preferred) or a NaI(Tl) detector.

Comments: This method measures gamma photons emitted from radionuclides without separating them from the sample matrix. This method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 0.06 to 2 MeV. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

8. Isotopic Analysis by Gamma Ray Spectra Using Lithium-Drifted Germanium Detectors

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 92. Available from NTIS.

Methodology: A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using a Ge(Li) detector.

Comments: This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from 0.06 to 2 MeV.

9. Method 7120 B - Gamma Spectroscopic Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge or Ge(Li) detectors.

Comments: This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from 0.6 to 2 MeV.

10. Method D 3649-91 - Standard Test Method for High-Resolution Gamma-Ray Spectrometry of Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.

Comments: This method applies to radionuclides emitting gamma rays with energies greater than 20 keV.

11. Method 4.5.2.3 - Gamma

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: A homogeneous water sample is put into a standard geometry; count by gamma ray spectrometer using Ge(Li), high purity germanium, or NaI(Tl) detectors.

Comments: This method applies to radionuclides emitting gamma rays with energies greater than 20 keV for germanium detectors and greater than 50 keV for thallium-activated sodium iodide detectors.

APPROVED METHODS - RADIOACTIVE IODINE

EPA has approved 12 methods for radioactive iodine analysis in drinking water (see Table 9). Seven of the methods employ radiochemical separation followed by beta counting, gamma counting, or beta/gamma coincidence, and the other five methods employ direct gamma counting.

1. Method 902.0 - Radioactive Iodine in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Radiochemical separation; counting by gamma ray spectrometer, gas-flow proportional beta counter, or beta/gamma coincidence scintillation counter.

Comments: This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time. According to the method description, gamma spectrometry will not meet the sensitivity required by the drinking water regulations.

2. Radioactive Iodine in Drinking Water - Precipitation Method

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 6. Available from NTIS, document no. PB 253258.

Methodology: Radiochemical separation; beta counting - no specific procedure noted.

Comments: This method can achieve a minimum detection level of 0.1-0.3 pCi/L for a 2-L sample volume and 60- to 1,000-minute counting times. The procedure description estimates that six samples can be run in eight hours.

3. Radioactive Iodine in Drinking Water - Distillation Method

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 9. Available from NTIS, document no. PB 253258.

Methodology: Radiochemical separation; beta counting - no specific procedure noted.

Comments: This method can achieve a minimum detection level of 0.1-0.3 pCi/L for a 2-L sample volume and 60- to 1,000-minute counting times. The procedure description estimates that two samples can be run in eight hours.

4. Method 7500-I B - Precipitation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical separation; counting by low-background beta counter or beta-gamma coincidence counter.

Comments: Standard Methods for the Examination of Water and Wastewater lists three radiochemical methods for iodine. All three methods can reach EPA's specified detection limit for iodine. According to *Standard Methods*, method 7500-I B is preferred because it is simple and involves the least time.

5. Method 7500-I C - Ion-Exchange Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical separation; counting by low-background beta counter or beta-gamma coincidence counter.

Comments: Standard Methods for the Examination of Water and Wastewater lists three radiochemical methods for iodine. All three methods can reach EPA's specified detection limit for iodine. Method 7500-I C, in which iodide is concentrated by absorption on an anion resin, purified, and counted in a beta-gamma coincidence system, is noted among the three methods to be particularly sensitive and accurate.

6. Method 7500-I D - Distillation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical separation; beta counting - no specific procedure noted.

Comments: Standard Methods for the Examination of Water and Wastewater lists three radiochemical methods for iodine. All three methods can reach EPA's specified detection limit for iodine. Although *Standard Methods* notes special features for methods 7500-I B and 7500-I C, no such features are noted for method 7500-I D.

7. Method D 4785-88 - Standard Test Method for Low-Level Iodine-131 in Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1992. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: Radiochemical separation; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.

Comments: ASTM published an updated version of this method in 1993 (D 4785-93). However, the EPA has approved only the 1988 version of the method.

