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

Air Kerma 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.

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, 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.

Wide-Angle Free-Air Chamber (WAFAC) 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 (Compumotor Model S57-83-MO) 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 (Parker, Model LV232-02-FL). All the motors are controlled by a GALIL DMC-4143 motor controller. A cathetometer (Gaertner Scientific, S/N 1796A) is set up for measuring the distance between the source and entrance aperture of the ionization chamber. Detailed specifications for WAFAC hardware are found in the "NIST Irradiator Control System Operation and Maintenance Manual" located in room 245/H115. (A procedure for constructing new Mylar electrodes is kept in a red loose-leaf notebook beside the WAFAC control computer in room 245/H115.)

- High-voltage power supply (Bertan, Model 225, S/N 4207 or equivalent) to bias the ionization chamber.
- Electrometer (calibrated Keithley, Model 6517B, S/N 4584325 or equivalent) to collect and measure liberated charge.
- Thermometer (Hart, Model 1504, S/N C3A668 or equivalent) with calibrated Thermistor probe (Fluke, Model 5610, S/N RC-231030153 or equivalent) to allow correction to reference conditions (22 ^{o}C and 760 mm Hg).
- Pressure gauge (Setra, Model 370, S/N 1215084) to allow correction to reference conditions (22 ^{o}C and 760 mm Hg).
- Computer with USB and Ethernet interface for data acquisition and instrument control, LabVIEW software, and WAFAC system control program.
- Sealed ^{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 Radiation Safety Division (RSD).

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 RSD (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 RSD (x5800) to notify them of the accident. Refer to SE-0001 for the most up-to-date IRSC-approved emergency procedures.

Procedures

Acceptance of Sources

1. Calibrations must be scheduled before the sources are shipped 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 RSD (electronically submitted).
2. Sources must be shipped directly to RSD for a contamination check upon arrival. (RSD 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 file on the network drive "Elwood": L:\internal\ridshare\QUALITY-DG-Index\DG Index.xlsx 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) before 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/H115-1) is recorded. In order to proceed with the calibration, the temperature must be within the range (22 ± 3) °C.

Calibration Set-up

1. If the LabVIEW program Main_qmh_alternating save buffers_csf.vi is not already open from the previous calibration, load it from the path C:\Users\csilla\Desktop\New WAFAC VIs\WAFAC Buffer Reads\Main_qmh_alternating save buffers_csf.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 with marked end down.
3. Remove the shield, then use the cathetometer to measure the distance between the center of the seed-mounting post and the front face of the WAFAC aperture.
4. Enter the measurement parameters (number of measurement cycles, number, and duration of leakage and exposure measurements, radionuclide) in the set-up screen of Main_qmh_alternating save buffers_csf.vi. Note that the actual parameters used depend on knowledge of approximate source strength supplied by the manufacturer and prior experience – use the laboratory notebook for previous calibrations of similar sources as a guide.

5. The filter on the filter wheel will be automatically selected during the run based on the radionuclide being used. Seed rotation will automatically start upon the start of the sequence.

Calibration Sequence

1. Once the 'Start Sequence' button is pressed, the measurement cycle will begin in Main_qmh_alternating save buffers_csf.vi. The preset number of cycles will be performed (default 3).
2. Once the sequence is finished, the seed rotation will stop, and the seed can be flipped: remove the seed from the post and, holding it with the tongs, rotate it π radians about the perpendicular bisector of the seed, flipping it end-for-end marked end facing up.
3. Remount the seed by placing it vertically on the seed mounting post with the aid of the seed-mounting jig.
4. Press the 'Start Sequence'button in the program Main_qmh_alternating save buffers_csf.vi. The measurement cycles will begin again with automatic seed rotation.

Analysis and Reporting of Results

1. All measured data is automatically saved to a .csv file created right after pushing the 'Start Sequence' button. This raw data file should be named "date_manufacurer_isotope_seedID.csv" and saved into the WAFAC folder of the calibration directory on OneDrive. All calibration data will be backed up after calibration on the network drive "Elwood": L:\internal\846.02\BrachySeeds_&_Beta\Brachy.
2. To analyze the results of each measurement cycle, measurement data from the saved .csv file 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), each measurement in a different tab. 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 tabs (see # 2 above) is copied over into the appropriate Excel analysis summary spreadsheet (Pd103WAFAC.xls for ^{103}Pd seeds, I125WAFAC.xls for ^{125}I seeds, or Cs131WAFAC.xls for ^{131}Cs seeds). Given that the WAFAC is very sensitive to changes in the environment (temperature and humidity changes, vibration), 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, and the buffer read files can be searched 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 copies of these data analysis spreadsheet template files, a copy of the WAFAC control program, and the ^{241}Am quality assurance measurement spreadsheet files Am241WAFACraw.xls, Am241WAFAC.xls, and Am241WAFACsum.xls are saved in the backup directory on One Drive and on Elwood.)

