Procedures for SP250 47010C (Calibration of Gamma-Ray Source containing ^{137}Cs, or ^{192}Ir) and 47011C (Each Additional Gamma-Ray Source of Same Radionuclide)

Purpose

This procedure describes the calibration of brachytherapy sources containing the radionuclides ^{137}Cs, or ^{192}Ir in terms of air-kerma strength. The national air-kerma strength standard for gamma-emitting encapsulated sources resides in calibration coefficients of either the spherical-aluminum re-entrant chamber (^{192}Ir) or the spherical-aluminum cavity chamber (^{137}Cs) which were derived from primary standard graphite-cavity chamber measurements[1-4].

Scope

Gamma-ray sources submitted for calibration that contain ^{137}Cs must be similar in design to the NIST "working standard" sources, and have air-kerma strengths within the range of 10 μGy m^2/h to 1500 μGy m^2/h. ^{192}Ir sources must be of the same type used to calibrate the NIST spherical aluminum re-entrant chamber, and have air-kerma strengths in the range of 0.1 μGy m^2/h to 30 μGy m^2/h.

Definitions

Air Kerma is the sum of the initial kinetic energies of all electrons liberated by photons in a volume element containing a given mass of air. The SI unit of air-kerma is the Gray (Gy), where 1 Gy = 1 J / kg.

Air-Kerma Strength is the product of the air-kerma rate, *in vacuo*, at a distance *d* and the square of this distance. Air-kerma strength is typically expressed in units of μGy m^2/h, but is also represented by "U".

Brachytherapy is a type of radiation therapy in which an encapsulated radioactive source is placed in or near a tumor or lesion.

Equipment

- Spherical aluminum re-entrant and cavity chambers, including source-mounting tube and trough, respectively.
- NIST-calibrated (using graphite-cavity chambers) "working standard" sources of ^{137}Cs (R.S.# 67-0385, 67-0386, 67-0387).
- ^{226}Ra source (R.S.# 65-0308) for constancy check on re-entrant chamber response.
- High-voltage power supply (Power Designs, Model HV-1565, S/N 702016 or equivalent) to bias the ionization chambers.
- Electrometer (Keithley, Model 617, S/N 0661363 or equivalent) and capacitor (e.g., General Radio Co., Model 1403-A, S/N 7095, calibrated by the NIST Electricity Division) to collect and measure liberated charge.

- Temperature (DigiTec, Model 5810, S/N 63560608 or equivalent) and pressure (Wallace & Tiernan, Model FA185260, S/N AE03821 or equivalent) gauges to allow correction to reference conditions (22 ^{o}C and 760 mm Hg).

Health and Safety Precautions

Radiation Safety – Sources shall always be handled with tongs, with the concrete barrier wall in room 245/B145 positioned between the source and the operator, and over a tray to contain the source in case it is accidentally dropped. An audible survey meter must be kept within reach to ensure that the location of the source is known at all times. A radiation dosimetry (TLD or similar) badge must be worn when working in the facility. Finger dosimeters shall be worn when manipulating a source. Great care shall be used when handling a source, as excessive force could damage the encapsulation and cause leakage of radioactive material. When measurements are in progress, a sign designating the immediate area around the ionization chambers as a high-radiation area shall be displayed, and the door to the laboratory shall be locked. When a source is not in use, it shall be placed in its lead pig or stored in the locked, lead-lined safe inside the locked laboratory. Radiation safety training and assessment services are provided by the Gaithersburg Radiation Safety Division (GRSD).

Electrical Safety – Ionization chambers shall remain in their original positions behind the concrete barrier at all times, out of the operator's reach, to avoid possible electric shock when high voltage (-1100 V DC) is applied.

Emergency Procedures - If a source is accidentally dropped and can not be immediately located visually, the operator shall move away from the last known position of the source (but remain in the room) and use the audible survey meter to ensure that the source is not attached to them. If the source is somehow attached to the operator, remove the source with tongs and call GRSD (x5800) to notify them of the accidental exposure. If not, use the survey meter to locate and secure the source. If a source is accidentally damaged, escape of radioactive material is possible. The operator shall move away from the source (but remain in the room) and call GRSD (x5800) to notify them of the accident.

