CALIBRATION OF ^{125}I, ^{103}Pd, or ^{131}Cs BRACHYTHERAPY SEEDS

Procedures for SP250 47020C (Calibration of ^{125}I, ^{103}Pd, or ^{131}Cs Brachytherapy Seeds) and 47021C (Each Additional ^{125}I, ^{103}Pd, or ^{131}Cs Seed of Same Design)

Purpose
This procedure describes the calibration of brachytherapy seeds containing the radionuclides ^{125}I, ^{103}Pd, or ^{131}Cs in terms of air-kerma strength. The national air-kerma strength standard for low energy (< 50 keV) photon-emitting encapsulated sources is the Wide-Angle Free-Air Chamber (WAFAC).

Scope
^{125}I, ^{103}Pd, or ^{131}Cs seeds submitted for calibration must have air-kerma strengths within the range of 0.5 µGy m^2/h to 100 µGy m^2/h.

Definitions
<u>Air Kerma</u> is the sum of the initial kinetic energies of all charged particles (e.g., electrons) liberated by uncharged particles (e.g., photons) in a mass of air. The SI unit of air kerma is the Gray (Gy), where 1 Gy = 1 J / kg.

<u>Air-Kerma Strength</u> 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, also represented by "U".

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

<u>Wide-Angle Free-Air Chamber (WAFAC)</u> is a cylindrical, variable-volume ionization chamber used to directly realize the quantity air kerma for low energy (< 50 keV) photon-emitting radioactive sources[1].

Equipment
- WAFAC system hardware – includes ionization chamber with two stepper motors for volume and position adjustment (Vexta, Model PK266-02B), motorized filter wheel (includes lead plug for leakage measurements and aluminum filters of various thicknesses), seed-mounting post with stepper motor for rotation of source about its axis (Compumotor, Model PK3/110V), and a cathetometer for measuring the distance between the source and entrance aperture of the ionization chamber (e.g., Gaertner Scientific, S/N 1796A). Detailed specifications for WAFAC hardware are found in the "NIST Irradiator Control System Operation and Maintenance Manual" located in room 245/B08. (A procedure for construction of new Mylar electrodes is kept in a red loose-leaf notebook located beside the WAFAC control computer in room 245/B08.)
- High-voltage power supply (Bertan, Model 225, S/N 4207 or equivalent) to bias the ionization chamber.

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- Electrometer (Keithley, Model 642, S/N 58461 or equivalent) and capacitor (e.g., General Radio Co., Model 1403-D, S/N 6265, calibrated by the NIST Electricity Division) to collect and measure liberated charge.
- Temperature (Hart, Model 1504, S/N 97168 or equivalent) and pressure (Setra, Model Datum 2000) gauges to allow correction to reference conditions (22 $^{\circ}$C and 760 mm Hg).
- Computer with interface cards for data acquisition and instrument control, LabVIEW software, and WAFAC system control program (WAFAC_20.vi).
- ^{241}Am source (R.S.# 00-0038) for periodic constancy check on ionization-chamber response.

Health and Safety Precautions

Radiation Safety – Sources shall always be handled with tongs behind a leaded-plastic shield containing 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, the door to the laboratory shall be locked. A sign that reads "Caution: Radiation Area" shall be displayed on the leaded-glass wall at the entrance to the area where the source is mounted. When a source is not in use, it shall be placed in its lead pig and stored in the locked, lead-lined safe inside the locked WAFAC laboratory. Radiation safety training and assessment services are provided by the Gaithersburg Radiation Safety Division (GRSD).

Electrical/Mechanical Safety – The operator shall heed the "Danger High Voltage" warning sign (attached directly to the WAFAC) and not touch the WAFAC to avoid possible electric shock when high voltage (-1674 V DC or -450 V DC) is applied. As the stepper motors controlling the ionization-chamber volume and position, filter-wheel position, and seed-mounting post are controlled by the computer, they could move without warning. The operator shall therefore avoid placing hands or objects near the motorized components of the system while they are turned on.

Emergency Procedures - If a source is accidentally dropped and cannot 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.

