ABSORBED-DOSE -TO-WATER CALIBRATIONS FOR IONIZATION CHAMBERS

Purpose

The purpose of this document is to describe the setup, measurement, and reporting procedures for absorbed-dose-to-water calibrations.

Scope

The measurement service described in this document is listed as NIST service code 46110C. The procedure covers the absorbed-dose-to-water calibration of ionization chambers in a ^{60}Co beam[1] that is traceable to the NIST water calorimeter[2]. All chambers must be waterproof or able to be made waterproof as measurements are made with chambers submersed in a water phantom. Appendix D of this document also includes a description of the associated absorbed dose to water proficiency test (from gamma-ray beams) listed as NIST service 46050S.

Definition

Absorbed dose to water is defined as the energy from ionizing radiation absorbed by a given mass of water, 1 J/kg = 1 Gy.

Equipment

- Computer equipped with an absorbed dose to water calibration program based on the LabVIEW programming language that allows automating the data acquisition process
- Electrometer for the measurement of the ionization current and electrical charge collection
- Temperature probes for continuous temperature monitoring of both the air in the vicinity of the chamber and the water in the phantom
- Pressure transducer
- Co-60 irradiator source that has been calibrated in terms of absorbed dose to water using the NIST primary standard instruments
- Water phantom with chamber mounting apparatus
- An aluminum meter scale with 1 mm precision
- An in-house secondary standard ionization chamber

The computer is interfaced to all devices used for calibration including an electrometer, thermometer and pressure transducer. The temperature probes, pressure transducers and electrometers are auxiliary equipment used for the calibration service. The temperature probes are calibrated against a reference standard thermometer. The pressure transducers are calibrated against a reference standard barometer. The electrometers are calibrated against reference class air capacitors. The calibration of the reference standards are provided by the NIST Measurement Services Division. A NIST check chamber is used to decide if this auxiliary equipment needs to be checked against reference standards calibrated by the Process and Measurements Division.

Reference Scale

A metallic scale is used to measure the distance between the source and the detector.

Other Equipment

Other equipment used during a typical calibration include a telemicroscope and a chamber clamping mount on a 2D translational stage for positioning the chamber at a fixed distance from the source and centered with the beam centerline. Also, a laser is used for positioning the detectors along the beam-centerline.

Support Equipment

The thermometers, barometers and electrometers referred to in this section are considered essential support equipment to the calibration of cavity ionization chambers. A list of all the thermometers, barometers and electrometers is maintained in an excel sheet that can be accessed by the facility computer from L:\internal\846.02\Gamma-Chamber-Cal. The Excel sheet includes: the identity of the item (and its software when applicable), manufacturer name, model number, serial number and use location. It also includes the calibration of all thermometers and barometers used in the facilities against the Dosimetry Group reference standard Thermometer and Barometer.

It is important to note the quality of the ionization chamber calibration is not monitored by the calibration of the support equipment but rather by the routine quality assurance check performed using the NIST reference standard chambers (aka NIST check chambers or NIST QA chambers) as discussed in the sections ahead. The quality check of the calibration of all customer ionization chambers is determined by the reproducibility of the calibration coefficients of the NIST check chamber. Therefore, if a calibration coefficient of the NIST check chamber does not reproduce, the performance and calibration of the support equipment would be investigated. There are no specified calibration intervals for the critical support equipment because the equipment is calibrated using the in-house reference standards if there is a question of reproducibility of the NIST check chamber. Since the QA procedure for all gamma-ray calibrations requires the calibration of a NIST reference standard ionization chamber, any change in the reproducibility above 0.5 % to 1 % of a typical chamber response depending on the chamber type and history, may require an investigation into the support equipment used for the calibration. If any of the critical support equipment is found to be out of calibration or damaged, it would be disconnected, and its condition clearly marked on the instrument. A calibrated, identical model replacement instrument would be used for calibrations to continue.

Safety

Radiation safety

Rooms containing ^{60}Co sources commonly used for absorbed-dose-to-water calibrations have been designated as High Radiation Areas and therefore are interlocked with the source opening shutter control. Specific requirements for entry and exit from the rooms are contained in these procedures and are posted on entry doors and walls. Radiation safety training and assessment services are provided by the NIST Gaithersburg Radiation Safety Division (GRSD).

Electrical safety

To avoid possible electrical shock, one must not touch any chamber or connector once voltage has been applied to the chamber. Certain chambers (for example, the Exradin A12) can carry the voltage on the outside of the chamber. When these chambers are submerged in the water tank, the water and any metal part coming in contact with the water become a potential shock hazard. To ensure safety during operation, the high voltage must be turned off before making a height adjustment.

Procedures

Communication with the Customer

Customers can request calibration services in a variety of ways. Typically, a new or first-time customer will establish contact with the Dosimetry Group by telephone and/or e-mail requesting information regarding techniques offered, charges, backlog time, turnaround time, and shipping/mailing information. At this stage, there is generally an opportunity to discuss with the prospective customer appropriate technical and/or logistics aspects of the calibration. Technical aspects may include discussions on the beam qualities, dose rates, conditions under which the instruments are used, etc… Logistics aspects may include discussions about how to submit purchase orders through the NIST storefront, how to ship instruments to NIST, any accessories that the customer may need to include in the shipment depending on the type of instrument being calibrated, etc… The customer is informed that a purchase order must be received at NIST before an official calibration is performed. The customer is instructed to make use of the NIST storefront which can be found on the NIST calibration service webpage. Through the storefront the customer will shop for the desired calibration service and will also be able to upload all necessary documentation which includes a type of payment such as a purchase order. The purchase order should include a detailed description of the calibration request, including instrument model and serial numbers, and the name and telephone number of a technical contact. If an incomplete purchase order is received, every effort is made to get a detailed description of the service requested.

