

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Purpose

The purpose of this Procedure is twofold:

- 1) To document the quality procedures used to insure that the NIST Standard Reference Materials (SRMs) for Radioactivity Measurements are of the highest metrological quality, and
- 2) To document the principles and practices of the production processes of the radioactivity SRMs.

There are a wide range of individual values and protocols that could be used to produce a radioactivity SRM. Hence, the exact values of properties and the exact production details of the current radioactivity SRMs are presented in appendices rather than in the body of this Procedure.

Background

NIST radioactivity SRMs represent the national basis for accurate radioactivity measurements. A number of commercial companies provide secondary radioactivity standards, both for specific and general needs. These secondary standards are linked to the NIST produced national standards through Measurement Assurance Programs with NIST. Generally, the radioactivity SRMs that are available from NIST are provided for one of several reasons: (a) they are not available from outside commercial suppliers, (b) commercially produced standards may not be traceable to national standards, (c) the accuracy of commercially produced standards is not adequate for a significant number of users, or (d) there are enough requests from the user community for a standard not otherwise available. Radioactivity SRMs can typically be classified into three general categories: (1) environmental and nuclear power, (2) medicine, and (3) basic and applied research using or involving radioactivity in the development of nuclear data and the examination of basic nuclear processes.

NIST issues a wide array of SRMs for radioactivity measurements. Typically there are 60 such SRMs in stock and calibrations have been performed on approximately 80 radionuclides. Expanded uncertainties of these calibrations are typically 2 percent or less. These calibrations are performed using approximately 40 radiometric and a few mass spectrometric methods. The SRMs are issued in a number of configurations, including gamma-ray point sources mounted between thin plastic sheets, acidic solutions of alpha, beta, gamma, and X-ray emitting radionuclides, gases, and Natural Matrix materials. The NIST Natural Matrix radioactivity SRMs (see IRD Procedure 16) are a result of a collaboration of national and international environmental laboratories. These SRMs are distributed as ground, homogenized powders of soils, sediments, and organic materials and are characterized for as many as 20 radionuclides at environmental levels.

NIST radioactivity measurements are compared with the primary standards of other National Metrology Laboratories (NMIs) world-wide through the International Bureau of Weights and Measures (BIPM) which organizes and analyses the measurements. The results of such International Comparisons, as well as an extensive data file of NIST Calibration and Measurement Capabilities (CMCs), may be found on the BIPM website at www.bipm.org.

Scope

Appendix A1 lists the properties of 72 radioactivity SRMs that are in stock or in preparation as of January 2005. The certified massic activities (activity divided by the total mass of the sample [1]) of the radioactivity SRMs have a range of more than 15 orders of magnitude, from less than 10^{-3} Bq·g⁻¹ to more than 10^{12} Bq·g⁻¹. The half lives have a range of more than 13 orders of magnitude, from less than 10^{-3} years (6 hours) to more than 10^{10} years. Radioactivity SRMs with short half lives are available only at certain

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	1 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

preannounced times. The radionuclides range from hydrogen-3 ($Z = 1$) to curium-244 ($Z = 96$), and include solids, liquids, and gases.

For such a wide variety of radioactivity SRMs there is not a single procedure (or even a small number of procedures) that can be used to describe how they are made. There is, however, a sequence of steps that can be used to describe the production process of an SRM, including a radioactivity SRM, in a general way. Each of these steps is discussed in greater detail in the Procedures section of this document. Within each step, the intent will be generally the same, but the exact sequence of the steps and the exact procedure by which each step is carried out may vary from SRM to SRM. Each of the most common procedures within each step will be described in detail in an appendix dedicated to that procedure. These appendices form a collection of "modular building blocks" from which the appropriate ones can be selected and combined to form the complete production procedure for any given radioactivity SRM. See Appendix A1 for the information necessary to construct the complete production procedure for each radioactivity SRM.

Safety

The production processes for the radioactivity SRMs involve working with radioactive materials, sometimes at very high levels of activity and dose rate, with various acids and other chemicals, and with potentially dangerous equipment. Safe work practices are an essential part of the production process. See step 6 in the procedures section.

Equipment

The production of the NIST radioactivity SRMs involves a large number of different machines and measuring instruments. See step 8 in the Procedures section.

Uncertainty Analysis

A measurement result is complete only when accompanied by a quantitative statement of its uncertainty. The uncertainty often determines the usefulness of the measurement result. The analysis and reporting of measurement uncertainties is an essential step in the production process. See step 20 in the Procedures section.

Records

The data in the production records should be complete enough so that anyone who is reasonably familiar with the SRM production processes can reproduce any or all of the calculations that lead to the final measurement results and uncertainties for the SRM (i.e., the Certificate values) and evaluate and reproduce the production process (e.g., for the next batch of that SRM). See step 22 in the Procedures section.

Filing and Retention

The radioactivity SRM production records are stored in Building 245, Room E103. The production records are retained for as long as the SRM is available for sale to the public, plus at least an additional 10 years. See step 22 in the Procedures section.

The Ionizing Radiation Division (IRD) Quality Manager shall maintain the original and all past versions of this IRD Procedure.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	2 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Copies of the current revision of this Procedure shall be placed in controlled Quality Manuals. Electronic copies of this Procedure are uncontrolled versions.

All deleted Procedures (including old revisions) shall be maintained by the IRD Quality Manager. All old revisions shall be maintained until such time as it is decided to delete the Procedure. Once the decision has been made to delete the Procedure, only the last revision shall be maintained by the IRD Quality Manager.

Procedures

The need for a new SRM largely derives from advice from the radioactivity user community. Interactions with this community include the annual CIRMS (Council on Ionizing Radiation Measurements and Standards) meeting, the NEI (Nuclear Energy Institute) steering committees, focused workshops and personal interactions with users within other laboratories, academia and industry. This need is usually identified by the principal investigator responsible for producing, calibrating and certifying the SRM. A need could also be identified by other Radioactivity Group (RG) members.

The responsibilities of the Radioactivity Group Leader, SRM Coordinator and SRM principal investigator as well as the coordination of SRM activities among them, is described in IRD-QM-II Sections 4.2.3.2.2 and 4.2.3.2.

Below is a sequence of general steps that can be used to describe the production process of a radioactivity SRM.

Step 1. Determine the intended use, the requirements, and the demand for the SRM.

Insuring that each NIST radioactivity SRM is of the highest metrological quality requires more than having low uncertainty of the certified values. It also requires that the form, chemical composition, size, activity, and packaging of the SRM are such that the user can easily make correct and accurate measurements; the price of the SRM must also be acceptable to the intended customers. In order to help insure all of these things, the RG seeks the advice of a number of organizations in addition to the requests and suggestions of individual customers.

If this SRM is a renewal (i.e., the production of a new batch of an already existing, but presently out-of-stock, SRM), the previous sales record is also considered. If there is some question about the continued need for a particular radioactivity SRM, then previous customers for that SRM are usually consulted to obtain their comments and suggestions.

See Appendix A1 for the (primary) intended use for each radioactivity SRM.

Step 2. Select the chemical and physical properties of the SRM, and select the chemical and physical quantities that are to be quantified and/or certified.

There are three basic guidelines for the selection of the chemical and physical properties of a radioactivity SRM:

1. The SRM should be stable (there is no chemical or physical change to the radioactivity SRM, other than the intrinsic radioactive decay, that changes a certified value by more than 25 percent of its stated uncertainty over the stated time period) for a period of at least ten half-lives of the primary radionuclide or for at least 20 years, whichever is less.
2. The SRM should be as similar as is practical to the sample(s) that the customer will measure. This

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	3 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

helps reduce or eliminate additional uncertainties due to dilution or due to corrections for different geometries, different photon absorptions, etc.

3. The SRM should be useable by as many customers as possible. For example, at the request of the U.S. Environmental Protection Agency, all new batches of solution radioactivity SRMs that are used as tracers for environmental measurements are made with nitric acid. This is because stainless-steel planchets are widely used to make deposited sources for environmental measurements and nitric acid does not significantly attack stainless steel (unlike, for example, hydrochloric acid).

There are two basic guidelines for the selection of the chemical and physical properties whose values are to be quantified:

1. All of the properties that are essential to the proper use of the radioactivity SRM must be described quantitatively. For example, some users are only able to dispense solution SRMs volumetrically using a pipette. Since the solution radioactivity SRMs have certified values of massic activity (activity per unit mass), the solution density must be accurately quantified in order for the SRM to be useful.
2. The precision of contributing measurements should be considered such that the expanded uncertainty of the SRM remains low enough to be satisfactory for the majority of users.

See Appendix A1 for the properties of each radioactivity SRM.

Step 3. Select a suitable container and packaging for the SRM.

The three basic guidelines for the selection of a suitable container for a radioactivity SRM are the same as for selecting the chemical and physical properties of the SRM (see step 2).

The containers currently in use for radioactivity SRMs have been selected according to these guidelines. See Appendix A1 for the container used for each radioactivity SRM.

As part of the production process, additional packaging is placed around the container of the radioactivity SRM. This packaging is designed to protect the SRM during handling and long-term storage, and is designed to pass the performance tests for Type-A packages of radioactive material. The packaging currently in use for the radioactivity SRMs have proven satisfactory over decades of use.

Step 4. Select a measurement model, suitable sampling and measurement method (experimental design), including the sequence of operations for the production process.

Four possible types of measurement models are considered for the radioactivity SRMs.

1. LMNL = Linear, Multiplicative, Normal, Low Correlation
2. LMNH = Linear, Multiplicative, Normal, High Correlation
3. LMOL = Linear, Multiplicative, Other than Normal, Low Correlation
4. NMNL = Non-Linear, Multiplicative, Normal, Low Correlation

The first type of measurement model has proven to be appropriate for most of the radioactivity SRMs. The measurement model is selected in consultation with the NIST Statistical Engineering Division, if needed.

Measurements are made on one or more samples of the master solution/mixture to determine the values of the properties that are to be quantified. In order for these measurements to be relevant to the SRM solution/mixture, the two solutions or mixtures must be gravimetrically related. In the IRD, only gravimetric measurements are used when dispensing or diluting the master and the SRM solutions.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	4 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

It is clearly advantageous in terms of production effort (and often in terms of minimizing the measurement uncertainty as well) to have the master solution and the SRM solution be the same, and this is done whenever practical. For most gamma-ray-emitting radioactivity SRMs, the master solution and the SRM solution are the same solution. For the gamma-ray-emitting solutions, both liquids and gases, the unopened SRM ampoule is the sample for measurement. For the point sources, the sample to be measured is a NIST standard borosilicate-glass ampoule containing (5.0 ± 0.1) mL of master solution of known mass.

For alpha-particle-emitting and beta-particle-emitting radioactivity SRMs, the master solution and the SRM solution may or may not be the same solution. For the low-level environmental tracer solutions, the SRM solution is a quantitative dilution of the master solution. Careful and thorough mixing of the solutions is essential if the calibration of the master solution is to be relevant to the SRM solution. The master solution is gravimetrically dispensed to make point sources and/or liquid scintillation sources for measurement. If the master solution is to be diluted to make the SRM solution, this is usually done at the same time.

The selection of primary and confirmatory measurement methods depends primarily on the decay mode of the primary radionuclide and on the activity and physical form of the sample(s) to be measured. The general criteria for the selection of a measurement method are:

1. Non-destructive to the sample (if possible)
2. Ease of measurement
3. Ease of sample preparation
4. Low measurement uncertainty
5. Selectivity (if more than one radionuclide is present)
6. High detection efficiency (especially if the decay rate is low)

There are presently 16 basic methods, some with many variations, that are used for primary and/or confirmatory and/or impurity measurements of the radioactivity SRMs. See Appendix A1 for the measurement method(s) used for each radioactivity SRM.

The sequence in which the required steps are to be carried out, and the required facilities, equipment, personnel, supplies, and funding, should be documented in whatever form is satisfactory for the purpose, such as lists, tables, drawings, flow charts, Gantt diagrams, etc..