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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 appropriate raw-data analysis Excel spreadsheet (Pd103WAFACraw.xls for ^{103}Pd seeds, I125WAFACraw.xls for ^{125}I seeds, or Cs131WAFACraw.xls for ^{131}Cs seeds) prior to beginning the calibration of a source. Note that these spreadsheet template files should be saved under a different name, specific to the seeds being calibrated.

Environmental Conditions – Prior to taking any measurements, the temperature in the calibration laboratory (245/B08) is recorded. In order to proceed with the calibration, the temperature must be within the range (22 ± 3) $^{\circ}$C.

Calibration Set-up

1. If the LabVIEW program WAFAC_20.vi is not already open from the previous calibration, load it from the path c:\WAFAC2006\WAFAC_20.vi.
2. Using tongs and a leaded-plastic shield, remove the seed to be calibrated from its lead pig and place it vertically on the seed-mounting post with the aid of the seed-mounting jig.
3. Remove the shield, then measure the distance between the center of the seed-mounting post and the front face of the WAFAC aperture using the cathetometer.
4. Enter the measurement parameters (number of measurement cycles, number and duration of leakage and exposure measurements, radionuclide, filter number) in the set-up screen of WAFAC_20.vi. Note that actual the parameters used depend on knowledge of approximate source strength supplied by the manufacturer and prior experience – use laboratory notebook for previous calibrations of similar sources as a guide.
5. Turn on source rotation (1 rpm) with the program GEMINI_1rpmStart_LV7.vi, and visually verify that the seed is actually rotating.

Calibration Sequence

1. Run the program WAFAC_20.vi. Three measurement cycles shall be completed.
2. After stopping the seed rotation with the program GEMINI_1rpmStop_LV7.vi, remove the seed from the post and holding it with spring-loaded tongs, rotate it π radians about the perpendicular bisector of the seed, flipping it end-for-end.

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3. Remount the seed by placing it vertically on the seed mounting post with the aid of the seed-mounting jig, then turn on source rotation (1 rpm) with the program GEMINI_1rpmStart_LV7.vi, and visually verify that the seed is actually rotating.
4. Run the program WAFAC_20.vi. Three measurement cycles shall be completed.

<u>Analysis and Reporting of Results</u>
1. All measured data is automatically appended to the file c:\WAFAC2006\Data Files\data.txt. The file data.txt should be backed up after calibration of each set of seeds by saving a copy to a dedicated external hard drive (or equivalent device), which is in turn backed up by transfer to a computer in room 456/A105-E.
2. To analyze the results of each measurement cycle, measurement data from the file data.txt is copied into the appropriate raw-data analysis Excel spreadsheet (Pd103WAFACraw.xls for ^{103}Pd seeds, I125WAFACraw.xls for ^{125}I seeds, or Cs131WAFACraw.xls for ^{131}Cs seeds). Note that these spreadsheet template files should be saved under a different name, specific to the seeds being calibrated, and the spreadsheet for each measurement cycle should be printed out.
3. To combine the results of all six measurements on a single source, the data from the measurement cycle printouts (see # 2 above) is in-put by hand into the appropriate Excel analysis spreadsheet (Pd103WAFAC.xls for ^{103}Pd seeds, I125WAFAC.xls for ^{125}I seeds, or Cs131WAFAC.xls for ^{131}Cs seeds). Given that the poor condition of building 245 adversely affects the environmental control and electrical power, it is recommended that more than six measurement cycles be completed for each seed. If an outlier in the data is suspected, the raw data file is checked for evidence of anomalies in environmental conditions, erroneous charge readings, and incorrect electrode positions. If such an anomaly is discovered, the data for that particular measurement cycle is excluded. If no anomaly exists, then the last three measurement cycles for each orientation of the seed are used in the analysis. Note that these spreadsheet template files should be saved under a different name, specific to the seeds being calibrated, and the spreadsheet for each seed should be printed out. The spreadsheet calculates an average value of air-kerma strength for the source, including uncertainty. This value is entered into the official calibration report, an example of which is given in Appendix A. (Note that a CD containing copies of these data analysis spreadsheet template files, a copy of the WAFAC control program WAFAC_20.vi, and the ^{241}Am quality assurance measurement spreadsheet files Am241WAFACraw.xls, Am241WAFAC.xls, and Am241WAFACsum.xls are located beside the WAFAC control computer in room 245/B08, with additional backup copies stored in room 456/A105-E on the dedicated external hard drive or equivalent device specified above in 1.)
4. After review and approval, the official calibration report is mailed to the customer. The lead pigs containing the calibrated sources are packaged in a cardboard box with foam insert and shipped either back to the customer or to an Accredited Dosimetry Calibration Laboratory (as specified by the customer).