4. After review and approval, the official calibration report or an electronic equivalent is sent to the customer by email or by mail if requested by the customer. An electronic version of the final report is uploaded to the E-commerce ordering system. The lead pigs containing the calibrated sources are packaged in a cardboard box with a foam insert and shipped either back to the customer or to an Accredited Dosimetry Calibration Laboratory (as specified by the customer).

<u>WAFAC Quality Assurance</u>

1. To verify the 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 saved .csv file is copied into the raw-data analysis Excel spreadsheet Am241WAFACraw.xls, and then the results from all cycles are copied into the spreadsheet Am241WAFAC.xls. Note that these spreadsheet template files should be saved under a different name specific to the measurement date, and the spreadsheet for each measurement cycle should be printed out. The overall measurement result is entered 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 common 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 a NIST-traceable calibration 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.

Calibration of Thermometer - 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 with a NIST-traceable calibration in an insulated box (cardboard/extruded polystyrene foam).
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.

Calibration of Barometer - 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 370 barometer in close proximity to a barometer with a NIST-traceable calibration.
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]. 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 stored in a filing cabinet in 245/H115. 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/H115) 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 – Sample Calibration Report

Components according to section 7.8.2.1 of the NIST Quality Manual (NIST-QM-1) are marked with red letters in parentheses.

National Institute of Standards and Technology

REPORT OF AIR-KERMA STRENGTH MEASUREMENT(a)

FOR

Customer Name
Address
City, State, Country(f)

Seed Identification: **Model XXX** **(h, m)**
Arrival Date: **XX Month 20XX** **(i)**
SP250 Service ID # **47020C, 47021C(d)**

Measurements performed by Csilla Szabo-Foster **(p)**

Report reviewed by Ronaldo Minniti

Report approved by Michael G. Mitch, Leader
Dosimetry Group

By
Alan K. Thompson
Chief of the Radiation Physics Division
Physical Measurement Laboratory **(c)**
For the Director of the National Institute of Standards and Technology

Information on technical aspects of this report may be obtained from Csilla Szabo-Foster, NIST, 100 Bureau Drive, Stop 8460, Gaithersburg, MD 20899 **(c)** csilla.szabo-foster@nist.gov or 301-975-4334.

Report format revised 01/25

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY U.S. DEPARTMENT OF COMMERCE **(b)**

DG: XXXXX/XX
Order #: 682.02/O-XXXXXX-XX
Report Date: XX Month 20XX(l)
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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 **(k)**
Temperature range during measurements: XX K to XX K
Pressure range during measurements: XXX kPa to XXX kPa **(j)**

Measurement Results**(n)**

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.

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY U.S. DEPARTMENT OF COMMERCE

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Explanation of Terms Used in the Calibration Procedures and Tables

Air-Kerma Strength: (g, q) 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. **(m, o)**

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 %.

Change of NIST WAFAC Standard

January 1, 2025

The National Institute of Standards and Technology (NIST) has revised its air-kerma-strength standard for ^{103}Pd, ^{125}I, and ^{131}Cs brachytherapy seeds as of January 1, 2025. The changes are due to the implementation of ICRU Report 90 recommendations for free-air chamber correction factors [1].

The changes to the correction factors resulted from the introduction in ICRU Report 90 of two new and related correction factors, $k_{ii}k_W$, as a function of photon energy. The k_W results from the W_{air}. The factor k_{ii} is related to E_e/W_{air}. The values of $k_{ii}k_W$ for each radionuclide are 0.9976 for ^{103}Pd, 0.9980 for ^{125}I, and 0.9981 for ^{131}Cs, each with a standard uncertainty of 0.12 % [2]. The air-kerma strengths have been adjusted due to the implementation of the new correction factors for all reports of air-kerma strength issued after January 1, 2025. Along with this change in corrections, the standard uncertainty of W_{air} has increased from 0.15 % to 0.35 %.

References

[1] ICRU 2016 *ICRU Report No. 90: Key Data for ionizing-radiation dosimetry: measurement standards and applications* vol 14.
[2] David Burns and Cecilia Kessler 2018 *Metrologia* **55** R21.

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, $I_{net,diff}$	s_I	0.06	s_I	0.06	s_I	0.06
W/e	-	0.35	-	0.35	-	0.35
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]	-	0.1	-	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
initial ion·mean energy per ion pair k_{ii} k_W	-	0.12	-	0.12	-	0.12
Combined standard uncertainty	$(s_I^2 + 0.833^2)^{1/2}$		$(s_I^2 + 0.802^2)^{1/2}$		$(s_I^2 + 0.866^2)^{1/2}$	

a) Assuming the time from the reference date is no more than ~15 days.
b) Including spectral variations due to possible Ag K x rays.