8. Method 901.1 - Gamma Emitting Radionuclides in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from NTIS, document no. PB 80-224744.

Methodology: A homogenous water sample is directly put into a standard geometry; count using a Ge(Li) detector (preferred) or a NaI(Tl) detector.

Comments: This method measures gamma photons emitted from radionuclides without separating them from the sample matrix. This method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 0.06 to 2 MeV. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

9. Isotopic Analysis by Gamma Ray Spectra Using Lithium-Drifted Germanium Detectors

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 92. Available from NTIS.

Methodology: A homogenous water sample is directly put into a standard geometry; count by gamma ray spectrometer using a Ge(Li) detector.

Comments: This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from 0.06 to 2 MeV.

10. Method 7120 B - Gamma Spectroscopic Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: A homogenous water sample is directly put into a standard geometry; count by gamma ray spectrometer using Ge or Ge(Li) detectors.

Comments: This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from 0.06 to 2 MeV.

11. Method D 3649-91 - Standard Test Method for High-Resolution Gamma-Ray Spectrometry of Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: A homogenous water sample is directly put into a standard geometry; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.

Comments: This method applies to radionuclides emitting gamma rays with energies greater than 20 keV.

12. Method 4.5.2.3 - Gamma

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: A homogenous water sample is directly put into a standard geometry; count by gamma ray spectrometer using Ge(Li), high purity germanium, or NaI(Tl) detectors.

Comments: This method applies to radionuclides emitting gamma rays with energies greater than 20 keV for germanium detectors and greater than 50 keV for thallium-activated sodium iodide detectors.

APPROVED METHODS - RADIOACTIVE STRONTIUM-89 AND -90

EPA has approved nine methods for radioactive strontium analysis in drinking water (see Table 10). All of the methods employ radiochemical methodologies.

1. Method 905.0 - Radioactive Strontium in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Radiochemical separation; beta counting - no specific procedure noted.

Comments: This method has a minimum detectable level of 0.5 pCi/L for a 100-minute counting time.

2. Radioactive Strontium in Drinking Water

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 29. Available from NTIS, document no. PB 253258.

Methodology: Radiochemical separation; beta counting - no specific procedure noted.

Comments: This method can achieve a minimum detection level for strontium-89 of 0.3-0.9 pCi/L and for strontium-90 of 0.1-0.5 pCi/L for a 1-L sample volume and 60- to 1,000-minute counting times. The procedure description estimates that four samples can be run in six hours.

3. Method Sr-04 - Radiochemical Determination in Water, Sea Water and Other Aqueous Media

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from NTIS, document no. PB 84-215581.

Methodology: Radiochemical separation; low background beta counting.

Comments: None.

4. Determination of Strontium-89 and Strontium-90 in Water, Vegetation, Soil, and Biological Tissue

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 65. Available from NTIS.

Methodology: Radiochemical separation; low-background beta counting.

Comments: None.

5. Method 303 - Total Radioactive Strontium-89 and Strontium-90 in Water

Reference: Standard Methods for the Examination of Water and Wastewater, 13th edition, 1971. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005 .

Methodology: Radiochemical separation; beta counting by gas-flow internal proportional counter or thin end-window low-background proportional counter.

Comments: This method was deleted from all editions of *Standard Methods for the Examination of Water and Wastewater* subsequent to the 13th edition, and, therefore, it may be difficult to obtain a copy of the method. Nevertheless, it is still an approved EPA method.

6. Method 7500-Sr - Precipitation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005 .

Methodology: Radiochemical separation; beta counting by gas-flow internal proportional counter or thin end-window low-background proportional counter.

Comments: None.

7. Method R-1160-76 - Strontium-90, Dissolved, Chemical Separation and Precipitation Method

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radiochemical separation; beta counting by low-background, anticoincidence, thin window, gas proportional counter.

Comments: This method measures both strontium-89 and strontium-90 but does not distinguish between them. All radioactive strontium is reported as strontium-90.