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WAFAC Quality Assurance

1. To verify constancy of the WAFAC over time, its response to an ^{241}Am source is periodically measured (approximately once every 6 months) using the above procedures. Measurement data from individual cycles in the file data.txt is copied into the raw-data analysis Excel spreadsheet Am241WAFACraw.xls, then the results from all cycles are typed by hand into the spreadsheet Am241WAFAC.xls. Note that these spreadsheet template files should be saved under a different name, specific to the date of the measurement, and the spreadsheet for each measurement cycle should be printed out. The overall measurement result is entered by keyboard into an Excel spreadsheet (Am241WAFACsum.xls) and compared to the history of such measurements to verify that there are no changes in the sensitivity of the WAFAC over time. 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 ^{241}Am source the > 1 % deviation continues to exist, the electrometer, thermometer, and barometer should be re-calibrated using the procedures given below.

2. To track the calibration results of a given seed design over time, the response of a well-ionization chamber to each WAFAC-calibrated seed is measured and a response coefficient equal to the quotient of the well-chamber current and the air-kerma strength is calculated. Variations of up to ± 2 % in the response coefficient are not uncommon due to source manufacturing variability and uncertainties in the WAFAC and well-chamber measurements themselves. Deviations greater than 2 % from the average of previous measurements should be investigated.

Calibration of Electrometer – The following procedure should be used to re-calibrate the electrometer in the case of out-of-tolerance ^{241}Am 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 factor for each coulomb scale by taking the average of all ratios of the known accumulated charge to the charge indicated by the electrometer.

<u>Calibration of Thermometer</u> - The following procedure should be used to re-calibrate the thermometer in the case of out-of-tolerance ^{241}Am source measurement results.
1. Place the Hart Model 1504 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 factor for the Hart thermometer by taking the average of all ratios of the known temperature to the temperature indicated by the Hart thermometer.

<u>Calibration of Barometer</u> - The following procedure should be used to re-calibrate the barometer in the case of out-of-tolerance ^{241}Am source measurement results.
1. Place the Setra Model Datum 2000 barometer in close proximity to a barometer that has been calibrated by the NIST Process Measurements 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 factor for the Setra barometer by taking the average of all ratios of the known pressure to the pressure indicated by the Setra barometer.

Evaluation of Measurement Uncertainties
WAFAC measurement uncertainties are determined based on the *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*[2]. The Type A component of uncertainty is equal to the standard deviation of the mean of replicate measurements. The Type B components are detailed in Appendix B. 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 ion pair formed by electrons completely slowing down in air, and g is the mean fraction of the energy of the secondary electrons that is lost to bremsstrahlung. (For the low-energy photons considered here, g is very small and set equal to zero.) Exposure is the total charge of ions of one sign per unit mass of air produced when all the electrons and positrons liberated or created by photons in air are stopped in the air (SI units of C/kg), and is directly realized by free-air chamber measurements, in this case by the WAFAC[1].

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More detailed information concerning traceability and uncertainty analyses is summarized in reference 1 and in SP250-19, available using the following hyperlinks: http://nvlpubs.nist.gov/nistpubs/jres/108/5/j85sel1.pdf
and https://dx.doi.org/10.6028/NBS.SP.250-19.

Records
Descriptions of all measurements performed are recorded in an official NIST laboratory notebook that is stored in a filing cabinet in 245/B08. Printouts of the WAFAC Excel spreadsheets that contain the results of each measurement are kept in a folder (stored in a file cabinet in room 245/B06) labeled with the source manufacturer's name, radionuclide, and month/year of calibration.