Procedures

Acceptance of Sources

1. Calibrations must be scheduled prior to shipment of the sources to NIST. The customer must provide the activity and encapsulated radionuclide of each source so that a NIST 364 form may be filled out and given to GRSD.
2. Sources must be shipped directly to GRSD for a contamination check upon arrival. (GRSD must have a copy of the source manufacturer's radioactive materials license.) Sources showing evidence of leakage or shipping containers having detectable removable contamination in any manner will not be accepted for calibration.

3. A Report of Calibration Number (DG) shall be obtained from the Dosimetry Group office (456/B106-C), and entered into the laboratory notebook prior to beginning the calibration of a source.

Environmental Conditions – Prior to taking any measurements, the temperature in the calibration laboratory (245/B145) is recorded. In order to proceed with the calibration, the temperature must be within the range (22 ± 4) ^{o}C. A lookup table, which explicitly shows the conversion of the temperature displayed by the thermometer to the actual temperature of the laboratory (taking into account the calibration coefficient for the thermometer) located below the thermometer, shall be used to verify that the actual temperature falls within the acceptable range for the calibration to proceed.

Calibration Set-up Using Re-Entrant Chamber System

1. With high voltage turned off, "work" the high voltage connections on the power supply and chamber to remove any oxidation that may have formed.
2. Turn on high-voltage power supply – the meter should read (-1100 ± 5) V.
3. Measure the background/leakage current.
4. Using long, spring-loaded tongs, remove the ^{226}Ra check source from drawer B10 in the lead safe, inserting it into the plastic funnel/tube assembly with the black end pointing up.
5. Place the tube into the re-entrant chamber and measure ionization current.
6. Re-position the ^{226}Ra check source in the tube with the black end pointing down and measure ionization current.
7. Return the ^{226}Ra check source to the lead safe.
8. Measure the background/leakage current.

Calibration Sequence Using Re-Entrant Chamber System

1. Using long, spring-loaded tongs, remove the ^{192}Ir seed to be calibrated from its lead pig and place it flat in the bottom of the glass tube.
2. Insert the thin, black rubber tubing approximately 2 cm into the top of the glass tube and place the assembly in the well of the re-entrant chamber.
3. Measure the ionization current two times.
4. Remove the tube assembly from the re-entrant chamber, gently shake to randomly re-orient the seed, and replace.
5. Repeat steps 3 and 4 twelve times.
6. Put the ^{192}Ir seed back in its lead pig.
7. Measure the background/leakage current.
8. Repeat the ^{226}Ra check source measurements as described above after all ^{192}Ir seeds have been measured.

Calibration Set-up Using Cavity Chamber System

1. With high voltage turned off, "work" the high voltage connection on the power supply to remove any oxidation that may have formed.

2. Position the signal-cable connection behind a lead brick.
3. Verify that the cross hairs viewed through the telemicroscope on the concrete barrier wall line up with the bottom of the "V" on the plastic trough (source holder).
4. Align the cross hairs of the cathetometer at the end of the calibration range with the center-line marked on the source holder.
5. Turn on high-voltage power supply – the meter should read (-1100 ± 5) V.
6. Measure the background/leakage current.
7. Using long, spring-loaded tongs, remove the ^{137}Csworking standard source that is closest in activity to the manufacturer's stated value for the source to be calibrated from the lead safe, placing it into the source holder.
8. Note the orientation of the seed using the telemicroscope, and verify using the cathetometer that the source is centered on the line on the source holder.
9. Measure the current at least five times.
10. Using tongs, rotate the source by 90 degrees about its long axis and repeat step 9.
11. Flip the source so that the end closest to the telemicroscope is now closest to the wall of the room behind the concrete barrier wall and repeat steps 9 and 10.
12. Using tongs, remove the working standard source from the source holder and return it to the lead safe.