Initiation of Paperwork and Inspection of Instruments sent to NIST for Calibration

Once an order for a calibration service is placed on the NIST storefront and both a purchase order has been submitted and the instruments have been received at NIST, every effort is made to start the calibration process as soon as possible. This process consists of two stages:

- Handling of the administrative portion of the calibration
- Handling of the instruments and their calibration.

Regarding the administrative portion of the calibration, after an order is received at NIST through the NIST storefront, a NIST order number consisting of 10 digits is generated with the following format: O-0000000000. The NIST technical contact (person performing the calibration) is then notified by email. The technical contact is able to review the order placed through the NIST calibration e-commerce platform called Salesforce. Information submitted by the customer through Salesforce includes the model and serial number of the instruments to be calibrated and the purchase order from the customer. Once this information is reviewed by the technical contact, if any information is missing from the customer, every effort is made to get the information needed by contacting the customer. All documentation associated with the calibration is stored under the NIST order number assigned to the calibration being requested. This includes the summary sheet on Salesforce, a copy of the purchase order submitted by the customer, the shipping document, copies of the calibration reports and all calibration data and corresponding data analysis sheets. A unique identifier named the Dosimetry Group (DG) number is used to identify the services for a given instrument received. This identifier is used by several members of the Dosimetry Group, and it consists of a 5-digit number followed by the fiscal year as DGN: 00000-00. Both the NIST order number and the DG number are included on the cover of the calibration report.

Regarding the handling of the instruments, instruments arriving for calibration are unpacked and inspected for damage. Special attention is given to the condition and type of connector. If an adapter is sent with the chamber, this should be noted on the inventory list along with the description of the chamber. Shipping damage is reported to the NIST shipping department. When an instrument arrives in a state of disrepair that is obvious by visual inspection, the customer is notified, and a decision is made whether to return the instrument to the customer, or if the repair is minor, have NIST personnel perform the repair.

Only ionization chambers known to be stable and reproducible are accepted for calibration in this program. Institutions submitting ionization chambers for calibration are strongly urged to perform stability checks involving redundant measurements in highly reproducible radiation fields before sending their instruments to NIST, and to repeat those checks after NIST calibration, and again at suitable intervals. Instruments submitted for calibration, and material submitted for irradiation, must be shipped in reusable containers.

Detector Setup and calibration

The instruments to be calibrated using gamma-ray beams are calibrated by using a previously determined value of the absorbed dose to water rate obtained by the decay of the initial value to the date and time of the calibration being made. The value of the absorbed dose to water rate for a given distance from the source at a given date and time is displayed by the data-acquisition program.

For all customer calibrations, a NIST reference-class transfer ionization chamber is calibrated for quality assurance. Generally, the NIST chamber selected is similar in design or collection volume to the customer chamber being calibrated and has a previous calibration history in the reference radiation qualities which were selected by the customer.

Follow the procedures for the setup and calibration sections below for one of the NIST reference-class transfer ionization chambers and then again for the customer chamber.

Setup

1. Set the water phantom on the moveable cart of the ^{60}Co platform and fill approximately 2/3 full of water. Allow water to come to temperature equilibrium, which is usually 1.0 ^{o}C to 1.5 ^{o}C lower than room temperature. This can take up to 24 hours.

2. Turn on the source control panel. Set the timer to 99999 and press the initialize button.

3. Enter name, date, and other pertinent information in the appropriate source logbook. Test lights and interlocks during this time using manual source controls.

4. Turn on the computer and click on the "absorbed dose calibration" icon to launch the LabVIEW program (see Appendix C for the entries to the program).

5. The following environmental conditions should be present when performing calibrations. The temperature of the room should be stable within one single measurement and ideally around 22 ^{o}C. If the temperature is not stable during a single measurement, calibrations should be postponed. Also, the temperature should not exceed 25 ^{o}C and should not be lower than 19 ^{o}C. If the temperature falls out of this range, the calibration should be postponed until the temperature is back within the working range. The preferred

humidity conditions are between 20 % and 50 % RH, but calibrations still can be performed if humidity levels fall out of this range. It is preferable to calibrate instruments on days that the pressure is around 101.3 kPa (760 mm Hg), but calibrations can still be performed if the atmospheric pressure deviates from this value. Calibrations should be postponed, however, if the pressure is not stable during a single measurement.

Calibration

1. Ensure that the chambers to be calibrated are properly waterproofed. When applicable, ensure that air vents extend beyond the phantom to prevent water from entering the chamber.

2. Thread the waterproof temperature probe from the bottom of the mounting apparatus through the hole in the horizontal mounting bracket where the chamber is to sit, then lay it along the groove.

3. Mount the chamber onto the bracket in such a way that allows the temperature probe to lie along the underside of the chamber. Lower the chamber (by rotating the height adjustment dial) into the water to approximately the desired depth, or at least to a depth such that the entire mounting block is under the water. Connect the signal and high voltage cables to the chamber.

4. On the ^{60}Co housing, find the two dials each controlling a pair of collimator jaws, east/west and north/south, respectively. Locate the plumb bob attached to a 50.8 mm x 50.8 mm aluminum block. Insert the block into the source collimator opening. This will define the beam center line. Translate the water phantom so that the front face of the phantom (south side) touches the beam center line. This procedure places the front water surface at the focal plane of the telemicroscope.

5. Fully open both pairs of jaws, then close each of them to 10.75 on the dial. Confirm that the jaws close tightly against the jig made for this dial setting. Do not touch the trimmer adjustment knobs.

6. Allow the water to settle such that the surface is stable. Adjust the telemicroscope such that the horizontal crosshair centers on the bottom most line of the water surface. Due to surface tension and optical effects, there are multiple lines visible in the scope. Always align with the line that is closest to the bottom. Once the telemicroscope is aligned to the water surface, push the phantom away from the beam center line.