Step 5. Have the proposed production process reviewed and approved.

The review and approval of the SRM production plan are carried out by the Radioactivity Group Leader and the SRM Coordinator. A record of this review shall be maintained with the SRM documentation.

Step 6. Have the proposed safety measures reviewed and approved by the NIST Occupational Health and Safety Division.

The acquisition and use of radioactive material at NIST must be approved, in advance, by the NIST Health Physics Group (HP), a part of the NIST Occupational Health and Safety Division. For the radioactivity SRM production process, this is done by submitting a written Standard Operating Procedure (SOP) for approval along with a properly signed (by the RG Leader or IRD Chief) NIST 364, "Proposal to Acquire a Radioactive Source." Once approved by the Health Physics Group, the SOP is assigned an identification number and can be referenced in future production processes.

Step 7. Obtain the necessary funding.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	5 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

This step is normally carried out by the Coordinator of radioactivity SRM production together with the RG leader. Funding of a radioactivity SRM production from the SRM Working Capital Fund requires the approval of the IRD Administrative Officer, the IRD Chief, the Director of the Physics Laboratory, and the NIST Comptroller.

Step 8. Arrange for the use of the necessary facilities, equipment, and personnel

A number of suitable general purpose radiochemistry laboratories are available in the NIST Ionizing Radiation Division/Radioactivity Group (IRD/RG) for the preparation of radioactivity SRMs and measurement of samples. The production of the NIST radioactivity SRMs involves a large number of different machines and measuring instruments. It is the intent of the IRD/RG that there are enough units of each type of equipment available so that no one piece of equipment is essential to the production process of any SRM. For example, the preparation of 50 mg radioactive point sources may require a microbalance with a capacity of >7 g, a readability of <5 µg, and a standard uncertainty of <50 µg (relative to the SI). The IRD/RG currently has at least 6 balances that meet these specifications, all of which are serviced and calibrated once per year with NIST traceable masses.

This step is normally carried out by, or in cooperation with, the Coordinator of radioactivity SRM production and with the concurrence of the RG leader.

Step 9. Acquire suitable materials.

As used here, materials include

- a. the radioactive material for the radioactivity SRM,
- b. chemical reagents and other consumable materials, and
- c. SRM containers, glassware, and other laboratory supplies.

Most radionuclides used to produce radioactivity SRMs are available from commercial suppliers. Radionuclidic purity and carrier concentration vary somewhat, but one can usually purchase suitable radioactive starting material that does not require any additional chemical purification. A few radionuclides that are used for radioactivity SRMs are the parent of a radioactive decay chain and chemical purification may be necessary to improve the calibration accuracy or because of the way in which the SRM is used.

Chemical reagents used as solvents and non-radioactive carriers are at least Analytical Grade reagents, and each bottle is provided with a lot analysis. Spectroscopic Grade reagents or Trace Element Grade reagents are preferred.

Borosilicate glass or Teflon containers are always used for solution radioactivity SRMs.

Step 10. Prepare and characterize the materials (as necessary).

The SRM containers, glassware, and other laboratory supplies are prepared, as necessary, using standard analytical laboratory techniques for washing, rinsing, drying, labeling, etc.

For most of the radioactivity SRMs, the radioactive starting material is received as a solution. The material is measured for radiological (and sometimes chemical) impurities. This is typically done using gamma-ray spectrometry. If the radioactive material is a pure alpha-particle emitter or a pure beta-particle emitter, a portion of the solution may also be measured using alpha-particle or beta-particle spectrometry. Depending upon the nature and level of the impurities, additional chemical separation may be required.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	6 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Step 11. Prepare the master solution (or mixture) and, if different from the master, the SRM solution (or mixture).

The master solution or mixture is the material that is calibrated and the measurements on this material are used to determine the certified values; it is always gravimetrically related to the SRM solution or mixture. The massic activity of the master solution is optimized for the calibration measurements.

For solution radioactivity SRMs, the density of the SRM solution is measured because some users are able to dispense solution SRMs volumetrically only using a pipette. In the IRD/RG, only gravimetric measurements are used when dispensing or diluting the master and the SRM solutions.

Step 12. Dispense the SRM solution (or mixture) into the SRM containers.

For a point source, this consists of gravimetrically dispensing from as little as 15 mg, to as much as 300 mg, of the SRM solution unto the center of the point source mount (filter round on adhesive polyester tape, bare tape, or stainless-steel disk) using a small plastic pycnometer. The mass dispensed depends upon the desired activity for the point source and the type of point source mount (plastic or stainless steel). A larger dispensed mass has a lower relative uncertainty associated with the measurement of the mass, but a smaller area for the deposited radionuclide is also desirable, especially when using the plastic source mounts. For the plastic source mounts, a deposited solution mass of 15 mg to 50 mg is usually satisfactory.

Solution radioactivity SRMs are prepared using a precision liquid dispenser to dispense the SRM solution. For gamma-ray-emitting solution SRMs, the volume of solution is (5.0 ± 0.1) mL in a NIST standard 5 mL borosilicate-glass ampoule (from a NIST ampoule stock reserved for this purpose), and each ampoule is weighed before and after filling (some gamma-ray-emitting solution SRMs are used for measurements as the unopened ampoule). Since the solution radioactivity SRMs have certified values of activity per unit mass, the total mass of the solution in the ampoule must also be measured and included in the certificate.

For alpha-particle-emitting and beta-particle-emitting radioactivity SRMs, the ampoules are also made of borosilicate glass but need not be NIST standard 5 mL ampoules. The volume of solution is approximately 5.0 mL and some of the ampoules (usually >10%) are weighed before and after filling. The mass of the solution may or may not be included in the certificate as alpha-particle and beta-particle measurements cannot be made on the solution in an unopened ampoule.

For gaseous radioactivity SRMs, the borosilicate-glass gas ampoules are filled to a measured pressure, usually somewhat less than atmospheric pressure, using a vacuum rack and a gas transfer system. No attempt is made to measure the exact volume of a gas ampoule. Gas ampoules are certified in terms of the total activity in each ampoule.

Step 13. Seal and sterilize the SRM containers.

Point sources: After the deposited solution dries, the point source is covered and sealed using another layer of adhesive polyester tape (or using another stainless-steel disk that is then welded around the edge). Point source radioactivity SRMs are not sterilized.

Ampoules: All ampoules are flame sealed. Some of the solution radioactivity SRMs are sterilized in a pressure cooker for 15 minutes at 103.421kPa (15 psi) to kill any organisms that may be present. This is important for those SRM solutions that have a pH between 1 and 13. The growth of organisms in solutions with pH greater than 13 or less than 1 is unlikely. The sterilization procedure also serves as a pressure test for the seal on the ampoule. After sterilization, the ampoules and the pressure cooker are checked to

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	7 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

determine any leakage of radioactive material

Step 14. Prepare samples for measurement.

For the gamma-ray-emitting solution radioactivity SRMs, both liquids and gases, the SRM is the sample for measurement. For the point sources, the sample to be measured is a NIST standard borosilicate-glass ampoule containing (5.0 ± 0.1) mL of master solution of known mass.

For the alpha-particle-emitting and beta-particle-emitting radioactivity SRMs, the master solution is the sample for the calibration measurements. The master solution is gravimetrically dispensed to make point sources and/or liquid scintillation sources for measurement. In addition, some of the SRM ampoules (typically the first, middle, and last ampoule filled) are opened and similar sources are made to check the gravimetric dilution ratio between the master solution and the SRM solution. In general, the uncertainty associated with the direct measurement of the dilution ratio will be much larger than the uncertainty associated with the gravimetric measurements. The direct measurement serves as a check on any serious error in the gravimetric measurements, in the calculations, or in the thoroughness of mixing the solution.

See Appendix A1 for the method of preparing the measurement samples for each radioactivity SRM.

Step 15. Measure the value of each selected property using a primary measurement method.

For the gamma-ray-emitting solution radioactivity SRMs, both liquids and gases, each ampoule is measured in the Pressurized Ionization Chamber "A" (PIC "A") to determine the total activity of the primary radionuclide. Corrections are made for the response due to any other photon-emitting radionuclides present.

See Appendix A1 for the primary measurement method used for each radioactivity SRM.

Step 16. Confirm each measured value using one or more confirmatory measurement methods.

Where possible, independent confirmatory measurement methods are used to verify the results from the primary measurement method. Comparison with samples from one or more of the previous batches of the same SRM is also used when such samples are available. A confirmatory method is also used to measure one or more of the individual radioactivity SRMs when the SRM solution is not the master solution. This serves as an additional check on the dispensing and/or dilution of the master solution.

See Appendix A1 for the confirmatory measurement method(s) used for each radioactivity SRM.

Step 17. Measure the homogeneity among (and possibly within) SRM units.

The homogeneity among radioactivity SRM units is usually confirmed by making measurements on several units within the same batch.

For gamma-ray-emitting solution radioactivity SRMs, the massic activity of the solution in each ampoule can be calculated from the measured activity and the measured solution mass. The massic activities are checked for deviant values and for correlations (such as with dispensing sequence or mass of solution).

For gamma-ray-emitting point sources, each point source can be measured with reproducible (but not necessarily known) efficiency. The massic response for each point source can be calculated from the measured response and the measured mass of solution dispensed unto the point source. The massic

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	8 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

responses are checked for deviant values and for correlations (such as with dispensing sequence or mass of solution). The activity of one or more of the point sources can be determined (usually using a calibrated photon spectrometry system) and compared with the activity expected from the mass of calibrated solution dispensed into the source.

For alpha-particle-emitting and pure beta-particle-emitting solution radioactivity SRMs, several ampoules (typically one of the first, middle, and last of the ampoules filled) are opened and the massic activity of each solution is measured. The massic activities are checked for deviant values and for correlations (such as with dispensing sequence).

See Appendix A1 for the homogeneity test(s) used for each radioactivity SRM.

Step 18. Establish traceability.

For solution radioactivity SRMs, the measurements include:

1. Radionuclide(s),
2. Massic Activity(ies),
3. Expanded Uncertainty(ies),
4. Reference Time,
5. Solution Mass, and
6. Solution Density (uncertified) at a reference temperature (usually 20 °C).

For gas ampoules and point sources, the measurements include:

1. Radionuclide(s),
2. Total Activity(ies),
3. Expanded Uncertainty(ies), and
4. Reference Time.

The measurements made as part of the calibration of a radioactivity SRM are traceable to NIST as follows:

1. Time
Measurements of clock time are made using direct time transmissions from NIST Boulder. Counting time increments obtained with calibration instruments are measured by counting the number of cycles from temperature compensated crystal oscillators whose frequencies are measured using a frequency meter traceable to NIST.
2. Mass
Balances and scales used to measure the mass of the SRM solution (or solid) are serviced and calibrated at least once per year using masses (weight sets) directly traceable to NIST.
3. Length (Volume)
Volumetric glassware used to determine the solution density is Class A glassware and is gravimetrically calibrated using distilled water and the well-established relationship between the density of pure water and the temperature.
4. Temperature / Pressure / Relative Humidity
The manufacturer's stated accuracy for instruments used to measure temperature, pressure and relative humidity are sufficient.

The determination of activity requires that the number of radioactive decays that occur during a finite time interval be counted. The time interval can usually be chosen so as to make its uncertainty negligible. The difficulty lies in determining the efficiency of the detector for the radioactive decays. Every radioactivity detector has some intrinsic inefficiency, has a finite size (and hence boundaries), cannot detect radioactive

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	9 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

decays that deposit less than some minimum amount of energy in the detector (threshold), and gives some count rate even in the absence of radioactive decays in the source (background count rate). The efficiency of a single detector (decays detected / total decays) cannot be verified without reference to one or more other detectors.