Calibration Sequence Using Cavity Chamber System

1. Place the lead pig containing the source to be calibrated in a tray behind the concrete barrier wall.
2. Open the lead pig and dump the source out onto the tray.
3. Using tongs, place the source into the source holder.
4. Note the orientation of the seed using the telemicroscope, and verify using the cathetometer that the source is centered on the line on the source holder.
5. If the radius of the source is large enough such that the top of the source extends beyond the top of the "V" trough, use a larger trough.
6. Measure the current at least five times.
7. Using tongs, rotate the source by 90 degrees about its long axis and repeat step 6.
8. Flip the source so that the end closest to the telemicroscope is now closest to the wall of the room behind the concrete barrier wall and repeat steps 6 and 7.
9. Using tongs, remove the source from the source holder and return it to the lead pig.

Analysis and Reporting of Results

1. All measured currents must be corrected for temperature and pressure deviations from reference conditions (22 ^{o}C and 760 mmHg), background/leakage, and radioactive decay prior to averaging.
2. The quotient of the average corrected current from the customer's source and the average corrected current from the working standard source is multiplied by the NIST air-kerma strength value of the working standard source to obtain the NIST

air-kerma strength value of the customer's source. This value is entered into the official calibration report, an example of which is given in Appendix A.

3. After review and approval, the official calibration report is mailed to the customer. The lead pigs containing the calibrated sources are re-packaged in their original container and shipped either back to the customer or to an Accredited Dosimetry Calibration Laboratory (as specified by the customer).

Quality Assurance

1. To verify constancy of the re-entrant chamber's response over time, the results of measurements of the ^{226}Ra source described above are compared to the history of such measurements to verify that there are no significant changes. Deviations greater than 1 % from the average of previous measurements should be investigated by repeating the measurement several times, noting any unusual behavior of the measurement system. If after repeated measurements of the ^{226}Ra source the > 1 % deviation continues to exist, the electrometer, thermometer, and barometer should be re-calibrated using the procedures given below. (Note that ^{226}Ra check source data exists from December 1977 through December 1987 and from February 2001 through the present. The lapse in data occurred due to non-use of the calibration service, which was subsequently re-established for ^{192}Ir source calibrations and internal quality assurance for Model 6711 ^{125}I seeds.)
2. To verify constancy of the cavity chamber's response over time, the results of measurements of the ^{137}Cs working standard sources described above are compared to the history of such measurements to verify that there are no significant changes. Deviations greater than 1 % from the average of previous measurements should be investigated by repeating the measurement several times, noting any unusual behavior of the measurement system. If after repeated measurements of the ^{137}Cs source(s) the > 1 % deviation continues to exist, the electrometer, thermometer, and barometer should be re-calibrated using the procedures given below.

Calibration of Electrometer – The following procedure should be used to re-calibrate the electrometer in the case of out-of-tolerance ^{226}Ra or ^{137}Cs check/working standard source measurement results.

1. Connect a capacitor that has been calibrated by the NIST Electromagnetics Division (e.g., NBS B-15) between the Fluke Model 343A DC voltage calibrator (S/N 2195014 or equivalent) and the electrometer to be calibrated.
2. Allow both the electrometer and voltage calibrator to warm up for at least 2 hours.
3. Based on which coulomb scales of the electrometer are used when performing calibrations, select a series of test voltages to be used to calibrate the electrometer, taking into account the capacitance value of the NIST-calibrated capacitor. (A minimum of 5 data points per electrometer coulomb scale should be acquired.)
4. Select a voltage on the voltage calibrator and measure the accumulated charge on the capacitor with the electrometer.

5. Repeat step 4 until data is acquired for all relevant coulomb scales.
6. Calculate the calibration coefficient for each coulomb scale by taking the average of all ratios of the known accumulated charge to the charge indicated by the electrometer.

Calibration of Thermometer - The following procedure should be used to re-calibrate the thermometer in the case of out-of-tolerance ^{226}Ra or ^{137}Cs check/working standard source measurement results.

1. Place the DigiTec Model 5810 thermometer probe and a thermometer that has been calibrated by the NIST Measurement Services Division (e.g., Taylor S/N 3738041) in an insulated box (cardboard/Styrofoam).
2. Record the temperatures obtained from both thermometers over a period of several hours until a minimum of 5 data points are acquired.
3. Calculate the calibration coefficient for the DigiTec thermometer by taking the average of all ratios of the known temperature to the temperature indicated by the DigiTec thermometer.