7. Insert the meter scale onto the holders under the source opening such that it is suspended under the source. Adjust the height of the entire platform using the wall mount control unit so that the horizontal crosshair of the telemicroscope

centers on the 53.8 cm mark of the meter scale. In the weaker intensity vertical beam this position corresponds to a distance of 95 cm from the source. Turn off the wall mount control unit. This is important to do to prevent possible drifts in the motion of the platform while the unit remains on. Lower the telemicroscope by 5.00 cm from the 53.8 cm position to 58.8 cm as seen on the scale. At this scale position, the telemicroscope provides a reference distance of 100 cm from the source. Remove the scale.

8. Slide the phantom back under the source, this time using the laser to align the chamber in the center of the beam. Adjust the height of the chamber so that its center aligns with the horizontal crosshair of the telemicroscope.

9. Activate the interlock and exit the room following the Safety Procedure for the Vertical Beam Facility (a copy of the procedure is kept inside the source logbook).

10. Apply voltage at the polarity and maximum allowable value as specified by the customer. Allow time for the chamber to "warm up" – this can take up to one hour, depending on the chamber. A periodic check measurement can determine if the current has stabilized. Perform pre irradiations of the chamber by opening the shutter at this time if necessary.

11. Complete the calibration following the prompts on the computer program (see Appendix C for the program main panel).

12. Adjust the high voltage on the chamber to half of its initial value. Allow at least 15 minutes before repeating the calibration.

13. Turn off the high voltage to the chamber. Remove the chamber from the water. Compare calibration results to the chamber history if available.

Analysis and Report

The average current, in units of A, or C/s, measured in the above procedures is normalized to reference environmental conditions (22 °C and 101.3 kPa). The decay corrected absorbed dose rate (traceable to the NIST primary standard), in the unit of Gy/s, is divided by the average current (normalized to the reference environmental conditions) to obtain a calibration coefficient in the units of Gy/C. This is the value reported to the customer. The ratio of current at full voltage to that at half voltage is also reported. See Appendix B for a report template.

Quality Control

A minimum of 5 total measurements should be made for each calibration point. The standard deviation within these 5 or more measurements is expected to be no greater than 0.5 % for the NIST reference-class chambers. If it is greater, the cause of the value being larger needs to be understood. For example, in some cases this could be caused by the chamber needing more time to equilibrate thermally. In other cases, it could be that an additional pre-irradiation time is required.

Results for customer chambers with histories should agree to within 2 % of any previous calibration. If this criterion is not met, check for trends in the data. It may also be advisable to contact the customer to see if they have noticed any unusual behavior with the chamber.

For all NIST reference-class chambers, a record is maintained of all calibrations, calibration results, calibration dates, and the previous calibrations are compared with the current calibration to detect any trend or measurement discrepancy. The calibration history and record for all NIST reference chambers can be accessed by the facility computer from L:\internal\846.02\Gamma-Chamber-Cal.

Uncertainty Analysis

The uncertainty analysis of the absorbed-dose-to-water calibration of ion chambers is outlined in the NIST Special Publication 250-74[1]. In brief, the various sources of uncertainty of the calibration outlined in the NIST SP250-74 reference are:

1. The determination of the reference absorbed-dose-to-water rate[2]

2. Co-60 decay constant

3. Charge variability – this value is obtained from the standard deviation of replicate measurements incorporating several reference class ionization chambers (for working standards this value will be higher)

4. Correction due to recombination loss

5. Time – shutter control reproducibility, a Type B uncertainty

6. Air density – the Type A portion of the uncertainty is determined from the standard deviation of replicate measurements. The manufacturers of the temperature probe and the pressure gauge provide the Type B uncertainty

7. Humidity – no correction is made for the effect of water vapor on the instrument being calibrated. It is assumed that both the calibration and the use of that instrument take place in air with a relative humidity between 10 % and 70 %, where the humidity correction is nearly constant

8. Variation in response due to positioning uncertainty at 5 cm depth in water, 0.05 %

9. Variation in response due to positioning uncertainty at 1 m from the source, 0.02 %

Documentation/Calibration Reports/Storage

After the instrument has been calibrated the calibration report is electronically generated. Currently, the reports are generated in the most recent version of Microsoft Word. Templates are available to simplify this procedure and to ensure consistency in the reporting format. A sample report can be found in Appendix B of this report. *All results reported relate only to the instruments or items tested and/or calibrated during the calibration as indicated in the calibration certificate (this statement is also included in the calibration report).*

All reports of Calibration and reports of Special Test are signed by personnel explicitly authorized to do so. The review and signing process can be summarized as follows: the calibration report is reviewed and initialed by the preparer and then sent electronically for review to a Dosimetry Group calibration staff member. This first reviewer may or may not find any issues with the report. In the case any issues are found, they are discussed with the person conducting the calibration to clarify and resolve the issue prior to the reviewer's approval. Once any potential issues are resolved the reviewer approves the final report and it is sent electronically to the remaining reviewers which are the Group Leader and Division Chief. Once all reviewers have approved and initialed/signed the report, the report is sent by the technical contact to the customer electronically. If the report is completed prior to the instruments being shipped, a hard copy of the report is also included in the box with the instruments.

After all requested calibration work is completed, the technical contact informs the accounting office that the calibration work has been completed and that the instruments need to be returned to the customer. The instruments are packed either in the original container or in a more suitable one if necessary. A shipping document is available on Salesforce which is printed and attached to the box of instruments for shipping. After shipment, all documents associated with the calibration are kept in the facility computer and a backup is kept in L:\internal\846.02\Gamma-Chamber-Cal. The calibration is identified by the NIST order number, and each instrument sent for calibration is identified by the DG number described previously.

Traceability

The SI unit of absorbed dose is the gray (Gy), which is defined as the energy from ionizing radiation absorbed by a given mass of water; 1 J/kg = 1 Gy, directly determined by the NIST water calorimeter in a ^{60}Co beam. More detailed information concerning traceability and uncertainty analyses is summarized in references 1 and 2.