The efficiency of a detector has to be calculated on the basis of one or more theoretical measurement models, each of which has some inherent uncertainty. For radioactive decay, the theoretical measurement models with the lowest uncertainties are those that use multiple detectors, time correlation measurements, and efficiency extrapolations. (See references [4], [5], [6].) These measurement models (and the related measurement methods - coincidence and anticoincidence counting with efficiency-extrapolation techniques) cannot be used with all radionuclides or types of decay. But activity calibrations using these models and techniques have become the cornerstone of the international measurement system for radioactivity. The calibration of virtually all radioactivity measurement instruments is based upon them.

Step 19. Evaluate the uncertainty.

Measurement uncertainty is evaluated in accordance with the *Guide to the Expression of Uncertainty in Measurement* [2] and the *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results* [3].

In general, the uncertainty components associated with the instruments and artifacts used to measure time, mass, length (volume), temperature, pressure, and relative humidity, are small and reasonably well known. For most radioactivity SRMs, the largest component of uncertainty arises from the uncertainty in the detection efficiency for the radioactive decays. The uncertainties associated with the detection efficiency (decays detected / total decays) vary with the type of radioactive decay, with the type of detector, and with the measurement method.

See Appendix A1 for the radionuclide, the decay mode(s), the expanded uncertainty, the measurement method(s), and other data for each radioactivity SRM.

Step 20. Label, package, and store the SRM containers.

As part of the production process, additional packaging is placed around the container for the radioactivity SRM. This packaging is designed to protect the SRM during handling and long-term storage. The packaged SRMs are stored in Room B49 until shipped to the customer.

The US Department of Transportation (USDOT) and the US Nuclear Regulatory Commission (USNRC) require that personnel that label and package radioactive material for shipping be certified to do so. USDOT certification is available through the NIST Health Physics Office.

Step 21. Prepare the SRM Certificate and conduct Technical Review.

The NIST Certificate for a radioactivity SRM contains information about the composition, the properties, and the proper use of the SRM. Additional required information, as stated in NIST-QM-I Sections 5.10.2 and 5.10.3. For an example of previously issued certificates, see Appendix A3.

Prior to issuance, the certificate undergoes a final technical review. The technical review must be approved (and signed) by the principal investigator, RG leader, the division chief and the SRM coordinator.

Step 22. Collect and store the production records.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	10 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

The radioactivity SRM production plan, detailed descriptions of the certification methods and procedures, methods of validation, measurement uncertainty, and sampling plans are archived together in a three ring binder. These documents and records are stored in Building 245, Room E103. The production information is retained for as long as the SRM is available for sale to the public, plus at least an additional 10 years.

A list of the typical contents of the Record File is presented below:

Preparatory

- Justification for SRM production. This is a simple statement as to why the SRM is being produced; e.g., reissue of previous one, new demand for new one and justification, etc. The SRM coordinator can assist in the justification.
- Funding request to and approval from SRM Program Office. This is largely handled by the SRM coordinator.
- Approval for acquisition and use of radioactive materials by Health Physics
- Description of the experimental design / plans (i.e., list, table, diagrams, outline, or flowchart, etc.), which may include measurement methods, sequence of steps to be used, facilities, equipment, supplies, personnel, counting source preparation details, etc.
- Production approval by SRM coordinator, including number to be produced, activity levels, composition, etc.
- Purchase order for radioactive material (if necessary)
- Acquisition of material explanation (if not purchased)

Production (as applicable)

- Any relevant technical information of the material provided by the manufacturer or from previous production.
- MSDS (if material has a physical, chemical or biological hazard)
- Preparation of carrier solution data
- Preparation of master solution or mixture data
- Dispenser test data (if applicable)
- SRM dispensing data (if applicable)
- Statement of SRM sterilization and independent documentation if available (e.g., radiation sterilization for natural matrix SRM)
- Preparation of counting sources / samples data (if applicable)

Data and Analyses (for standardization)

- Hardcopies of all original data, including all original hand-written data sheets and all instrument print outs
- Notations of any equipment and instruments settings (as needed)
- Hardcopies of all data analyses records (electronic version is acceptable to include, but hardcopy is needed), including all analysis software output, all spreadsheets, all summary tables, graphs, etc.
- Any calculations performed, e.g., for corrected masses, solution composition, decay corrections, decay-corrected K values for appropriate RRS, LS detection efficiencies, etc.
- Explanation of any calculation assumptions.
- An uncertainty analysis page (including basis, assumptions, and derivations as needed)

Certification and Transfer

- Summary statement(s) – in short paragraph or tabular form-- regarding the basis for the certified values and how they were determined.
- Production/calibration schedule of all principal steps (from the initial design & lab set up through the certification) listing the person(s) responsible and date.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	11 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

- All the drafts of the certificate and revisions (see NIST-QM-I Sections 5.10.2 and 5.10.3 for everything that the certificate must contain at a minimum)
- Packaging information and a sample of the SRM label
- All packaging inserts; user notes, MSDS, etc.
- Technical review sheet (signed).
- Transfer form(s) to SRM stock or inventory control. This is largely handled by the SRM coordinator.

References

The first four references below are of general interest. The calibration and/or production processes for some of the radioactivity SRMs have been published in the literature. Where this is the case, it is noted under "Other Information" in Appendix A1 and the reference is listed below.