Calibration of Barometer - The following procedure should be used to re-calibrate the barometer in the case of out-of-tolerance ^{226}Raor ^{137}Cs check/working standard source measurement results.

1. Place the Wallace & Tiernan Model FA185260 barometer in close proximity to a barometer that has been calibrated by the NIST Measurement Services Division (e.g., Wallace & Tiernan S/N XX11242).
2. Record the pressures obtained from both barometers over a period of several hours until a minimum of 5 data points are acquired.
3. Calculate the calibration coefficient for the Wallace & Tiernan barometer by taking the average of all ratios of the known pressure to the pressure indicated by the Wallace & Tiernan barometer.

Evaluation of Measurement Uncertainties

Uncertainties for measurements performed with both the re-entrant and cavity chambers are determined based on the *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*[5]. The Type A components of uncertainty are equal to the standard deviation of the mean of replicate measurements, and the Type B components are evaluated by other means, detailed in Appendices B and C. The combined standard uncertainty of the air-kerma strength calibration is equal to the square root of the quadratic sum of the Type A and Type B uncertainties, with a final reported expanded uncertainty obtained by multiplying the combined standard uncertainty by a coverage factor of two (k=2), representing an interval having a level of confidence of approximately 95 %.

Traceability of Measurements

The SI unit of air kerma (K_{air}) is the Gray (Gy), which is related to the quantity exposure (X) by multiplicative constants, $K_{air} = X (W/e) / (1-g)$, where *W/e* is the mean energy per unit charge expended in air by electrons, and *g* is the mean fraction of the energy of the secondary electrons that is lost to bremsstrahlung. Exposure is the total charge per unit mass liberated in free air by a photon beam (SI units of C/kg), and is directly realized by Bragg-Gray graphite cavity chamber measurements[1,3]. The traceability of spherical aluminum re-entrant and spherical aluminum cavity chamber measurements described in this procedure to the fundamental Bragg-Gray graphite cavity chamber measurements resides in the calibration coefficients of each aluminum chamber for each type of brachytherapy source. These calibration coefficients were determined by measuring the responses of both Bragg-Gray and spherical-aluminum-type chambers to the same source (or multiple sources, in the case of ^{192}Ir). More detailed information concerning traceability and uncertainty analyses is summarized in SP250-19, available using the following hyperlink: https://dx.doi.org/10.6028/NBS.SP.250-19

Records

All data acquired during measurements is recorded in an official NIST laboratory notebook that is stored in a filing cabinet in 245/B06.

References

1. Loftus, T. P., Standardization of Cesium-137 Gamma-Ray Sources in Terms of Exposure Units (Roentgens), *J. Res. Nat. Bur. Stand. (U.S.)* 74A, 1-6 (1969).
2. Loftus, T. P., and Weaver, J. T., Standardization of ^{60}Co and ^{137}Cs Gamma-Ray Beams in Terms of Exposure, *J. Res. Nat. Bur. Stand. (U.S.)* 78A, 465-476 (1974).
3. Loftus, T. P., Standardization of Iridium-192 Gamma-Ray Sources in Terms of Exposure, *J. Res. Nat. Bur. Stand. (U.S.)* 85, 19-25 (1980).
4. Weaver, James T., Loftus, Thomas P., Loevinger, Robert, NBS Measurement Services: Calibration of Gamma-Ray-Emitting Brachytherapy Sources, *Nat. Bur. Stand. (U.S.) Spec. Publ. 250-19*, 60 pages (Dec. 1988).
5. Taylor, Barry N., and Kuyatt, Chris E., Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, *National Institute of Standards and Technology Technical Note 1297*, 24 pages (Sep. 1994).

Filing and Retention

The RPD Quality Manager shall maintain the original and all past versions of this RPD Procedure.

Appendix A – Calibration Report

National Institute of Standards and Technology

REPORT OF AIR-KERMA STRENGTH MEASUREMENT

FOR

Customer Name
Address
City, State, Country

Seed Identification: **Model XXX**
Arrival Date: **XX Month 20XX**
SP250 Service ID # **47010C, 47011C**

Measurements performed by Jason Walia

Report reviewed by Ronaldo Minniti

Report approved by Michael G. Mitch, Leader
Dosimetry Group

For the Director
National Institute of Standards and Technology
by:

James M. Adams, Chief
Radiation Physics Division
Physical Measurement Laboratory

Information on technical aspects of this report may be obtained from Jason Walia, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460, Gaithersburg, MD 20899-8460, 301-975-5592. Report format revised 09/18.