International Comparisons

International comparisons have been made with other National Metrology Institutes around the world. During these international comparisons, a reference class chamber is calibrated at both facilities and the values of the calibration coefficients obtained at both institutions are compared. The reference section lists comparisons made in the last few years using the same ^{60}Co gamma-ray beam that is used for the calibration service described in this procedure.

Filing and Retention

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

References

1. Minniti R., Shobe J. Seltzer S. M., Chen-Mayer H. and Domen, S.R., Absorbed Dose to Water Calibration of Ionization Chambers in a ^{60}Co Gamma-Ray Beam, NIST Special Publication 250-74, September 2006.

2. Domen, S.R., A sealed water calorimeter for measuring absorbed dose, J. Res. Natl. Inst. Stand. Technol., 99, pp. 121 – 141, 1994.

3. P. J. Allisy-Roberts and J. Shobe, “Comparison of the standards of absorbed dose to water of the NIST and the BIPM for ^{60}Co gamma rays,” Rapport BIPM 98/5 (1998).

4. I. Csete, AG. Leiton, V. Sochor, A. Lapenas, J.-E Grindborg , I. Jokelainen, H. Bjerke, J. Dobrovodsky, A. Megzifene, H. J. Costas, R. Ivanov, B. Vekic, J. , Kokocinski, J. Cardoso, L.Buermann, W. Tiefenboeck , G. Stucki, E. van Dijk, M. P. Toni, R. Minniti, J. P. McCaffrey, C. N. M. Silva, I. Kharitonov, D Webb, M. Saravi, F. Delaunay, “Comparison of air kerma and absorbed dose to water measurements of ^{60}Co radiation beams for radiotherapy, Report on EUROMET project no. 813, identifiers in the BIPM key comparison database (KCDB) are EUROMET.RI(I)-K1 and EUROMET.RI(I)-K4,” Metrologia Vol. 47, Tech. Suppl 06012, April 2010.

Appendix A

Sample Uncertainty Analysis

	Type A (%)	Type B (%)
Absorbed dose rate at 5 cm in water[1]	0.16	0.39
Charge	0.10	0.10
Time		0.05
Air density		0.03
Positioning at 5 cm depth in water		0.03
Positioning at 1 m source distance		0.05
Measurement reproducibility		0.05
Recombination	0.01	0.05
Humidity		0.06
^{60}Co decay constant[5]		0.05
quadratic summation	0.19	0.43

Relative combined standard uncertainty 0.47

Relative expanded uncertainty, k = 2 0.94

Appendix B

Sample Calibration Report

National Institute of Standards and Technology

REPORT OF ABSORBED-DOSE-TO-WATER CALIBRATION

FOR

Detector Technologies Inc
100 Technology Road
Gaithersburg, MD 20899

Radiation Detection Chamber: PTW Model N23333, SN 1890

Calibrations performed by Ronaldo Minniti

Report reviewed by Michelle O'Brien

Report reviewed by [name of Fellow Scientist]

Report approved by Michael G. Mitch, Leader
Dosimetry Group

James M. Adams
Chief of the Radiation Physics Division
Physical Measurement Laboratory
For the Director of the National Institute of Standards and Technology

Information on technical aspects of this report may be obtained from Ronaldo Minniti, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460, Gaithersburg, MD 20899, (301)975-5586, ronnie.minniti@nist.gov.

Report format revised: September 1, 2021

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

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REPORT OF ABSORBED-DOSE-TO-WATER CALIBRATION

FOR

Detector Technologies Inc
100 Technology Road
Gaithersburg, MD 20899

Radiation Detection Chamber: PTW Model N23333, SN 1890

Chamber orientation: The cavity was positioned in the center of the beam with the stem of the chamber perpendicular to the beam direction.
Chamber collection potential: A potential difference of 300 volts was applied to the chamber (negative charge collected).
Chamber rotation: The reference mark on the chamber stem faced the source of radiation.
Environmental conditions: The chamber is assumed to be open to the atmosphere. The measurements are normalized to a temperature of 295.15 K (22 °C) and a pressure of one standard atmosphere (101.325 kPa) as described in the *Explanation of Terms* section of this report. The average measured values of temperature and pressure during calibration were 295.5 K and 99.9 kPa.
Waterproofing: The chamber is not waterproof. A latex sleeve was used to waterproof the chamber.
Depth in water: 5 cm
Average background current: 0.01 % of the collector current
Field size: 15.4 cm x 15.4 cm
Calibration dates: April 12, 2017
Current ratio at full to half collection potential: 1.000 for an absorbed dose to water rate of 8.39×10^{-4} Gy/s. A detailed study of the ion recombination was not performed and no correction was applied to the calibration coefficient(s). If the chamber is used to measure an air kerma rate significantly different from that used for the calibration, it may be necessary to correct for recombination loss.

Beam Code	Half Value Layer (mm Cu)	Calibration Coefficient (Gy/C) 295.15 K (22 °C) and 101.325 kPa (1 Atm)	Absorbed Dose To Water Rate (Gy/s)	Calibration Distance (cm)
^{60}Co	14.9	5.295×10^{7}	8.39×10^{-4}	100

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Explanation of Terms Used in the Calibration Procedures and Tables

Absorbed-Dose-to-Water: The absorbed-dose-to-water rate at the NIST is realized at the calibration position by a water calorimeter. This realization of the radiation quantity of absorbed dose to water establishes the National standard, which can be transferred to other measurement facilities through a suitable measuring instrument, thus enabling traceability to the National standard. The ^{60}Co gamma-ray rate at NIST is corrected to the date of calibration (from the previously measured value) by a decay correction based on a half-life of 5.27 years.