- [1] International Organization for Standardization (ISO), *ISO Standards Handbook - Quantities and Units*, 1993. Available from Global Engineering Documents, 12 Inverness Way East, Englewood, CO 80112, U.S.A. Telephone 1-800-854-7179.
- [2] International Organization for Standardization (ISO), *Guide to the Expression of Uncertainty in Measurement*, 1993 (corrected and reprinted, 1995). Available from Global Engineering Documents, 12 Inverness Way East, Englewood, CO 80112, U.S.A. Telephone 1-800-854-7179.
- [3] B.N. Taylor and C.E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, 1994. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20407, U.S.A.
- [4] National Council on Radiation Protection and Measurements Report No. 58, *A Handbook of Radioactivity Measurements Procedures*, Second Edition, 1985. Available from the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Bethesda, MD 20814 U.S.A.
- [5] International Commission on Radiation Units and Measurements (ICRU) Report 52, *Particle Counting in Radioactivity Measurements*, 1994. Available from ICRU Publications, 7910 Woodmont Avenue, Bethesda, MD 20814 U.S.A.
- [6] W.B. Mann, A. Ritz, and A. Spagnol, *Radioactivity Measurements - Principles and Practice*, 1991, Pergamon Press, Oxford.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	12 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4201B	4218F	4222C	4226C
Radionuclide	Nb-94	Eu-152	C-14	Ni-63
Decay Mode(s) (>1%)	BP,GR	BP,EC,GR	BP	BP
Half Life	20.3 ka	13.537 a	5.70 ka	100.1 a
Intended Use	CAL(Ge,NaI)	CAL(Ge,NaI)	CAL(LSC)	CAL(LSC)
Physical State	Solid	Solid	Liquid	Liquid
Chemical Form	NbO	EuCl ₃	n-Hexadecane	NiCl ₂
Solution/Mixture Composition	-	-	n-Hexadecane	0.9 M Hcl
Solution/Mixture Mass (g)	-	-	~5	5.080
Solution density (g·mL ⁻¹)	-	-	0.771	1.014
Containment	PSG	PSG	5AMP	5AMP
Non-radioactive Carrier	NbO	EuCl ₃	None	NiCl ₂
Carrier Concentration (mg·L ⁻¹)	~140 ug total	~10 ug total	-	220
Massic Activity (Bq·g ⁻¹)	~4 kBq total*	<150 kBq total*	54.02 k	50.53 k
Reference Time	Apr 1970	01 Jan 1999	03 Sep 1990	15 Aug 1995
Expanded Uncertainty (k=2) (%)	1.5	0.78	0.81	0.92
Source of Starting Material(s)	PUR(COM)	PUR(USDOE)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0&2(Ge)	GRS0&2(Ge)	GRS0(Ge),LSC2	GRS0(Ge),LSC2
Radionuclidic Impurities Detected	Nb-93m	Eu-154	None	None
Relative Activity of the Impurity	7.1E-1	3.8E-3	-	-
Preparation of Master Solution	DIL	DIL	DIL	CAR,DIL
Preparation of SRM Solution	= Master	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	DIL5	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	CAC	PIC1(CPD)	LSC2+ET(H-3)	LSC2+ET(H-3)
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	None	None
Homogeneity Test	ALL	ALL	SEQ	SEQ
Other Information	[a]	[a]	-	-
Production Steps not Used	14,17,27	14,17,27	14,17,27	14,27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	13 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4233E	4234A	4241C	4251C
Radionuclide	Cs-137	Sr-90	Ba-133	Ba-133
Decay Mode(s) (>1%)	BP,GR	BP	EC,GR	EC,GR
Half Life	30.04 a	28.79 a	10.52 a	10.52 a
Intended Use	CAL(Ge,NaI)	CAL(LSC)	CAL(Ge,NaI)	CAL(Ge,NaI)
Physical State	Liquid	Liquid	Solid	Liquid
Chemical Form	CsCl	SrCl ₂	BaCl ₂	BaCl ₂
Solution/Mixture Composition	1 M HCl	1 M HCl	-	1 M HCl
Solution/Mixture Mass (g)	In preparation	5.063	-	5.054
Solution density (g·mL ⁻¹)	In preparation	1.015	-	1.015
Containment	5NIST	5AMP	PSG	5NIST
Non-radioactive Carrier	CsCl	SrCl ₂ ;YCl ₃	BaCl ₂	BaCl ₂
Carrier Concentration (mg·L ⁻¹)	In preparation	500;600	~7 ug total	120
Massic Activity (Bq·g ⁻¹)	~300 k	2.494 M	<140 kBq total*	487.6 k
Reference Time	In preparation	13 Mar 1995	01 Jan 1999	01 Sep 1993
Expanded Uncertainty (k=2) (%)	In preparation	0.56	0.60	0.52
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0&2(Ge)	GRS2(Ge)	GRS0&2(Ge)	GRS0&2(Ge)
Radionuclidic Impurities Detected	None	Cs-137;Am-241	None	None
Relative Activity of the Impurity	-	6.E-6;2.E-6	-	-
Preparation of Master Solution	CAR,DIL	CAR,DIL	DIL	CAR,DIL
Preparation of SRM Solution	= Master	= Master	= Master	= Master
Preparation of Measurement Samples	None	GRV2	DIL5	None
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC2(CAC)	LSC2+ET(H-3)	PIC1(CAC)	PIC2(CAC)
Confirmatory Method(s)	CPD2(Ge)	None	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	In preparation	SEQ	ALL	ALL
Other Information	In preparation	-	[a]	-
Production Steps not Used	In preparation	14,27	14,17,27	14,27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	14 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4274	4288A	4320A	4321C
Radionuclide	Ho-166m	Tc-99	Cm-244	U-NAT
Decay Mode(s) (>1%)	BP,GR	BP	AP	AP
Half Life	1.20 ka	211 ka	18.1 a	4.468 Ga
Intended Use	CAL(Ge,NaI)	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	HoCl ₃	KTcO ₄	Cm(NO ₃) ₃	UO ₂ (NO ₃) ₂
Solution/Mixture Composition	1 M HCl	0.001 M KOH	1 M HNO ₃	1 M HNO ₃
Solution/Mixture Mass (g)	In preparation	4.998	~5	5.258
Solution density (g·mL ⁻¹)	In preparation	0.998	1.030	1.053
Containment	5NIST	5AMP	5AMP	5AMP
Non-radioactive Carrier	HoCl ₃	None	None	None
Carrier Concentration (mg·L ⁻¹)	In preparation	-	-	-
Massic Activity (Bq·g ⁻¹)	~20 k	32.61 k	37.06	486.2
Reference Time	In preparation	01 Sep 1996	01 Feb 1996	01 Aug 1997
Expanded Uncertainty (k=2) (%)	In preparation	1.14	0.68	0.78
Source of Starting Material(s)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)
Preparation of Starting Material(s)	None	None	DSS	DSS
Impurity Measurement Method	GRS0&2(Ge)	GRS0&2(Ge)	GRS0(Ge),APS2	GRS1(Ge),APS2
Radionuclidic Impurities Detected	Tm-170	None	Pu-240;Cm-243	None
Relative Activity of the Impurity	In preparation	-	6.E-3;1.E-4	-
Preparation of Master Solution	DIL	DIL	DIL	QDIL
Preparation of SRM Solution	= Master	= Master	= Master	QDIL
Preparation of Measurement Samples	None	GRV2	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC2(CAC)	CAC+ET(Co-60)	LSC1	WTR0,MS2
Confirmatory Method(s)	CPD2(Ge)	LSC2+ET(H-3)	LSC2	LSC2,SB
Homogeneity Test	In preparation	SEQ	SEQ	SEQ
Other Information	In preparation	-	-	-
Production Steps not Used	In preparation	14,27	14,27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	15 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4322B	4323B	4324B	4325C
Radionuclide	Am-241	Pu-238	U-232	Be-10/9
Decay Mode(s) (>1%)	AP,GR	AP	AP	BP
Half Life	432.2 a	87.7 a	68.9 a	1.51 Ma
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	AMS,GEO
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	Am(NO ₃) ₃	Pu(NO ₃) ₆	UO ₂ (NO ₃) ₂	BeCl ₂
Solution/Mixture Composition	1 M HNO ₃	3 M HNO ₃	2 M HNO ₃	1 M HCl
Solution/Mixture Mass (g)	~5.2	~5.5	5.321	~50
Solution density (g·mL ⁻¹)	1.025	1.101	1.064	Not given
Containment	5NIST	5AMP	5NIST	60TB
Non-radioactive Carrier	None	None	None	BeCl ₂
Carrier Concentration (mg·L ⁻¹)	-	-	-	5 150 (as Be)
Massic Activity (Bq·g ⁻¹)	39.24	41.52	38.22	0.0002
Reference Time	09 Sep 1991	15 Nov 1999	01 Jul 2002	Aug 1986
Expanded Uncertainty (k=2) (%)	0.95	0.68	0.80	5.1
Source of Starting Material(s)	PUR(USDOE)	PUR(USDOE)	PUR(COM)	DON(USDOE)
Preparation of Starting Material(s)	DSS	DSS	None	DSS
Impurity Measurement Method	GRS0(Ge),APS 2	GRS0(Ge),APS2	GRS0(Ge),APS1	GRS0&1(Ge)
Radionuclidic Impurities Detected	Pa-233	None	None	None
Relative Activity of the Impurity	8.E-6	-	-	-
Preparation of Master Solution	DIL	DIL	None	QDIL
Preparation of SRM Solution	QDIL	QDIL	QDIL	QDIL
Preparation of Measurement Samples	GRV1	GRV1	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	LSC1	LSC1	CAC	WTR0,MS0
Confirmatory Method(s)	LSC2	LSC2	PIC1(THE),CPR	AMS2,LSC0
Homogeneity Test	SEQ	SEQ	SEQ	None
Other Information	-	-	-	[e]
Production Steps not Used	27	27	27	7,8,17,21,27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	16 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4326	4328B	4329	4330A
Radionuclide	Po-209	Th-229	Cm-243	Pu-239
Decay Mode(s) (>1%)	AP	AP,GR	AP,GR	AP
Half Life	102 a	7.340 ka	29.1 a	24.110 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	PoCl ₄	Th(NO ₃) ₄	Cm(NO ₃) ₃	Pu(NO ₃) ₆
Solution/Mixture Composition	2 M HCl	1.1 M HNO ₃	1 M HNO ₃	3.1 M HNO ₃
Solution/Mixture Mass (g)	5.160	5.174	5.156	~5.5
Solution density (g·mL ⁻¹)	1.031	1.036	Not given	1.101
Containment	5AMP	5NIST	5AMP	5AMP
Non-radioactive Carrier	None	None	None	None
Carrier Concentration (mg·L ⁻¹)	-	-	-	-
Massic Activity (Bq·g ⁻¹)	85.42	33.36	69.50	39.24
Reference Time	15 Mar 1994	01 Jul 1996	13 Jun 1984	15 Nov 1999
Expanded Uncertainty (k=2) (%)	0.42	0.66	1.4	0.68
Source of Starting Material(s)	PUR(COM)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)
Preparation of Starting Material(s)	None	None	DSS	DSS
Impurity Measurement Method	GRS0(Ge),APS1	GRS0(Ge)	GRS0(Ge),APS2	GRS0(Ge),APS2
Radionuclidic Impurities Detected	Po-208	None	Am-243;Cm-244	None
Relative Activity of the Impurity	1.E-3	-	8.E-4;8.E-4	-
Preparation of Master Solution	DIL	DIL	DIL	DIL
Preparation of SRM Solution	QDIL	QDIL	= Master	QDIL
Preparation of Measurement Samples	GRV1	GRV1	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	LSC1	DSA1,LSC1	DSA1	LSC1
Confirmatory Method(s)	GCE1,SB1	SB1,LSC2	None	LSC2
Homogeneity Test	SEQ	SEQ	None	SEQ
Other Information	-	-	-	-
Production Steps not Used	27	None	14,21,27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	17 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4332D	4334H	4337	4338A
Radionuclide	Am-243	Pu-242	Pb-210	Pu-240
Decay Mode(s) (>1%)	AP,GR	AP	BP,GR	AP
Half Life	7.370 ka	373.5 ka	22.2 a	6.564 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	Am(NO ₃) ₃	Pu(NO ₃) ₆	Pb(NO ₃) ₂	Pu(NO ₃) ₆
Solution/Mixture Composition	1 M HNO ₃	3.2 M HNO ₃	1 M HNO ₃	2.8 M HNO ₃
Solution/Mixture Mass (g)	5.143	~5.5	In preparation	5.471
Solution density (g·mL ⁻¹)	1.030	1.105	In Preparation	1.091
Containment	5AMP	5AMP	5NIST	5AMP
Non-radioactive Carrier	None	None	Pb(NO ₃) ₂	None
Carrier Concentration (mg·L ⁻¹)	-	-	In preparation	-
Massic Activity (Bq·g ⁻¹)	36.27	26.31	~10 k	40.88
Reference Time	19 May 1995	07 Jun 1994	In Preparation	01 May 1996
Expanded Uncertainty (k=2) (%)	0.78	0.72	In Preparation	0.76
Source of Starting Material(s)	PUR(USDOE)	PUR(USDOE)	PUR(COM)	PUR(USDOE)
Preparation of Starting Material(s)	DSS	DSS	None	DSS
Impurity Measurement Method	GRS0(Ge),APS2	GRS1(Ge),APS2	GRS0&2(Ge)	GRS0(Ge),APS2
Radionuclidic Impurities Detected	Am-241	Pu-241	In preparation	Pu-238;Am-241
Relative Activity of the Impurity	2.E-3	3.5E-3	In preparation	9.E-3;2.E-4
Preparation of Master Solution	DIL	DIL	DIL	DIL
Preparation of SRM Solution	QDIL	QDIL	= Master	QDIL
Preparation of Measurement Samples	GRV1	GRV1	None	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	DSA1	LSC1	CAC1	DSA1,LSC1
Confirmatory Method(s)	LSC2	LSC2	CPD2	LSC2
Homogeneity Test	SEQ	SEQ	In preparation	SEQ
Other Information	-	-	In preparation	-
Production Steps not Used	27	27	In preparation	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	18 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4339A	4340A	4341	4342
Radionuclide	Ra-228	Pu-241	Np-237	Th-230
Decay Mode(s) (>1%)	BP	BP	AP,GR	AP
Half Life	5.75 a	14.35 a	2.14 Ma	75.38 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	Ra(NO ₃) ₂	Pu(NO ₃) ₆	Np(NO ₃) ₃	Th(NO ₃) ₄
Solution/Mixture Composition	1 M HNO ₃	2.8 M HNO ₃	2 M HNO ₃	1.3 M HNO ₃
Solution/Mixture Mass (g)	5.162	~5.5	~5	~5.2
Solution density (g·mL ⁻¹)	1.031	1.0895	Not given	1.043
Containment	5NIST	5AMP	5AMP	5NIST
Non-radioactive Carrier	Ba(NO ₃) ₂	None	None	None
Carrier Concentration (mg·L ⁻¹)	80	-	-	-
Massic Activity (Bq·g ⁻¹)	214.5	250.4	97.0	47.48
Reference Time	12 Apr 1994	02 Dec 1995	Mar 1992	08 Jun 1993
Expanded Uncertainty (k=2) (%)	2.20	1.06	1.28	0.58
Source of Starting Material(s)	DON(NIST)	PUR(USDOE)	PUR(USDOE)	PUR(USDOE)
Preparation of Starting Material(s)	DSS,SEP	None	DSS	DSS,SEP
Impurity Measurement Method	GRS1(Ge)	GRS1(Ge),APS2	GRS0(Ge),APS1	GRS1,MS0
Radionuclidic Impurities Detected	Ra-226	None	None	Th-229;Th-232
Relative Activity of the Impurity	6.E-3	-	-	3E-4;5.E-7
Preparation of Master Solution	DIL	DIL	DIL	DIL
Preparation of SRM Solution	QDIL	QDIL	QDIL	QDIL
Preparation of Measurement Samples	GRV1&2	GRV1	GRV1	GRV1
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	CPD1	LSC1	DSA1	LSC1
Confirmatory Method(s)	CPD2	LSC2	None	LSC2
Homogeneity Test	SEQ	SEQ	None	SEQ
Other Information	-	-	-	-
Production Steps not Used	27	27	20,21,27	None