NIST National Institute of Standards and Technology U.S. Department of Commerce

DG: XXXXX/XX
Order #: 682.02/O-XXXXXX-XX
Report Date: XX Month 20XX

National Institute of Standards and Technology

REPORT OF AIR-KERMA STRENGTH MEASUREMENT

FOR

Customer Name
Address
City, State, Country

Seed Identification: **Model XXX**
Arrival Date: **XX Month 20XX**
SP250 Service ID # **47010C, 47011C**

Description of seed provided by customer*:*
Construction:
Diameter (mm):
Length (mm):
Half-Life (d):
Radionuclide:
Purity rating:
NIST Reference time and date: 00:00:01 EST, XX Month 20XX
Temperature range during measurements: XX K to XX K
Pressure range during measurements: XXX kPa to XXX kPa

Measurement Results

Source ID No.	Number of Measurements	Air-Kerma Strength (μGy m^2/h) at 295.15 K (22 °C) and 101.325 kPa (1 Atm)	Reproducibility[a] (%)	Expanded Combined Relative Uncertainty[b] (%)

[a] Obtained from the replicate measurements as the standard deviation of the mean.
[b] See page 3 for note on uncertainty.

Explanation of Terms Used in the Calibration Procedures and Tables

Air-Kerma Strength: The realization of the radiation quantity air-kerma strength done at NIST establishes the National Standard. This can in turn be transferred to other measurement facilities through a suitable measuring instrument, thus enabling traceability to the National Standard. The air-kerma strength is the product of the air-kerma rate and the square of the distance to the reference point assumed in vacuum, in a direction perpendicular to the long axis of the cylindrical encapsulated brachytherapy source. For more details see *Specification of Brachytherapy Source Strength*, Report 21 of the American Association of Physicists in Medicine, Am. Inst of Phys., MD, June 1987.

The air-kerma rate of ^{192}Ir and ^{137}Cs brachytherapy sources is directly realized at NIST using a variety of spherical, graphite-walled cavity ionization chambers. Measurements are performed free-in-air at source-to-chamber distances between 0.5 m and 1.0 m with a chamber of volume and wall thickness such that Bragg-Gray conditions are satisfied.

The air-kerma rate, $\dot{K}_{air}(Q)$, is calculated using the equation:

$$\dot{K}_{air}(Q) = \left(\frac{\overline{W}}{e}\right)\left(\frac{1}{\rho_{air}V}\right)\left(\frac{1}{1-\overline{g}}\right)\frac{(\overline{\mu}_{en}/\rho)_{air}}{(\overline{\mu}_{en}/\rho)_{gr}}\frac{(\overline{L}_{\Delta}/\rho)_{gr}}{(\overline{L}_{\Delta}/\rho)_{air}}K_{dr}(\dot{K})M_{det}(\dot{K},Q)K_{stem}K_{wall}(Q)K_{h}(Q)$$

where:

$\overline{W}$ = the mean energy per ion pair expended when the initial kinetic energy of a charged particle is completely dissipated in air

e = the elementary charge

ρ_{air} = the density of air

V = volume of air in the chamber

$\overline{g}$ = is the mean fraction of kinetic energy lost by charged particles in radiative processes

$\overline{\mu}_{en}/\rho$ = the mean photon-energy-fluence-weighted mass energy-absorption coefficient

$\overline{L}_{\Delta}/\rho$ = the mean Spencer-Attix electron-fluence-weighted electron mass stopping power

$K_{dr}(\dot{K})$ = the recombination correction

$M_{det}(\dot{K},Q)$ = the net current (corrected for radioactive decay)

K_{stem} = the stem-scatter correction factor

$K_{wall}(Q)$ = the wall correction factor

$K_h(Q)$ = the humidity correction factor

The air-kerma strength is calculated from $\dot{K}_{air}(Q)$ using the equation: $S_k = \dot{K}_{air}(Q)\, d^2$. With d being the source-to-chamber distance. The air-kerma strength(s) given in this report can be used to determine a well-chamber calibration coefficient for the identified source model.