Absorbed-Dose-to-Water Calibration Coefficient, N_{Dw}: The transfer of the National standard of absorbed dose to water to a measurement facility through a suitable measuring instrument is accomplished by calibration of such instrument in the NIST standard radiation beams. As a result of the calibration, a calibration coefficient is obtained and forms part of the reported result. The absorbed-dose-to-water calibration coefficients, $N_{D,w}$, given in this report are quotients of the absorbed-dose-to-water and the charge generated by the radiation in the ionization chamber under test. The average charge used to compute the calibration coefficient is based on measurements with the wall of the ionization chamber at the stated polarity and potential. With the assumption that the chamber is open to the atmosphere, the measurements are normalized to a pressure of one standard atmosphere (101.325 kPa) and a temperature of 295.15 K (22 °C). Use of the chamber at other pressures and temperatures requires normalization of the ion currents to these reference conditions using the normalizing factor F (see below). The absorbed-dose-to-water calibration coefficient provided in this report can be used to determine absorbed-dose-to-water rate values at the customer's facility by multiplying it with the ionization current generated in the cavity volume when exposed to a radiation field in which the measurement conditions approximate those used at NIST as part of the ionization chamber's calibration.

Normalizing Factor F: The normalizing factor F is computed from the following expression: $F=(273.15+T)/(295.15H)$ where T is the temperature in degrees Celsius, and H is the pressure expressed as a fraction of a standard atmosphere (1 standard atmosphere = 101.325 kilopascals = 1013.25 millibars = 760 millimeters of mercury).

Waterproofing Sleeve: For the case of non-waterproof chambers, NIST uses a commercially available waterproofing sleeve made of 1 mm PMMA over the collecting volume of the chamber. A latex sleeve is attached to the back of the PMMA sleeve to ensure no water seepage to the chamber. Two o-rings are installed around the latex sleeve to ensure a waterproof setup.

Calibration Distance: The calibration distance is that between the radiation source and the detector center or the reference line. For thin-window chambers with no reference line, the window surface is the plane of reference. The beam size at the stated distance is appropriate for the chamber dimensions.

Beam Size: The collimator defines a square field of 15.4 cm x 15.4 cm (50 % intensity line), perpendicular to the centerline of the calibration beam.

Half-Value Layer: The value of the ^{60}Co half-value layer (HVL) is 14.9 mm of copper which has been determined from calculations.

Uncertainty: The expanded, combined uncertainties of the NIST reference absorbed-dose-to-water rate and the absorbed dose to water calibration described in this report are 0.8 % and 1.0 % respectively. The expanded, combined uncertainty is formed by taking two times the square root of the sum of the squares of the standard deviations of the mean for component uncertainties obtained from replicate determinations, and assumed approximations of standard deviations for all other uncertainty components; it is considered to have the approximate significance of a 95 % confidence limit. Examples of uncertainty analyses are given in the references below.

Measurement Results: The results relate only to the instrument calibrated and/or tested in this report.

References

Minniti R., Shobe J., Seltzer S. M., Chen-Mayer H. and Domen S. R., "Absorbed Dose to Water Calibration of Ionization Chambers in a ^{60}Co Gamma-Ray Beam," NIST Special Publication 250-74 (2007); http://www.nist.gov/calibrations/upload/sp250-74.pdf

Minniti, R., Chen-Mayer, H., Seltzer, S.M., Saiful-Huq, M., Dewerd, L., Micka, J., Bryson, L., Slowey, T., Hanson, W., Wells, N., "The US radiation dosimetry standards for ^{60}Co therapy level beams, and the transfer to the AAPM accredited dosimetry calibration laboratories". Med. Phys. 33 (4), 1074-1077 (2006).

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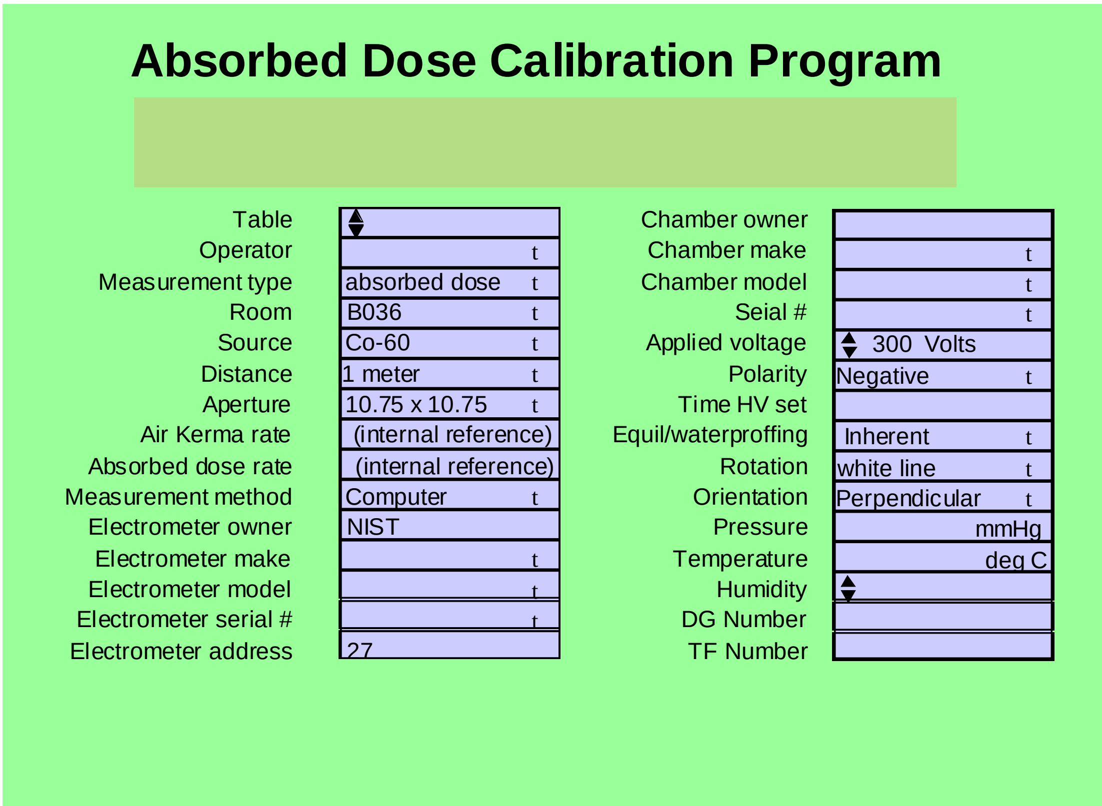
Appendix C