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005.					
Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	19 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.			
SRM Number	4350B	4351	4352
Radionuclide	See Appendix 2	See Appendix 2	See Appendix 2
Decay Mode(s) (>1%)	AP,BP,GR	AP	AP,GR
Half Life	2 a to 14 Ga	2 a to 14 Ga	2 a to 14 Ga
Intended Use	ENV	ENV	ENV
Physical State	Solid Powder	Solid Powder	Solid Powder
Chemical Form	Sediment	Animal Tissue	Animal Tissue
Solution/Mixture Composition	River Sediment	Human Lung	Human Liver
Solution/Mixture Mass (g)	85	45	45
Solution density (g·mL ⁻¹)	-	-	-
Containment	250PB	200SERUM	200SERUM
Non-radioactive Carrier	-	-	-
Carrier Concentration (mg·L ⁻¹)	-	-	-
Massic Activity (Bq·g ⁻¹)	See Appendix 2	See Appendix 2	See Appendix 2
Reference Time	09 Sep 1981	01 Oct 1982	01 June 1982
Expanded Uncertainty (k=2) (%)	4 to 21	13 to 110	19 to 44
Source of Starting Material(s)	DON(USDOE)	DON(USDOE)	DON(USDOE)
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ
Impurity Measurement Method	-	-	-
Radionuclidic Impurities Detected	-	-	-
Relative Activity of the Impurity	-	-	-
Preparation of Master Solution	None	DIL,BL	DIL,BL
Preparation of SRM Solution	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMOL	LMOL	LMOL
Primary Measurement Method	APS2,BPS2,GRS2,MS	APS2	APS2
Confirmatory Method(s)	GRS2(Ge)	None	GRS2(Ge)
Homogeneity Test	RAN	RAN	RAN
Other Information	ELE,SIZ	SIZ	SIZ
Production Steps not Used	14,27	14,27	14,27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	20 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.			
SRM Number	4353A	4354	4355
Radionuclide	See Appendix 2	See Appendix 2	See Appendix 2
Decay Mode(s) (>1%)	AP,BP,GR	AP,BP,GR	AP,BP,GR
Half Life	2 a to 14 Ga	2 a to 14 Ga	2 a to 14 Ga
Intended Use	ENV	ENV	ENV
Physical State	Solid Powder	Solid Powder	Solid Powder
Chemical Form	Soil	Sediment	Soil
Solution/Mixture Composition	RF Soil II	Lake Sediment	Peruvian Soil
Solution/Mixture Mass (g)	85	25	75
Solution density (g·mL ⁻¹)	-	-	-
Containment	250PB	250PB	250PB
Non-radioactive Carrier	-	-	-
Carrier Concentration (mg·L ⁻¹)	-	-	-
Massic Activity (Bq·g ⁻¹)	See Appendix 2	See Appendix 2	See Appendix 2
Reference Time	In preparation	14 Feb 1986	01 Jun 1982
Expanded Uncertainty (k=2) (%)	In preparation	7 to 81	5 to 36
Source of Starting Material(s)	DON(USDOE)	DON(USDOE)	DON(IAEA)
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ
Impurity Measurement Method	-	-	-
Radionuclidic Impurities Detected	-	-	-
Relative Activity of the Impurity	-	-	-
Preparation of Master Solution	BL	BL	BL
Preparation of SRM Solution	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMOL	LMOL	LMNL
Primary Measurement Method	APS2,BPS2,GRS2	APS2,BPS2,GRS2	APS2,BPS2,GRS2
Confirmatory Method(s)	GRS2(Ge)	GRS2(Ge)	GRS2(Ge)
Homogeneity Test	RAN	RAN	RAN
Other Information	In preparation	ELE,SIZ	SIZ
Production Steps not Used	In preparation	14,27	14,27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	21 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.			
SRM Number	4356	4357	4358
Radionuclide	See Appendix 2	See Appendix 2	See Appendix 2
Decay Mode(s) (>1%)	AP,BP,GR	AP,BP,GR	AP,BP,GR
Half Life	2 a to 14 Ga	2 a to 14 Ga	2 a to 14 Ga
Intended Use	ENV	ENV	ENV
Physical State	Solid Powder	Solid Powder	Solid Powder
Chemical Form	Ash	Sediment	Animal Tissue
Solution/Mixture Composition	Ashed Bone	Ocean Sediment	Ocean Shellfish
Solution/Mixture Mass (g)	15	85	75? x 2
Solution density (g·mL ⁻¹)			-
Containment	60JAR	250PB	250PB x 2 + ALBAG
Non-radioactive Carrier	-	-	-
Carrier Concentration (mg·L ⁻¹)	-	-	-
Massic Activity (Bq·g ⁻¹)	See Appendix 2	See Appendix 2	See Appendix 2
Reference Time	31 Dec 1995	16 Feb 1994	In preparation
Expanded Uncertainty (k=2) (%)	13 to 71	10 to 91	In preparation
Source of Starting Material(s)	DON(USDOE)	DON(IAEA)	DON(IAEA)
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ	DRY,G/P,SC,BL,STZ
Impurity Measurement Method	-	-	-
Radionuclidic Impurities Detected	-	-	-
Relative Activity of the Impurity	-	-	-
Preparation of Master Solution	DIL,BL	DIL,BL	DIL,BL
Preparation of SRM Solution	= Master	= Master	= Master
Preparation of Measurement Samples	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMOL	LMNL,LMOL	LMOL
Primary Measurement Method	APS2,BPS2,GRS2	APS2,BPS2,GRS2	APS2,BPS2,GRS2
Confirmatory Method(s)	GRS2(Ge)	GRS2(Ge)	GRS2(Ge)
Homogeneity Test	RAN	RAN	RAN
Other Information	-	ELE,SIZ	In preparation
Production Steps not Used	14,27	14,27	In preparation

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	22 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.			
SRM Number	4359		
Radionuclide	See Appendix 2		
Decay Mode(s) (>1%)	AP,BP,GR		
Half Life	2 a to 14 Ga		
Intended Use	ENV		
Physical State	Solid Powder		
Chemical Form	Vegetation		
Solution/Mixture Composition	Seaweed		
Solution/Mixture Mass (g)	?		
Solution density (g·ml ⁻¹)	-		
Containment	500GB		
Non-radioactive Carrier	-		
Carrier Concentration (mg·L ⁻¹)	-		
Massic Activity (Bq·g ⁻¹)	See Appendix 2		
Reference Time	In preparation		
Expanded Uncertainty (k=2) (%)	In preparation		
Source of Starting Material(s)	DON(IAEA)		
Preparation of Starting Material(s)	DRY,G/P,SC,BL,STZ		
Impurity Measurement Method	-		
Radionuclidic Impurities Detected	-		
Relative Activity of the Impurity	-		
Preparation of Master Solution	DIL,BL		
Preparation of SRM Solution	= Master		
Preparation of Measurement Samples	GRV2		
Primary Measurement Model Type	LMNL,LMOL		
Primary Measurement Method	APS2,BPS2,GRS2		
Confirmatory Method(s)	GRS2(Ge)		
Homogeneity Test	RAN		
Other Information	In preparation		
Production Steps not Used	In preparation		

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	23 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4361C	4370C	4401H	4401L
Radionuclide	H-3	Eu-152	I-131	I-131
Decay Mode(s) (>1%)	BP	BP,EC,GR	BP,GR	BP,GR
Half Life	12.32 a	13.537 a	8.02070 d	8.02070 d
Intended Use	HYD	CAL(Ge,NaI)	CAL,NM	CAL,NM
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	H ₂ O	EuCl ₃	KI	KI
Solution/Mixture Composition	H ₂ O	1 M Hcl	0.008 M LiOH+	0.007 M LiOH+
Solution/Mixture Mass (g)	~500	5.0338	4.9420*	4.9744*
Solution density (g·ml ⁻¹)	0.998	Not given	0.999	0.999
Containment	500GB	5NIST	5NIST	5NIST
Non-radioactive Carrier	None	EuCl ₃	KI	KI
Carrier Concentration (mg·L ⁻¹)	-	277	600	70
Massic Activity (Bq·g ⁻¹)	2.009	93.90 k	206.8 M	5.365 M
Reference Time	03 Sep 1998	02 Feb 1987	every Jan	every Jan
Expanded Uncertainty (k=2) (%)	0.76	1.1	0.70	0.70
Source of Starting Material(s)	PUR(COM)	PUR(USDOE)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0(Ge),BPS 1	GRS1(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	None	Eu-154	None	None
Relative Activity of the Impurity	-	2.9E-3	-	-
Preparation of Master Solution	= 4926E	CAR,DIL	CAR,DIL	= 4401H
Preparation of SRM Solution	QDIL	= Master	= Master	CAR,QDIL
Preparation of Measurement Samples	GRV2	None	None	None
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	GCI	PIC1(CPD)	PIC1(CAC)	PIC1&2(CAC)
Confirmatory Method(s)	LSC2	CPD2(Ge)	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	SEQ	ALL	ALL	ALL
Other Information	[e]	-	-	-
Production Steps not Used	17, 27	27	None	None