References
1. Seltzer, Stephen M., Lamperti, Paul L., Loevinger, Robert, Mitch, Michael G., Weaver, James T., and Coursey, Bert M., New National Air-Kerma-Strength Standards for ^{125}I and ^{103}Pd Brachytherapy Seeds, *J. Res. Natl. Inst. Stand. Technol.* **108**, 337-358 (2003).
2. 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 – WAFAC 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 # **47020C, 47021C**

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 11/19.

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

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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 # **47020C, 47021C**

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 ºC) 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.

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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 instrument used to obtain the results given in this report, the Wide-Angle Free-Air Chamber (WAFAC), directly realizes the quantity air kerma.

The measured air-kerma strength is obtained from:

$$S_K = (W/e)I_{net}d^2\ \Pi_i k_i/(\rho_{air}\ V_{eff})$$

where

W/e = 33.97 J/C
ρ_{air} = air density
I_{net} is the net current (background and leakage subtracted)
d is the source-to-aperture distance
V_{eff} is the effective detector volume
$\Pi_i k_i$ is the product of the correction factors to be applied to the measurement

The air-kerma strength(s) given in this report can be used to determine a well-chamber calibration coefficient for the identified source model.

Measurement Geometry: The measurements were performed with a wide-angle free-air chamber whose aperture, 8 cm in diameter, is located at a nominal distance of 30 cm from the seed axis. This arrangement thus effectively averages the air-kerma rate within a cone whose half-angle is approximately 8°. Any contribution to the measurement from titanium x rays, produced in the encapsulation, has been eliminated by the use of an appropriate absorber. To mitigate possible geometric anomalies and source non-uniformity, each seed was rotated about its long axis during a measurement, and reversed end-for-end for each successive measurement.

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 %.

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Appendix B – Relative Standard Uncertainties in the Determination of Air-Kerma Strength S_K for ^{125}I, ^{103}Pd, and ^{131}Cs Brachytherapy Seeds Using the Wide-Angle Free-Air Chamber

Estimated relative uncertainties ($k = 1$) are given in percent, and include the Type A uncertainty, s_i, estimated by statistical methods, and the Type B uncertainty, u_j, estimated by other means.

	^{125}I		^{103}Pd		^{131}Cs	
	$s_i(\%)$	$u_j(\%)$	$s_i(\%)$	$u_j(\%)$	$s_i(\%)$	$u_j(\%)$
net current, $I_{\text{net,diff}}$	s_I	0.06	s_I	0.06	s_I	0.06
W/e	-	0.15	-	0.15	-	0.15
air density, ρ_{air}	-	0.03	-	0.03	-	0.03
aperture distance, d	-	0.24	-	0.24	-	0.24
effective chamber volume, V_{eff}	0.11	0.01	0.11	0.01	0.11	0.01
decay correction, k_1	-	0.02[a]	-	0.08[a]	-	0.18[a]
recombination, k_2	-	0.05	-	0.05	-	0.05
attenuation in filter, k_3	-	0.61[b]	-	0.51	-	0.64
air attenuation in WAFAC, k_4	-	0.08[b]	-	0.10	-	0.06
source-aperture attenuation, k_5	-	0.24[b]	-	0.31	-	0.22
inverse-square correction, k_6	-	0.01	-	0.01	-	0.01
humidity, k_7	-	0.07	-	0.07	-	0.07
in-chamber photon scatter, k_8	-	0.07	-	0.07	-	0.07
source-holder scatter, k_9	-	0.05	-	0.05	-	0.05
electron loss, k_{10}	-	0.05	-	0.05	-	0.05
aperture penetration, k_{11}	-	0.02	-	0.08	-	0.03
external photon scatter, k_{12}	-	0.17	-	0.19	-	0.16
Combined standard uncertainty	$(s^2_I + 0.762^2)^{1/2}$		$(s^2_I + 0.728^2)^{1/2}$		$(s^2_I + 0.797^2)^{1/2}$	

[a] Assuming time from reference date is no more than ~15 days.

[b] Including spectral variations due to possible Ag K x rays.