Calibration Program Control Panel



Notes:

- A field with ▲▼ on the left is a "counter" which accepts either manual input or incremental input from the counter.
- A field with "t" on the right is a "pull down" menu containing pre-entered values for selection.
- The two internal reference fields, upon program execution, will automatically provide for the user the decay corrected air kerma rate (irrelevant to this calibration procedure) and absorbed dose rate used in the calibration.
- Other fields accept manual input.

APPENDIX D: Service 46050S, Proficiency Test for absorbed dose to water

General

The proficiency test for this measurement service complies with the NIST QMS ISO/IEC 17025:2017 Appendix F for proficiency testing. This sub-level quality document provides the details of the additional requirements of ISO 17043:2010 for this measurement service proficiency test program.

Design of proficiency testing schemes

The protocol for each proficiency test will include the following details, taken from QMI, Appendix F, but repeated here for thoroughness. Each participant will receive a personalized proficiency test protocol. A sample protocol is provided in this procedure with the required elements listed below

a) the name and location of the NIST ***measurement service***;
b) identification of the ***proficiency testing*** program manager and other personnel involved in the design and operation of the ***proficiency testing*** scheme;
c) the activities to be conducted by NIST ***collaborators*** and the names and addresses of NIST ***collaborators*** involved in the operation of the ***proficiency testing*** scheme; collaborations do not exist for this proficiency test.
d) criteria to be met for participation if applicable;
e) the number and type of expected ***participants*** in the ***proficiency testing*** scheme;
f) selection of the measurand(s) or characteristic(s) of interest, including information on what the participants are to identify, measure, or test for in the specific ***proficiency testing round***;
g) a description of the range of values or characteristics, or both, to be expected for the ***proficiency test items***;
h) the potential major sources of errors involved in the area of ***proficiency testing*** offered;
i) requirements for the production, quality control, storage and distribution of ***proficiency test items***;
j) reasonable precautions to prevent collusion between ***participants*** or falsification of results, and procedures to be employed if collusion or falsification of results is suspected;
k) a description of the information which is to be supplied to ***participants*** and the time schedule for the various phases of the ***proficiency testing*** scheme;
l) for continuous ***proficiency testing*** schemes, the frequency or dates upon which proficiency test items are to be distributed to ***participants***, the deadlines for the return of results by ***participants*** and, where appropriate, the dates on which testing or measurement is to be carried out by ***participants***;
m) any information on methods or procedures which ***participants*** need to use to prepare the test material and perform the tests or measurements;
n) procedures for the test or measurement methods to be used for the homogeneity and stability testing of proficiency test items and, where applicable, to determine their biological viability;
o) preparation of any standardized reporting formats to be used by ***participants***;
p) a detailed description of the statistical analysis to be used;
q) the origin, ***metrological traceability*** and ***measurement uncertainty*** of any ***assigned values***;
r) criteria for the evaluation of performance of ***participants***;
s) a description of the data, interim reports or information to be returned to ***participants***;
t) a description of the extent to which ***participant*** results, and the conclusions that will be based on the outcome of the ***proficiency testing*** scheme, are to be made public; and
u) actions to be taken in the case of lost or damaged ***proficiency test items***.

Preparation of proficiency test items

The NIST proficiency test chamber must meet the stated stability specifications of the manufacturer. The NIST reference class transfer ionization chambers have been determined appropriate for use through published comparison studies and history of use. The NIST ***proficiency testing*** program calibrates each using the calibration procedure associated with this service. The NIST ***proficiency testing*** program uses the same acquisition and storage procedures as the calibration service. The chambers procured for the proficiency testing quality assurance are dedicated to that purpose. The NIST ***proficiency testing*** program uses the same type chambers as are used for the calibration service. NIST will ship the chamber in a reusable shipping container which should be used for the return of the chamber to NIST.

Homogeneity and stability

The performance of the NIST testing chamber is evaluated at NIST according to the calibration procedure. The collected charge from the testing chamber is statistically analyzed in the same manner as stated in the calibration procedure. If the chamber completes the procedure at NIST with acceptable stability and is found to become unstable at the participant's facility, NIST should be notified and the chamber should be excluded from the measurement comparison and a replacement chamber will be provided. NIST calibrates the ionization chamber once it is returned. If the proficiency test involves multiple participants, the testing is a star shaped design which means NIST recalibrates the chamber after it is used at each facility. This allows NIST to monitor the stability of the chamber throughout the comparison.

Statistical design

The same statistical design is used for the proficiency test data as is used for the calibration service. Each chamber is measured at least three times and the average is used. The NIST value will be the average of the results before and after the chamber was sent to the customer. The standard deviation on the charge measurement is used in the uncertainty analysis. The proficiency test is a direct comparison of the measured calibration coefficients determined at NIST and the participating facility. The criteria for the comparison are established by the accreditation program, not by NIST. NIST does not provide the normalized error nor the Z-score.