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	24 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4404H	4404L	4407H	4407L
Radionuclide	Tl-201	Tl-201	I-125	I-125
Decay Mode(s) (>1%)	EC,GR	EC,GR	EC,GR	EC,GR
Half Life	72.912 h	72.912 h	59.400 d	59.400 d
Intended Use	CAL,NM	CAL,NM	CAL,NM	CAL,NM
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	TlNO ₃	TlNO ₃	KI	KI
Solution/Mixture Composition	1.2 M HNO ₃	1.2 HNO ₃	0.07 M LiOH	0.01 M LiOH
Solution/Mixture Mass (g)	5.3317*	5.2051*	5.1459*	4.9608*
Solution density (g·ml ⁻¹)	1.039	1.040	1.007	0.999
Containment	5NIST	5NIST	5NIST	5NIST
Non-radioactive Carrier	TlNO ₃	TlNO ₃	KI	KI
Carrier Concentration (mg·L ⁻¹)	200	100	5000	60
Massic Activity (Bq·g ⁻¹)	67.22 M	5.858 M	211.0 M	1.433 M
Reference Time	every Jun	every Jun	every Dec	every Dec
Expanded Uncertainty (k=2) (%)	0.80	0.80	0.78	0.78
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1&2(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	Tl-200;Tl-202	Tl-200;Tl-202	None	None
Relative Activity of the Impurity	2.E-3;2.E-3	2.E-3;2.E-3	-	-
Preparation of Master Solution	CAR,DIL	= 4404H	DIL	= 4407H
Preparation of SRM Solution	= Master	CAR,QDIL	= Master	CAR,QDIL
Preparation of Measurement Samples	None	None	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC1(CAC)	PIC1&2(CAC)	SPC2	SPC
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	ALL	ALL	ALL	ALL
Other Information	-	-	-	-
Production Steps not Used	14,27	27	14,27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	25 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4410H		4412H	4412L
Radionuclide	Tc-99m		Mo-99	Mo-99
Decay Mode(s) (>1%)	IT,GR		BP,GR	BP,GR
Half Life	6.01 h		65.94 h	65.94 h
Intended Use	CAL,NM		CAL,NM	CAL,NM
Physical State	Liquid		Liquid	Liquid
Chemical Form	NaTcO ₄		Na ₂ MoO ₄	Na ₂ MoO ₄
Solution/Mixture Composition	0.16 M NaCl		3.1M HNO ₃	3.1M HNO ₃
Solution/Mixture Mass (g)	4.9865*		5.4834*	5.5053*
Solution density (g·ml ⁻¹)	1.005		1.102	1.102
Containment	5NIST		5NIST	5NIST
Non-radioactive Carrier	None		Na ₂ MoO ₄	Na ₂ MoO ₄
Carrier Concentration (mg·L ⁻¹)	-		1000	90
Massic Activity (Bq·g ⁻¹)	1.408 G		353.9 M	15.22 M
Reference Time	every May		every Feb	every Feb
Expanded Uncertainty (k=2) (%)	0.64		0.72	0.72
Source of Starting Material(s)	PUR(COM)		PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None		None	None
Impurity Measurement Method	GRS2(Ge)		GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	Mo-99		None	None
Relative Activity of the Impurity	1.E-6		-	-
Preparation of Master Solution	DIL		CAR,DIL	= 4412H
Preparation of SRM Solution	= Master		= Master	CAR,QDIL
Preparation of Measurement Samples	None		None	None
Primary Measurement Model Type	LMNL		LMNL	LMNL
Primary Measurement Method	PIC1(CAC)		PIC1(CAC)	PIC1&2(CAC)
Confirmatory Method(s)	CPD2(Ge)		CPD2(Ge)	CDP2(Ge)
Homogeneity Test	ALL		ALL	ALL
Other Information	-		-	-
Production Steps not Used	14,27		14,27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	26 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4415H	4415L	4416H	4416L
Radionuclide	Xe-133	Xe-133	Ga-67	Ga-67
Decay Mode(s) (>1%)	BP,GR	BP,GR	EC,GR	EC,GR
Half Life	5.243 d	5.243 d	3.2612 d	3.2612 d
Intended Use	CAL,NM	CAL,NM	CAL,NM	CAL,NM
Physical State	Gas	Gas	Liquid	Liquid
Chemical Form	Xe	Xe	GaCl ₃	GaCl ₃
Solution/Mixture Composition	Xe	Xe	2 M Hcl	2 M Hcl
Solution/Mixture Mass (g)	~20 mg total	~7 mg total	5.0180*	5.1523*
Solution density (g·ml ⁻¹)	~75 kPa	~25 Kpa	1.033	1.033
Containment	5GAS	5GAS	5NIST	5NIST
Non-radioactive Carrier	None	None	GaCl ₃	GaCl ₃
Carrier Concentration (mg·L ⁻¹)	-		800	800
Massic Activity (Bq·g ⁻¹)	7.560 G total*	563.8 M total*	89.88 M	4.688 M
Reference Time	every Sep	every Sep	every Apr	every Apr
Expanded Uncertainty (k=2) (%)	0.78	0.78	0.60	0.60
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1&2(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	Kr-85;Xe-131m	Kr-85;Xe-131m	None	None
Relative Activity of the Impurity	4.E-6;1.5E-2	5.E-6;1.5E-2	-	-
Preparation of Master Solution	CAR,DIL	= 4415H	CAR,DIL	= 4416H
Preparation of SRM Solution	= Master	CAR,QDIL	= Master	CAR,QDIL
Preparation of Measurement Samples	None	None	None	None
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC1(GCI)	PIC1&2(GCI)	PIC1(CAC)	PIC1&2(CAC)
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	CPD2(Ge)	CDP2(Ge)
Homogeneity Test	Not applicable	Not applicable	ALL	ALL
Other Information	-	-	-	-
Production Steps not Used	14,17,21,27	17,21,27	14,27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	27 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4417H	4417L	4427H	4427L
Radionuclide	In-111	In-111	Y-90	Y-90
Decay Mode(s) (>1%)	EC,GR	EC,GR	BP	BP
Half Life	2.8047 d	2.8047 d	64.0 h	64.0 h
Intended Use	CAL,NM	CAL,NM	CAL,NM	CAL,NM
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	InCl ₃	InCl ₃	YCl ₃	YCl ₃
Solution/Mixture Composition	2.8 M HCl	3.2 M HCl	1.1 M HCl	1.1 M HCl
Solution/Mixture Mass (g)	5.235*	5.265*	5.0200*	5.0844*
Solution density (g·mL ⁻¹)	1.047	1.053	1.017	1.017
Containment	5NIST	5NIST	5NIST	5NIST
Non-radioactive Carrier	InCl ₃	InCl ₃	YCl ₃	YCl ₃
Carrier Concentration (mg·L ⁻¹)	500	60	50	50
Massic Activity (Bq·g ⁻¹)	64.23 M	6.224 M	74.73 M	5.731 M
Reference Time	every Aug	every Aug	every Oct	every Oct
Expanded Uncertainty (k=2) (%)	0.54	0.54	0.72	0.72
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1&2(Ge)	GRS2(Ge)	GRS1&2(Ge)
Radionuclidic Impurities Detected	In-114m	In-114m	Sr-90	Sr-90
Relative Activity of the Impurity	3.E-4	3.E-4	7.E-8	7.E-8
Preparation of Master Solution	CAR,DIL	= 4417H	CAR,DIL	= 4427H
Preparation of SRM Solution	= Master	CAR,QDIL	= Master	CAR,QDIL
Preparation of Measurement Samples	None	None	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC1(CAC)	PIC1&2(CAC)	LSC2	LSC2
Confirmatory Method(s)	CPD2(Ge)	CPD2(Ge)	PIC2(LSC)	PIC2(LSC)
Homogeneity Test	ALL	ALL	ALL	ALL
Other Information	-	-	-	-
Production Steps not Used	14,27	27	14,27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	28 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4915E	4919H	4926E	4927F
Radionuclide	Co-60	Sr-90	H-3	H-3
Decay Mode(s) (>1%)	BP,GR	BP	BP	BP
Half Life	5.2712 a	28.79 a	12.32 a	12.32 a
Intended Use	CAL(Ge,NaI)	CAL(LSC)	CAL(LSC),HYD	CAL(LSC)
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	CoCl ₂	SrCl ₂	H ₂ O	H ₂ O
Solution/Mixture Composition	1 M HCl	0.9 M HCl	H ₂ O	H ₂ O
Solution/Mixture Mass (g)	5.063	~5.0	~20	~5.0
Solution density (g·mL ⁻¹)	1.016	1.014	0.998	0.998
Containment	5NIST	5AMP	20SERUM	5AMP
Non-radioactive Carrier	CoCl ₂	SrCl ₂ ;YCl ₃	None	None
Carrier Concentration (mg·L ⁻¹)	100	200;200	-	-
Massic Activity (Bq·g ⁻¹)	75.55 k	4.010 k	5.038 k	634.7 k
Reference Time	01 Jan 1995	01 Jul 1995	03 Sep 1998	03 Sep 1998
Expanded Uncertainty (k=2) (%)	0.54	0.74	0.72	0.72
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS2(Ge)	GRS1(Ge)	GRS0(Ge),BPS0	GRS0(Ge),BPS1
Radionuclidic Impurities Detected	None	None	None	None
Relative Activity of the Impurity	-	-	-	-
Preparation of Master Solution	CAR,DIL	= 4234A	=4927F	DIL
Preparation of SRM Solution	= Master	CAR,QDIL	QDIL	=Master
Preparation of Measurement Samples	None	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	PIC2(CAC)	LSC2+ET(H-3)	GCI1	GCI2
Confirmatory Method(s)	CPD2(Ge)	None	LSC2	LSC2
Homogeneity Test	ALL	SEQ	SEQ	SEQ
Other Information	-	-	-	-
Production Steps not Used	14,27	27	17,27	14,27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	29 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4929E	4943	4947C	4949C
Radionuclide	Fe-55	Cl-36	H-3	I-129
Decay Mode(s) (>1%)	EC	BP,EC	BP	BP,GR
Half Life	2.737 a	301 ka	12.32 a	15.7 Ma
Intended Use	CAL(LSC),EN V	CAL(LSC),ENV	CAL(LSC)	ENV,CAL(LSC)
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	FeCl ₂	NaCl	Toluene	NaI
Solution/Mixture Composition	1 M HCl	H ₂ O	Toluene	0.01 M NaOH+
Solution/Mixture Mass (g)	In preparation	~3	~4	~5.0
Solution density (g·mL ⁻¹)	In preparation	Not given	0.8669	1.003
Containment	5AMP	5AMP	5AMP	5AMP
Non-radioactive Carrier	FeCl ₂	NaCl	None	None
Carrier Concentration (mg·L ⁻¹)	In preparation	200	-	-
Massic Activity (Bq·g ⁻¹)	~30 k	10.95 k	308.1 k	3.451 k
Reference Time	In preparation	Dec 1984	04 Mar 1987	21 Mar 1993
Expanded Uncertainty (k=2) (%)	In preparation	0.82	1.2	0.64
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS1&2(Ge)	GRS0(Ge),BPS2	GRS1(Ge),BPS2	GRS1(Ge),BPS2
Radionuclidic Impurities Detected	In preparation	None	None	None
Relative Activity of the Impurity	In preparation	-	-	-
Preparation of Master Solution	CAR,DIL	DIL	DIL	DIL
Preparation of SRM Solution	CAR,QDIL	=Master	=Master	CAR,QDIL
Preparation of Measurement Samples	GRV2	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	DSA1	GCE1	LSC2	CAC1
Confirmatory Method(s)	In preparation	LSC2	None	LSC2
Homogeneity Test	In preparation	SEQ	SEQ	SEQ
Other Information	In preparation	-	-	-
Production Steps not Used	In preparation	14,27	14,17,27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	30 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4965	4966	4967A	4969
Radionuclide	Ra-226	Ra-226	Ra-226	Ra-226
Decay Mode(s) (>1%)	AP,GR	AP,GR	AP,GR	AP,GR
Half Life	1.600 ka	1.600 ka	1.600 ka	1.600 ka
Intended Use	CAL,ENV	CAL,ENV	CAL,ENV	CAL,ENV
Physical State	Liquid	Liquid	Liquid	Liquid
Chemical Form	RaCl ₂	RaCl ₂	RaCl ₂	RaCl ₂
Solution/Mixture Composition	1.4 M HCl	1.4 M HCl	1 M HCl	1.5 M HCl
Solution/Mixture Mass (g)	5.098	5.1138	5.086	5.122
Solution density (g·mL ⁻¹)	1.019	1.020	1.017	1.024
Containment	5NIST	5NIST	5NIST	5NIST
Non-radioactive Carrier	BaCl ₂	BaCl ₂	BaCl ₂	BaCl ₂
Carrier Concentration (mg·L ⁻¹)	1700	1670	80	100
Massic Activity (Bq·g ⁻¹)	30.99	268.2	2.482 k	3.047
Reference Time	09 Sep 1991	09 Sep 1991	01 Sep 2003	15 Sep 1998
Expanded Uncertainty (k=2) (%)	1.23	1.19	1.20	1.8
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0&1(Ge)	GRS0&1(Ge)	GRS0&1(Ge)	GRS0&1(Ge)
Radionuclidic Impurities Detected	None	None	None	None
Relative Activity of the Impurity	-	-	-	-
Preparation of Master Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	CAR,QDIL
Preparation of SRM Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	CAR,QDIL
Preparation of Measurement Samples	GRV2	GRV2	GRV2	GRV2
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	WTR0	WTR0	WTR0	WTR0
Confirmatory Method(s)	LSC2	LSC2	LSC2	LSC2
Homogeneity Test	PIC2,CPD2	PIC2,CPD2	PIC2,CPD2	PIC2,CPD2
Other Information	-	-	-	-
Production Steps not Used	27	27	27	27

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	31 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A1: Properties and Preparation of the NIST Radioactivity SRMs, as of January 2005. Certified values are in bold type. Abbreviations and Notes are provided at the end of Appendix A1.				
SRM Number	4971	4972	4973	4990C
Radionuclide	Ra-226	Ra-226	Ra-226	C-14
Decay Mode(s) (>1%)	AP,GR	AP,GR	AP,GR	BP
Half Life	1.600 ka	1.600 ka	1.600 ka	5.70 ka
Intended Use	RN222	RN222	RN222	C14
Physical State	Liquid	Liquid	Liquid	Solid
Chemical Form	RaCl ₂	RaCl ₂	RaCl ₂	Oxalic Acid
Solution/Mixture Composition	1 M HCl	1 M HCl	1 M HCl	Powder
Solution/Mixture Mass (g)	~0.2	~0.2	~0.2	28 x 8
Solution density (g·mL ⁻¹)	1.015	1.015	1.015	-
Containment	POLY	POLY	POLY	60JAR x 8
Non-radioactive Carrier	BaCl ₂	BaCl ₂	BaCl ₂	None
Carrier Concentration (mg·L ⁻¹)	In preparation	In preparation	In preparation	-
Massic Activity (Bq·g ⁻¹)	~4 Bq total*	~40 Bq total*	~400 Bq total*	0.008
Reference Time	In preparation	In preparation	In preparation	1980
Expanded Uncertainty (k=2) (%)	In preparation	In preparation	In preparation	1.6
Source of Starting Material(s)	PUR(COM)	PUR(COM)	PUR(COM)	PUR(COM)
Preparation of Starting Material(s)	None	None	None	None
Impurity Measurement Method	GRS0(Ge)	GRS0(Ge)	GRS0(Ge)	GRS0(Ge)
Radionuclidic Impurities Detected	None	None	None	None
Relative Activity of the Impurity	-	-	-	-
Preparation of Master Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	OA
Preparation of SRM Solution	CAR,QDIL	CAR,QDIL	CAR,QDIL	OA
Preparation of Measurement Samples	GRV2	GRV2	GRV2	OA
Primary Measurement Model Type	LMNL	LMNL	LMNL	LMNL
Primary Measurement Method	WTR0	WTR0	WTR0	GCI2
Confirmatory Method(s)	LSC2	LSC2	LSC2	LSC2
Homogeneity Test	ALL	ALL	ALL	RAN
Other Information	[c]	[c]	[c]	[d],[e]
Production Steps not Used	In preparation	In preparation	In preparation	-

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	32 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

ABBREVIATIONS AND ACRONYMS

General

* = Representative value; Each unit is individually measured and certified.

+ = Solution also contains other components. See the SRM Certificate for more information.