8. Method Sr-01 - Strontium-89

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: Radiochemical separation; counting by low-level beta scintillation counter.

Comments: Strontium-89 is normally determined at the same time as strontium-90. Therefore, the radiochemical procedures in this method are those described in a companion method, Sr-02.

9. Method Sr-02 - Strontium-90

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: Radiochemical separation; counting by low-level beta scintillation counter.

Comments: This method measures strontium-90. A companion method, Sr-01, measures strontium-89.

APPROVED METHODS - TRITIUM

EPA has approved eight methods for radioactive iodine analysis in drinking water (see Table 11). All of the methods employ liquid scintillation spectrometry.

1. Method 906.0 - Tritium in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by coincidence-type liquid scintillation spectrometer.

Comments: This method can achieve a minimum detectable level of 300 pCi/L for a 100-minute counting time.

2. Tritium in Drinking Water

Reference: Interim Radiochemical Methodology for Drinking Water, EPA 600/4-75-008 (revised), prepared by EPA's Environmental Monitoring and Support Laboratory, March 1976, page 34. Available from NTIS, document no. PB 253258.

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by liquid scintillation spectrometer.

Comments: This method can achieve a minimum detection level of 70-500 pCi/L for sample sizes ranging from 4 to 8 mL and 60-minute to 1,000-minute counting times. The procedure description estimates that four samples can be run in two hours.

3. Method H-02 - Radiochemical Determination of Tritium in Water - Dioxane Method

Reference: Radiochemistry Procedures Manual, EPA 520/5-84-006, prepared by EPA's Eastern Environmental Radiation Facility, August 1984. Available from NTIS, document no. PB 84-215581.

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by liquid scintillation spectrometer.

Comments: None.

4. Determination of Tritium in Water and Biological Tissue (Direct Method)

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 87. Available from NTIS.

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by liquid scintillation spectrometer.

Comments: None.

5. Method 306 - Tritium in Water

Reference: Standard Methods for the Examination of Water and Wastewater, 13th edition, 1971. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005 .

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by liquid scintillation spectrometer.

Comments: This method was deleted from all editions of *Standard Methods for the Examination of Water and Wastewater* subsequent to the 13th edition, and, therefore, it may be difficult to obtain a copy of the method. Nevertheless, it is still an approved EPA method.

6. Method 7500-^{3}H - Liquid Scintillation Spectrometric Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005 .

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by coincidence type liquid scintillation spectrometer.

Comments: None.

7. Method D 4107-91 - Standard Test Method for Tritium in Drinking Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by coincidence-type liquid scintillation spectrometer.

Comments: None.

8. Method R-1171-76 - Tritium, Liquid Scintillation Method, Denver Lab

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Distillation, portion of distillate mixed with scintillator solution, beta counting by liquid scintillation spectrometer.

Comments: None.

APPROVED METHODS - GAMMA EMITTERS

EPA has approved 11 methods for gamma-emitter analysis in drinking water (see Table 12). All of the methods employ gamma ray spectrometry, and six of them employ radiochemical steps before spectrometry.

1. Method 901.0 - Radioactive Cesium in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from U.S. Department of Commerce, National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, document no. PB 80-224744.

Methodology: Radiochemical separation; gamma ray spectrometry or gas-flow proportional beta counting (when Cs-134 is present alone).

Comments: This method covers measurement of cesium-134 and cesium-137 in the same sample of drinking water. This method makes it possible to determine whether an undesirable concentration of a specific radionuclide is present when a gross beta screening analysis exceeds 15 pCi/L. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

2. Method 902.0 - Radioactive Iodine in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from NTIS, document no. PB 80-224744.

Methodology: Radiochemical separation; counting by gamma ray spectrometer, gas-flow proportional beta counting, or beta/gamma coincidence scintillation counting.

Comments: This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time. According to the method description, gamma spectrometry will not meet the sensitivity required by the drinking water regulations.