Uncertainty: The combined standard uncertainty assigned to these results has been evaluated as the square root of the quadratic sum of the component standard uncertainties, including those evaluated by statistical means (Type A) and those evaluated by other means (Type B). The expanded uncertainty has been obtained by multiplying the combined standard uncertainty by a coverage factor of two, to represent an interval having a level of confidence of approximately 95 %.

Appendix B – Uncertainty analysis for ^{137}Cs and ^{60}Co source calibration by substitution. Estimated relative uncertainties (k = 1) are given in percent, and include the Type A uncertainty estimated by statistical methods, and the Type B uncertainty estimated by other means.

(a) Measurement of secondary working standard using primary graphite standard chambers.		A (%)	B (%)
Volume		0.1	0.05
Charge		0.04	0.1
Timing		0.03	0.03
Air density		0.03	0.1
Recombination loss			0.07
Humidity			0.06
Leakage and radiation background			0.02
W / e			0.15
Stopping-power ratio			0.60
Energy-absorption coefficient ratio			0.06
Wall correction			0.17
Stem Scatter			0.02
Effective measurement point			0.05
Radial nonuniformity			0.01
Distance (50 cm)			0.1
Correction to vacuum			
	Air attenuation		0.05
	Room scatter		0.3
Source nonuniformity			0.2
Half-life			0.14
Long-term reproducibility			0.3
Quadratic sum		0.12	0.84

(b) Measurement of source using 2.8-liter spherical ionization chamber.			
Charge		0.05	0.1
Timing			0.03
Air density		0.05	0.05
Recombination loss			0.1
Leakage and radiation background			0.2
Distance			0.1

Difference in scatter		0.2
Source nonuniformity		0.2
Source size		0.1
Quadratic sum	0.07	0.40

	Comparison of user source with secondary standard	tertiary standard
Combined standard uncertainty	1.03	1.18
Expanded uncertainty (k = 2)	2.05	2.36

Appendix C – Uncertainty analysis for ^{192}Ir source calibration with the re-entrant chamber. Estimated relative uncertainties (k = 1) are given in percent, and include the Type A uncertainty estimated by statistical methods, and the Type B uncertainty estimated by other means.

(a) Measurement of array of seeds using graphite standard chambers.	A (%)	B (%)
Volume	0.01	
Charge	0.03	0.05
Timing		0.01
Air density	0.03	0.05
Recombination loss		0.03
Humidity		0.06
Leakage and radiation background		0.02
W / e		0.15
Stopping-power ratio		0.72
Energy-absorption coefficient ratio		0.06
Stem Scatter		0.02
Wall correction		0.17
Effective measurement point		0.05
Radial nonuniformity		0.01
Distance	0.04	
Correction to vacuum		
Air attenuation		0.1
Room scatter		0.3
Half-life		
Platinum encapsulated (2.82 half-lives)		0.5
Stainless steel encapsulated (0.12 half-lives)		0.02
Array cover attenuation		0.1
Reproducibility in exposure measurement	0.2	
Quadratic sum for graphite chamber measurement		
Platinum encapsulated seeds	0.21	0.97
Stainless steel encapsulated seeds	0.21	0.83

(b) Calibration of aluminum re-entrant chamber using individual seeds of the array.		
Charge	0.03	0.05
Timing		0.01
Air density	0.05	0.05
Recombination loss		0.1

Humidity		0.06
Leakage and radiation background		0.02
Reproducibility in re-entrant chamber	0.1	
Quadratic sum for re-entrant chamber calibration	0.12	0.16

(c) Measurement of single unknown source in re-entrant chamber

Charge	0.05	0.1
Timing		0.01
Air density	0.05	0.1
Recombination loss		0.1
Leakage and radiation background		0.02
Reproducibility in re-entrant chamber	0.1	
Plastic cover		0.3
Quadratic sum for unknown measurement	0.12	0.35

	Platinum	Stainless steel
Combined standard uncertainty	1.08	0.95
Expanded uncertainty (k = 2)	2.2	1.9