Decay Modes

AP = Alpha-Particle emission

BP = Beta-Particle emission

EC = Electron Capture

GR = Gamma-Ray emission

IT = Internal Transition

Intended Use

AMS = Accelerator Mass Spectrometry

CAL() = Calibration of instruments () and procedures

C14 = Carbon-14 dating measurements

ENV = Environmental measurements

GEO = Geological and geochronological measurements

HYD = Hydrological measurements

NM = Nuclear Medicine

RN222 = Radon-222 measurements

Containment - See the Appendices for more information

200SERUM = 200 mL glass serum bottle

20SERUM = 20 mL glass serum vial

250PB = 250 mL wide-mouth plastic bottle

500GB = 500 mL glass bottle

5AMP = 5 mL standard glass ampoule

5GAS = 5 mL gas ampoule [b]

5NIST = 5 mL NIST glass ampoule

60JAR = 60 mL glass jar

60TB = 60 mL teflon bottle

ALBAG = Heat-sealed aluminized Mylar bag

POLY = Polyethylene capsule [c]

PSG = Point Source for Gamma-ray emitters [a]

Source of Starting Material - See the Appendices for more information

COM = Commercial supplier

DON () = Donated by ()

IAEA = International Atomic Energy Agency

PUR () = Purchased from ()

USDOE = United States Department of Energy

Preparation of Starting Material(s) - See the Appendices for more information

BL = Blending

DRY = Drying

DSS = Dissolution of solid material(s)

G/P = Grinding / Pulverizing

SC = Screening

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	33 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

SEP = Radiochemical Separation / Purification
STZ = Sterilization

Measurement Methods - See the Appendices for more information

0 = Starting material
1 = Material from the Master Solution
2 = Material from the SRM container
AC = Atom Counting
APS = Alpha-particle Spectrometry
BPS = Beta-particle Spectrometry
CAC = Coincidence/Anticoincidence Counting
CPD() = Calibrated Photon Detection System (Ge, NaI, etc.)
CPR = Compared with previous RSRM
DSA = Defined Solid Angle Counting
ET() = Efficiency Tracing using () as the tracing radionuclide
GCE = Gas Counting (External)
GCI = Gas Counting (Internal)
Ge = Germanium photon detector
GRS() = Gamma-ray Spectrometry using ()
LSC = Liquid Scintillation Counting
MS = Mass Spectrometry
NaI = Sodium Iodide photon detector
OA = Other Agency. Distributed but not certified by NIST.
PIC() = Ionization Chamber calibrated using ()
SB = Surface Barrier alpha-particle detector
SPC = Sum-Peak Counting
THE = Theoretically Computed
WTR = Weight of Radionuclide

Preparation of Solutions/Mixtures - See the Appendices for more information

BL = Blending
CAR = Addition of non-radioactive carrier
DIL = Dilution
DIL5 = Dilution to (5.0 ± 0.1) mL in a 5 mL NIST ampoule
QDIL = Quantitative dilution

Preparation of Measurement Samples - See the Appendices for more information

0 = Starting material
1 = Material from the Master Solution
2 = Material from the SRM container
DIL5 = Dilution to (5.0 ± 0.1) mL in a 5 mL NIST ampoule
GRV = Dispense by mass
QDIL = Quantitative dilution

Measurement Models - See the Appendices for more information

LMNL = Linear, Multiplicative, Normal Distribution, Low Correlation
LMNH = Linear, Multiplicative, Normal Distribution, High Correlation
LMOL = Linear, Multiplicative, Other than Normal Distribution, Low Correlation
NMNL = Non-Linear, Multiplicative, Normal Distribution, Low Correlation

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	34 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Homogeneity Test - See the Appendices for more information

ALL = Measure every SRM dispensed

SEQ = Measure sequential samples of the SRM (typically the first, some of the middle, and the last dispensed)

RAN = Measure SRMs randomly selected out of the total dispensed

Other Information

ELE = Semi-quantitative elemental analysis

SIZ = Particle size distribution

[letter] = Note

[number] = Reference

NOTES

[a] The standard consists of a dried deposit, usually with a diameter of less than 0.5 cm, of the radionuclide sealed between two layers of 0.006 cm thick polyester tape that are supported on an aluminum annulus. The annulus has an outside diameter of 5.4 cm, an inside diameter of 3.8 cm, and a thickness of 0.05 cm.

[b] Flame-sealed borosilicate glass ampoule with an outside diameter of 1.5 cm and a length of 4.5 cm.

[c] SRMs 4971, 4972, and 4973 are intended for the calibration of radon-222 measuring instruments. They consist of small heat-sealed polyethylene cylinders containing approximately 0.2 g of radium-226 solution. These SRMs are calibrated in terms of radium-226 activity and in terms of the emanation fraction of radon-222 under specified conditions.

[d] SRM 4990C replaces SRM 4990, which has been in use in radiocarbon dating laboratories since 1958. The material is part of a 450 kg lot of oxalic acid that was prepared by fermentation of French beet molasses from the 1977 spring, summer, and fall harvests. The ratio of the massic activity of SRM 4990C to that of SRM 4990, and the isotopic ratios of carbon-13 to carbon-12 in each, were measured by eleven international carbon dating laboratories in an intercomparison organized by L.M. Cavallo and W.B. Mann. See Proceedings of the 11th International Radiocarbon Dating Conference, M. Stuiver and R. Kra, Editors, *Radiocarbon* **25**, No. 2 (1983).

[e] This standard is not radioactive material for licensing or shipping purposes.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	35 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A2: Radionuclides and Massic Activities in the Natural Matrix radioactivity SRMs (see IRD Procedure 16)					
SRM Number	4350B	4351	4352	4353A	4354
Description	River Sediment	Human Lung	Human Liver	RF Soil II	Lake Sediment
Radionuclide	Massic Activity (mBq·g ⁻¹) Certified values are in bold type.				
⁴⁰ K	560.	-	-	In preparation	-
⁵⁵ Fe	17.	-	-	-	-
⁶⁰ Co	4.64	-	-	-	320.
⁹⁰ Sr	5.3	-	-	-	1090.
¹²⁹ I	-	-	-	-	-
¹³⁷ Cs	29.0	-	-	-	59.2
¹⁵² Eu	30.5	-	-	-	-
¹⁵⁴ Eu	3.78	-	-	-	-
¹⁵⁵ Eu	-	-	-	-	-
²⁰⁸ Tl	-	-	-	-	-
²¹⁰ Po	-	-	-	-	-
²¹⁰ Pb	-	-	-	-	120.
²¹² Pb	-	-	-	-	-
²¹⁴ Bi	-	-	-	-	-
²²⁶ Ra	35.8	-	-	-	30.
²²⁸ Ra	-	-	-	-	-
²²⁸ Ac	-	-	-	-	-
²²⁸ Th	33.5	0.22	0.51	-	28.6
²³⁰ Th	29.5	0.20	0.20	-	13.
²³² Th	33.2	0.21	0.058	-	26.8
²³⁴ U	33.2	0.100	0.10	-	19.
²³⁵ U	1.7	-	0.009	-	0.75
²³⁸ U	30.8	0.101	0.088	-	17.4
²³⁷ Np	-	-	-	-	-
²³⁸ Pu	0.013	0.017	0.055	-	0.26
²³⁹⁺²⁴⁰ Pu	0.508	1.1	2.06	-	4.00
²⁴¹ Am	0.150	-	0.15	-	1.1
²⁴³⁺²⁴⁴ Cm	-	0.11	-	-	-

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	36 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A2: Radionuclides and Massic Activities in the Natural Matrix radioactivity SRMs (see IRD Procedure 16)					
SRM Number	4355	4356	4357	4358	4359
Description	Peruvian Soil	Ashed Bone	Ocean Sediment	Ocean Shellfish	Seaweed
Radionuclide	Massic Activity (mBq·g ⁻¹) Certified values are in bold type.				
⁴⁰ K	585.	49.	225.	In preparation	In preparation
⁵⁵ Fe	2.	-	-	-	-
⁶⁰ Co	<0.016	-	-	-	-
⁹⁰ Sr	0.22	42.6	4.4	-	-
¹²⁹ I	-	-	0.009	-	-
¹³⁷ Cs	0.33	-	12.7	-	-
¹⁵² Eu	<0.23	-	-	-	-
¹⁵⁴ Eu	<0.2	-	-	-	-
¹⁵⁵ Eu	<0.2	-	1.4	-	-
²⁰⁸ Tl	12.,15.	-	-	-	-
²¹⁰ Po	-	13.	14.	-	-
²¹⁰ Pb	-	20.	24.	-	-
²¹² Pb	-	-	14.1	-	-
²¹⁴ Bi	42.,39.	-	15.	-	-
²²⁶ Ra	-	14.5	12.7	-	-
²²⁸ Ra	-	6.1	13.3	-	-
²²⁸ Ac	-	6.9	-	-	-
²²⁸ Th	42.2	7.1	12.1	-	-
²³⁰ Th	39.7	0.52	12.0	-	-
²³² Th	43.0	0.98	13.0	-	-
²³⁴ U	-	0.64	12.	-	-
²³⁵ U	-	0.028	0.6	-	-
²³⁸ U	-	0.63	12.	-	-
²³⁷ Np	-	-	0.007	-	-
²³⁸ Pu	3.,3.27	0.86	2.29	-	-
²³⁹⁺²⁴⁰ Pu	0.0076	1.26	10.4	-	-
²⁴¹ Am	0.004	9.98	10.	-	-
²⁴³⁺²⁴⁴ Cm	-	0.12	-	-	-

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	37 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Appendix A3.



National Institute of Standards & Technology Certificate

Standard Reference Material 4404L, Lot 27 Thallium-201 Radioactivity Standard

This Standard Reference Material (SRM) consists of radioactive thallium-201 nitrate, non-radioactive thallium nitrate, and nitric acid dissolved in 5 mL of distilled water. The solution is contained in a flame-sealed NIST borosilicate-glass ampoule. The SRM is intended for the calibration of ionization chambers and solid-state gamma-ray spectrometry systems.

Radiological Hazard: The SRM ampoule contains thallium-201 with a total activity of approximately 30 MBq. Thallium-201 decays by electron capture. During the decay process, X-rays and gamma rays with energies from approximately 2 keV to 167 keV are emitted. Most of these photons escape from the SRM ampoule and can represent a radiation hazard. Approximate unshielded dose rates at several distances (as of the reference time) are given in note [a]*. Appropriate shielding and/or distance should be used to minimize personnel exposure. The SRM should be used only by persons qualified to handle radioactive material.

Chemical Hazard: The SRM ampoule contains nitric acid with a concentration of approximately 1 mole per liter of water. The solution is corrosive and represents a health hazard if it comes in contact with eyes or skin. If the ampoule is to be opened to transfer the solution, the recommended procedure is given on page 2. The ampoule should be opened only by persons qualified to handle both radioactive material and strong acid solution.

Storage and Handling: The SRM should be stored and used at a temperature between 5 and 65 °C. The solution in an unopened ampoule should remain stable and homogeneous until at least June 2005. The ampoule (or any subsequent container) should always be clearly marked as containing radioactive material. If the ampoule is transported it should be packed, marked, labeled, and shipped in accordance with the applicable national, international, and carrier regulations. The solution in the ampoule is a dangerous good (hazardous material) because of the radioactivity.

Preparation: This Standard Reference Material was prepared in the Physics Laboratory, Ionizing Radiation Division, Radioactivity Group, M.P. Unterweger, Acting Group Leader. The overall technical direction and physical measurements leading to certification were provided by D.B. Golas and O.T. Palabrica, Nuclear Energy Institute Research Associates. The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the Standard Reference Materials Program.

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Gaithersburg, Maryland 20899
August 2004

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Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	38 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

Recommended Procedure for Opening the SRM Ampoule

- 1) If the SRM solution is to be diluted, it is recommended that the diluting solution have a composition comparable to that of the SRM solution.
- 2) Wear eye protection, gloves, and protective clothing and work over a tray with absorbent paper in it. Work in a fume hood. In addition to the radioactive material, the solution contains strong base and is corrosive.
- 3) Shake the ampoule to wet all of the inside surface of the ampoule. Return the ampoule to the upright position.
- 4) Check that all of the liquid has drained out of the neck of the ampoule. If necessary, gently tap the neck to speed the process.
- 5) Holding the ampoule upright, score the narrowest part of the neck with a scribe or diamond pencil.
- 6) Lightly wet the scored line. This reduces the crack propagation velocity and makes for a cleaner break.
- 7) Hold the ampoule upright with a paper towel, a wiper, or a support jig. Position the scored line away from you. Using a paper towel or wiper to avoid contamination, snap off the top of the ampoule by pressing the narrowest part of the neck away from you while pulling the tip of the ampoule towards you.
- 8) Transfer the solution from the ampoule using a pycnometer or a pipet with dispenser handle. NEVER PIPETTE BY MOUTH.
- 9) Seal any unused SRM solution in a flame-sealed glass ampoule, if possible, to minimize the evaporation loss.