Assigned values

The calibration coefficient determined through the proficiency test process is clearly explained in the calibration service and the proficiency test report and repeated here for convenience: The absorbed-dose-to-water rate at the NIST is realized at the calibration position by a water calorimeter. This realization of the radiation quantity of absorbed dose to water establishes the National standard, which can be transferred to other measurement facilities through a suitable measuring instrument, thus enabling traceability to the National standard. The ^{60}Co gamma-ray rate at NIST is corrected to the date of calibration (from the previously measured value) by a decay correction based on a half-life of 5.27 years. The absorbed-dose-to-water calibration coefficients, $N_{D,w}$, are quotients of the absorbed-dose-to-water and the charge generated by the radiation in the ionization chamber. The average charge is based on measurements with the wall of the ionization chamber at the stated polarity and potential.

Choice of method or procedure

The participant must have a linking traceable measurement of air-kerma in order to participate in a proficiency test. The participant agrees to use the NIST chamber. Using the participant's established measurement methods and procedures, the participant should provide NIST with the calibration coefficient(s) for the chamber found at their facility for each beam in units of Gy/C.

Operation of proficiency testing schemes - Instructions for participants

The proficiency test is requested by the participant or group of participants and the coordination of the test date is established on a mutually agreed upon schedule. The instructions for the test are provided in the test protocol.

Proficiency test items handling and storage

The NIST test chamber is stored in the laboratory where the test is conducted at NIST which is conducive to the manufacturer's recommendations of the conditions for use.

Packaging, labelling and distribution of proficiency test items

The chambers are securely packed with foam in reusable boxes. All chambers have unique serial numbers which are documented in the NIST reports.

Data analysis and evaluation of proficiency testing scheme results

The data analysis and records are handled according to the calibration service. Evaluation of performance is conducted by NIST staff. The evaluation is limited to a direct comparison as a percent difference. Generally, NIST commentary is not provided, since that is left to the accrediting body which would analyze the results applying the established criteria. NIST would include in the proficiency test report, commentary, where applicable, on an educational basis if the participant encounters complications.

Reports

The NIST **proficiency testing** report for each proficiency test will include the following details, taken from QMI, Appendix F, but repeated here for thoroughness. A sample NIST report is provided in this procedure. NIST **proficiency testing** reports include the following, unless it is not applicable or the NIST *proficiency testing* program has valid reasons for not doing so:

a) the name and contact details for the NIST ***proficiency testing*** program;
b) the name and contact details for the coordinator;
c) the name(s), function(s), and signature(s) or equivalent identification of person(s) authorizing the report;
d) an indication of which activities are performed by the ***participant(s)***;
e) the date of issue and status (e.g. preliminary, interim, or final) of the report;
f) page numbers and a clear indication of the end of the report;
g) a statement of the extent to which results are confidential;
h) the report number and clear identification of the proficiency testing scheme;
i) a clear description of the ***proficiency test items*** used, including necessary details of the ***proficiency test item's*** preparation and homogeneity and stability assessment;
j) the ***participants'*** results;

k) statistical data and summaries, including ***assigned values*** and range of acceptable results and graphical displays;
l) procedures used to establish any assigned value;
m) details of the ***metrological traceability*** and ***measurement uncertainty*** of any assigned value;
n) procedures used to establish the standard deviation for proficiency assessment, or other criteria for evaluation;
o) ***assigned values*** and summary statistics for test methods/procedures used by each group of ***participants*** (if different methods are used by different groups of ***participants***);
p) comments on ***participants'*** performance by the NIST ***proficiency testing*** program and technical advisers;
q) information about the design and implementation of the ***proficiency testing scheme***;
r) procedures used to statistically analyze the data;
s) advice on the interpretation of the statistical analysis, only when applicable; and
t) comments or recommendations, based on the outcomes of the ***proficiency testing round,*** only when applicable.

When it is necessary to issue a new or amended report for a ***proficiency testing scheme***, the report includes the following:

a) a unique identification;
b) a reference to the original report that it replaces or amends; and
c) a statement concerning the reason for the amendment or re-issue.

Communication with participants

The NIST calibration ordering system includes the option to request proficiency testing and provides the following details.

a) documented eligibility criteria for participation;
b) confidentiality arrangements; and
c) details of how to apply.

If changes to the ***proficiency test scheme*** design or operation are required, the participant will be notified by email. If the results conclude in a performance that the participant needs to appeal, a retest will be offered at the expense of the participant, after an investigation by NIST and the participant. The participant must communicate the error of the previous test and the reason for the request to retest. If an error was made by NIST, the proficiency test will be repeated at no expense to the participant. If no reason is determined for poor performance, the test can be repeated at the expense of the participant.

Sample Report

See below for a sample proficiency test report

National Institute of Standards and Technology

REPORT OF PROFICIENCY TEST
OF ABSORBED-DOSE-TO-WATER CALIBRATIONS

FOR

Detector Technologies Inc
100 Technology Road
Gaithersburg, MD 20899

Radiation Detection Chamber: [Chamber Name] Model [ABC], SN [123]

Calibrations performed by Ronaldo Minniti

Report reviewed by [name of Fellow Scientist]

Report approved by Michael G. Mitch, Leader
Dosimetry Group

Report approved by Michael G. Mitch, Leader
Dosimetry Group

James M. Adams
Chief of the Radiation Physics Division
Physical Measurement Laboratory
For the Director of the National Institute of Standards and Technology

Information on technical aspects of this report may be obtained from Ronaldo Minniti, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460, Gaithersburg, MD 20899, (301)975-5586, ronnie.minniti@nist.gov.
Report format revised: September 1, 2021

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

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National Institute of Standards and Technology

REPORT OF PROFICIENCY TEST OF ABSORBED-DOSE-TO-WATER CALIBRATIONS

FOR

Detector Technologies Inc
100 Technology Road
Gaithersburg, MD 20899

Radiation Detection Chamber: [Chamber Name] Model [ABC], SN [123]

Proficiency test protocol
The protocol for proficiency testing involves the calibration of a NIST reference class, transfer ionization chamber, by the participating facility. After the participating facility calibrates the NIST ionization chamber, using their appropriate NIST equivalent beam quality(s), the chamber is returned to NIST. The participant provides NIST with the calibration coefficient(s), for the NIST chamber found at their facility in units of Gy/C in terms of the half-value layer of the NIST beam quality(s). The chamber is re-calibrated upon arrival at NIST, to detect damage or any changes which may have occurred while in transit. The participant calibration coefficient is compared to the average of the NIST calibration coefficients. The comparative results are given in the following tables. The results reveal the degree to which the participating calibration facility can demonstrate proficiency in transferring a NIST air kerma calibration under the conditions of the said facility at the time of the proficiency test. It is the responsibility of the participant to inform the accrediting body of the results of this proficiency test.