3. Method 7500-Cs B - Precipitation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical separation; count by low-background beta counter or gamma spectrometer.

Comments: None.

4. Method 7500-I B - Precipitation Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: Radiochemical separation; counting by low-background beta counter or beta-gamma coincidence counter.

Comments: Standard Methods for the Examination of Water and Wastewater lists three radiochemical methods for iodine. All three methods can reach EPA's specified detection limit for iodine. According to *Standard Methods*, method 7500-I B is preferred because it is simple and involves the least time.

5. Method D 4785-88 - Standard Test Method for Low-Level Iodine-131 in Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1992. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: Radiochemical separation; count by gamma ray spectrometer using Ge(Li) or high purity germanium detectors.

Comments: ASTM published an updated version of this method in 1993 (D 4785-93). However, the EPA has approved only the 1988 version of the method.

6. Method R-1110-76 - Cesium-137 and Cesium-134, Dissolved - Inorganic Ion-Exchange Method - Gamma Counting

Reference: Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, Chapter A5 in Book 5 of *Techniques of Water-Resources Investigations of the United States Geological Survey,* 1977. Available from U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225-0425.

Methodology: Radiochemical separation through a column of inorganic ion-exchanger; count dried ion-exchanger by a well-type NaI gamma detector /gamma ray spectrometer.

Comments: None.

7. Method 901.1 - Gamma Emitting Radionuclides in Drinking Water

Reference: Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA 600/4-80-032, prepared by EPA's Environmental Monitoring and Support Laboratory, August 1980. Available from NTIS, document no. PB 80-224744.

Methodology: A homogeneous water sample is put into a standard geometry; counting by a Ge(Li) detector (preferred) or a NaI(Tl) detector.

Comments: This method measures gamma photons emitted from radionuclides without separating them from the sample matrix. This method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 0.06 to 2 MeV. This method has a minimum detectable level of 1.0 pCi/L for a 100-minute counting time.

8. Isotopic Analysis by Gamma Ray Spectra Using Lithium-Drifted Germanium Detectors

Reference: Radiochemical Analytical Procedures for Analysis of Environmental Samples, EMSL-LV-0539-17, prepared by EPA's Environmental Monitoring and Support Laboratory, March 1979, page 92. Available from NTIS.

Methodology: A homogeneous water sample is put into a standard geometry; counting by a gamma ray spectrometer using a Ge(Li) detector.

Comments: This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from 0.06 to 2 MeV.

9. Method 7120 B - Gamma Spectroscopic Method

Reference: Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995. Available from American Public Health Association, 1015 Fifteenth Street N.W., Washington, D.C. 20005.

Methodology: A homogeneous water sample is put into a standard geometry; counting by a gamma ray spectrometer using Ge or Ge(Li) detectors.

Comments: This method is applicable for analysis of gamma-emitting radionuclides with gamma energies ranging from 0.06 to 2 MeV.

10. Method D 3649-91 - Standard Test Method for High-Resolution Gamma-Ray Spectrometry of Water

Reference: Annual Book of ASTM Standards, Vol. 11.02, 1994. Available from American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Methodology: A homogeneous water sample is put into a standard geometry; counting by a gamma ray spectrometer using Ge(Li) or high purity germanium detectors.

Comments: This method applies to radionuclides emitting gamma rays with energies greater than 20 keV.

11. Method 4.5.2.3 - Gamma

Reference: EML Procedures Manual, HASL-300, 27th Edition, Volume 1, 1990. Available from the Environmental Measurements Laboratory, U.S. Department of Energy, 376 Hudson Street, New York, NY 10014-3621.

Methodology: A homogeneous water sample is put into a standard geometry; counting by a gamma ray spectrometer using Ge(Li), high purity germanium, or NaI(Tl) detectors.

Comments: This method applies to radionuclides emitting gamma rays with energies greater than 20 keV for germanium detectors and greater than 50 keV for thallium-activated sodium iodide detectors.

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