See also reference [4]*.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	39 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

PROPERTIES OF SRM 4404L, Lot 27, Ampoule 4

Certified values

Radionuclide	Thallium-201
Reference time	1000 EST, 09 June 2004
Massic activity of the solution [b]*	5.858 MBq·g⁻¹
Relative expanded uncertainty (k=2)	0.80% [c] [d]
Solution mass	(5.2102 ± 0.0003) g [e]
Solution density	(1.040 ± 0.002) g·mL⁻¹ at 20 °C [e]

Uncertified values

Physical Properties:			
Source description	Liquid in flame-sealed NIST borosilicate-glass ampoule		
Ampoule specifications	Body outside diameter	(16.5 ± 0.5) mm	
	Wall thickness	(0.60 ± 0.04) mm	
	Barium content	Less than 2.5%	
	Lead-oxide content	Less than 0.02%	
	Other heavy elements	Trace quantities	
Chemical Properties:			
Solution composition	Chemical Formula	Concentration (mol·L ⁻¹)	Mass Fraction (g·g ⁻¹)
	H ₂ O	53	0.93
	HNO ₃	1.2	0.07
	TlNO ₃	4 × 10 ⁻⁴	1 × 10 ⁻⁴
	²⁰¹ TlNO ₃	4 × 10 ⁻⁹	1 × 10 ⁻⁹
Radiological Properties:			
Photon-emitting impurities	Tl-200: (9.3 ± 2.6) kBq·g ⁻¹ [e] [f] Tl-202: (9.5 ± 2.7) kBq·g ⁻¹ [e] [f]		
Half lives used	Thallium-200: (26.1 ± 0.1) h [g] [5] Thallium-201: (3.0423 ± 0.0014) d [g] [s] Thallium-202: (12.23 ± 0.02) d [g] [5] Radium-226: (1600 ± 7) a [g] [5]		
Calibration method and measuring instrument(s)	Pressurized "4π"γ ionization chamber A calibrated using a thallium-201 solution whose activity was determined by the 4π(e+X)-γ-coincidence efficiency-extrapolation technique.		

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	40 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

EVALUATION OF THE UNCERTAINTY OF THE MASSIC ACTIVITY [c] [d]*

Input Quantity x_i , the source of uncertainty (and individual uncertainty components where appropriate)	Method Used To Evaluate $u(x_i)$, the standard uncertainty of x_i (A) denotes evaluation by statistical methods (B) denotes evaluation by other methods	Relative Uncertainty Of Input Quantity, $u(x_i)/x_i$, (%) [h]	Relative Sensitivity Factor, $ \partial y/\partial x_i \cdot$ (x_i/y) [i]	Relative Uncertainty Of Output Quantity, $u_c(y)/y$, (%) [j]
PIC A net response per gram of SRM 4404L, measured relative to RRS200 [k]	Standard deviation of the mean for >100 repeated measurements (A)	0.02	1.0	0.02
PIC A net response per Bq of thallium-201 in solution, measured relative to RRS200.	Standard deviation of the mean for >100 repeated measurements (A)	0.01	1.0	0.01
Activity used to calibrate PIC A net response per Bq of thallium-201 in solution	Standard uncertainty of the activity determined by the $4\pi(e+X)$ - γ -coincidence efficiency-extrapolation technique. (B)	0.35	1.0	0.35
Half life of thallium-201 Half life of radium-226	Standard uncertainty of the half life (A)	0.04 [m] 0.44 [m]	0.02 [n] 0.012 [n]	0.001 0.005
Gravimetric measurements	Estimated (B)	0.05	1.0	0.05
Live time [p]	Estimated (B)	0.05	1.0	0.05
PIC A charge collection	Estimated (B)	0.05	1.0	0.05
Source positioning	Estimated (B)	0.05	1.0	0.05
Photon-emitting impurities	Estimated (B) [q] Estimated (B) [q] Limit of detection (B) [r]	14. 14. 100.	0.009 0.004 0.0004	0.13 0.06 0.04
Relative Combined Standard Uncertainty of the Output Quantity, $u_c(y)/y$, (%)				0.40
Coverage Factor, k				<u>x 2</u>
Relative Expanded Uncertainty of the Output Quantity, U/y , (%)				0.80

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	41 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

NOTES

- [a] The Sievert is the SI unit for dose equivalent. See reference [1]. One μSv is equal to 0.1 mrem.
Distance from Ampoule (cm): 1 30 100
Approximate Dose Rate ($\mu\text{Sv/h}$): 600 6 <1
- [b] **Massic activity** is the preferred name for the quantity activity divided by the total mass of the sample. See reference [1].
- [c] The reported value, y , of massic activity (activity per unit mass) at the reference time was not measured directly but was derived from measurements and calculations of other quantities. This can be expressed as $y = f(x_1, x_2, x_3, \dots, x_n)$, where f is a mathematical function derived from the assumed model of the measurement process. The value, x_i , used for each input quantity i has a **standard uncertainty**, $u(x_i)$, that generates a corresponding uncertainty in y , $u_i(y) \equiv |\partial y / \partial x_i| \cdot u(x_i)$, called a **component of combined standard uncertainty** of y . The **combined standard uncertainty** of y , $u_c(y)$, is the positive square root of the sum of the squares of the components of combined standard uncertainty. The combined standard uncertainty is multiplied by a **coverage factor** of $k=2$ to obtain U , the **expanded uncertainty** of y .
- Since it can be assumed that the possible estimated values of the massic activity are approximately normally distributed with approximate standard deviation $u_c(y)$, the unknown value of the massic activity is believed to lie in the interval $y \pm U$ with a level of confidence of approximately 95 percent.
- For further information on the expression of uncertainties, see references [2] and [3].
- [d] The value of each component of combined standard uncertainty, and hence the value of the expanded uncertainty itself, is a best estimate based upon all available information, but is only approximately known. That is to say, the "uncertainty of the uncertainty" is large and not well known. This is true for uncertainties evaluated by statistical methods (e.g., the relative standard deviation of the standard deviation of the mean for the massic response is approximately 50%) and for uncertainties evaluated by other methods (which could easily be over estimated or under estimated by substantial amounts). The unknown value of the expanded uncertainty is believed to lie in the interval $U/2$ to $2U$ (i.e., within a factor of 2 of the estimated value).
- [e] The stated uncertainty is two times the standard uncertainty.
- [f] Estimated limits of detection for photon-emitting impurities, as of the reference time, expressed as massic photon emission rates, are:
 $1 \times 10^2 \text{ s}^{-1} \cdot \text{g}^{-1}$ for energies between 30 keV and 40 keV,
 $3 \times 10^2 \text{ s}^{-1} \cdot \text{g}^{-1}$ for energies between 40 keV and 163 keV,
 $1 \times 10^2 \text{ s}^{-1} \cdot \text{g}^{-1}$ for energies between 171 keV and 240 keV,
 $4 \times 10^1 \text{ s}^{-1} \cdot \text{g}^{-1}$ for energies between 240 keV and 1450 keV, and
 $2 \times 10^1 \text{ s}^{-1} \cdot \text{g}^{-1}$ for energies between 1450 keV and 3600 keV, provided that the photons are separated in energy by 4 keV or more from photons emitted in the decay of thallium-201.
- [g] The stated uncertainty is the standard uncertainty.
- [h] Relative standard uncertainty of the input quantity x_i .
- [i] The relative change in the output quantity y divided by the relative change in the input quantity x_i . If $|\partial y / \partial x_i| \cdot (x_i / y) = 1.0$, then a 1% change in x_i results in a 1% change in y . If $|\partial y / \partial x_i| \cdot (x_i / y) = 0.05$, then a 1% change in x_i results in a 0.05% change in y .

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	42 of 44	Procedure15v200

- [j] Relative component of combined standard uncertainty of output quantity y , rounded to two significant figures or less. The relative component of combined standard uncertainty of y is given by $u_i(y)/y \equiv |\partial y/\partial x_i| \cdot u(x_i)/y = |\partial y/\partial x_i| \cdot (x_i/y) \cdot u(x_i)/x_i$. The numerical values of $u(x_i)/x_i$, $|\partial y/\partial x_i| \cdot (x_i/y)$, and $u_i(y)/y$, all dimensionless quantities, are listed in columns 3, 4, and 5, respectively. Thus, the value in column 5 is equal to the value in column 4 multiplied by the value in column 3. The input quantities are independent, or very nearly so. Hence the covariances are zero or negligible.
- [k] The response of pressurized ionization chamber A (PIC A) is determined from measurement of the time required to collect a given amount of charge on a stable fixed capacitor. All of the response measurements in the NIST pressurized ionization chambers are made relative to the response of one or more artifact standards. These artifact standards consist of microgram quantities of aged radium-226 in small welded stainless-steel capsules. These capsules are encapsulated in plastic rods whose dimensions are similar to those of the standard NIST ampoule. The artifact standards are called **Radium Reference Sources** and are designated as RRSx, where x is the nominal mass (in micrograms) of radium-226 in the capsule.
- [m] The relative standard uncertainty of $\lambda \cdot t$ is determined by the relative standard uncertainty of λ (i.e., of the half life). The relative standard uncertainty of t is negligible.
- [n] $|\partial y/\partial x_i| \cdot (x_i/y) = \lambda \cdot t$
- [p] The live time is determined by counting the pulses from a gated crystal-controlled oscillator.
- [q] The standard uncertainties given are for the detected impurities. $|\partial y/\partial x_i| \cdot (x_i/y) = \{(\text{response per Bq of impurity})/(\text{response per Bq of Tl-201})\} \cdot \{(\text{Bq of impurity})/(\text{Bq of Tl-201})\}$.
- [r] The standard uncertainty for each undetected impurity that might reasonably be expected to be present is estimated to be equal to the estimated limit of detection for that impurity, i.e. $u(x_i)/x_i = 100\%$. $|\partial y/\partial x_i| \cdot (x_i/y) = \{(\text{response per Bq of impurity})/(\text{response per Bq of Tl-201})\} \cdot \{(\text{Bq of impurity})/(\text{Bq of Tl-201})\}$. Thus $u_i(y)/y$ is the relative change in y if the impurity were present with a massic activity equal to the estimated limit of detection.
- [s] This is the equally-weighted mean and the standard deviation of the mean of five published half-life values for thallium-201:

	Published Half Life and One Standard Uncertainty	From the Mean	Standard Deviations
1.	(3.0456 ± 0.0015) days [6]	+1.1	
2.	(3.043 ± 0.003) days [7]	+0.3	
3.	(3.0408 ± 0.0013) days [8]	-0.5	
4.	(3.0379 ± 0.0007) days [9]	-1.5	
5.	(3.0440 ± 0.0048) days [9]	+0.6	
Mean	(3.0423 ± 0.0014) days = (73.015 ± 0.015) hours		

The value currently recommended in the Evaluated Nuclear Structure Data File (ENSDF) is based upon only value number 4 above. We believe that all of the above data should be considered and that a larger uncertainty is appropriate.

Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	43 of 44	Procedure15v200

Ionizing Radiation Division	SRM Series 4xxx	IRD-P-15
RADIOACTIVITY STANDARD REFERENCE MATERIALS		

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Version	Date	Author	Approval	Pages	Filename
2.00	11/30/2005	RC	Uncontrolled Copy	44 of 44	Procedure15v200