Stability Assessment
The NIST QA procedure requires stability for the transfer chamber and primary chamber measurements. Any change in the reproducibility of the charge above 0.2 % will be investigated.

Confidentiality of Results
The identification of the test results will remain confidential and secured and with limited access to authorized NIST calibration staff. Summary reports may be published but the identification of the participant will be withheld. It is the decision and the responsibility of the owner of the transfer chamber to provide proficiency test results to the accreditation organization.

Statistical Design
The chamber is measured a minimum of three times for each beam by NIST and the average is used. The standard deviation on the charge measurement is used in the uncertainty analysis as the type A uncertainty component. The proficiency test is a direct comparison of the measured calibration coefficients determined at NIST and the participating facility. The criteria for the comparison are established by the accreditation program, not by NIST. NIST will not provide the normalized error or the Z-score.

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REPORT OF PROFICIENCY TEST OF ABSORBED-DOSE-TO-WATER CALIBRATIONS

FOR

Detector Technologies Inc
100 Technology Road
Gaithersburg, MD 20899

Radiation Detection Chamber: [Chamber Name] Model [ABC], SN [123]

Conditions for the Chamber in the NIST Facility

Calibration distance: 100 cm
Chamber orientation: The cavity was positioned in the center of the beam with the stem of the chamber perpendicular to the beam direction.
Chamber collection potential: -300 volts applied to the outer electrode (negative charge is collected).
Chamber rotation: The black line faced the source of radiation.
Waterproofing: the chamber is waterproof
Depth in water: 5 cm
Field size: 15.4 cm x 15.4 cm
Environmental conditions: The chamber is assumed to be open to the atmosphere. The measurements are normalized to a temperature of 295.15 K (22 °C) and a pressure of one standard atmosphere (101.325 kPa) as described in the *Explanation of Terms* section of this report. The average measured values of temperature and pressure during calibration were 295.5 K and 99.9 kPa.
Average background current: 0.01 % of signal.
A detailed study of ionization recombination was not performed, and no correction was applied to the calibration coefficient(s). If the chamber is used to measure an air kerma rate significantly different from that used for the calibration, it may be necessary to correct for recombination loss.

Calibration Results from the NIST Facility

Beam Code	Half Value Layer (mm Cu)	Calibration Coefficient (Gy/C) 295.15 K (22 °C) and 101.325 kPa (1 Atm)	Absorbed-Dose-to-Water Rate (Gy/s)
^{60}Co	14.9	5.448 x 10^{7}	6.93 x 10^{-4}

National Institute of Standards and Technology

REPORT OF PROFICIENCY TEST
OF ABSORBED-DOSE-TO-WATER CALIBRATIONS

FOR

Detector Technologies Inc
100 Technology Road
Gaithersburg, MD 20899

Radiation Detection Chamber: [Chamber Name] Model [ABC], SN [123]

Participant's Calibration Conditions as reported by Participant

Chamber type: Farmer
Atmospheric communication: open
Field size: 10 cm x 10 cm at 100 cm source to chamber distance
Depth in water: 5 cm
Chamber orientation: black stripe toward beam
Chamber reference point: center of chamber volume
Collecting electrode bias: +300 V
Charge collected: negative
Pre-irradiation leakage: -3.0 x 10^{-15} A
Calibration uncertainty: 1.4 %
Ion collection efficiency (Aion): 0.9997
Dose rate: 6.09 mGy/s

Comparative Results for the NIST Transfer Standard

NIST Beam Code	NIST Calibration Coefficient (Gy/C) 295.15 K (22 °C) and 101.325 kPa (1 Atm)	Participant Calibration Coefficient (Gy/C) 295.15 K (22 °C) and 101.325 kPa (1 Atm)	Difference in Percent (%)
^{60}Co	5.448 x 10^{7}	5.447 x 10^{7}	-0.02

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Explanation of Terms Used in the Calibration Procedures and Tables

Absorbed-Dose-to-Water: The absorbed-dose-to-water rate at the NIST is realized at the calibration position by a water calorimeter. This realization of the radiation quantity of absorbed dose to water establishes the National standard, which can be transferred to other measurement facilities through a suitable measuring instrument, thus enabling traceability to the National standard. The ^{60}Co gamma-ray rate at NIST is corrected to the date of calibration (from the previously measured value) by a decay correction based on a half-life of 5.27 years.

Absorbed-Dose-to-Water Calibration Coefficient, N_{Dw}: The absorbed-dose-to-water calibration coefficients, $N_{D,w}$, are quotients of the absorbed-dose-to-water and the charge generated by the radiation in the ionization chamber. The average charge is based on measurements with the wall of the ionization chamber at the stated polarity and potential. With the assumption that the chamber is open to the atmosphere, the measurements are normalized to a pressure of one standard atmosphere (101.325 kPa) and a temperature of 295.15 K (22 °C). Use of the chamber at other pressures and temperatures requires normalization of the ion currents to these reference conditions using the normalizing factor F (see below).

Normalizing Factor F: The normalizing factor F is computed from the following expression: $F = (273.15 + T)/(295.15H)$ where T is the temperature in degrees Celsius, and H is the pressure expressed as a fraction of a standard atmosphere. (1 standard atmosphere = 101.325 kilopascals = 1013.25 millibars = 760 millimeters of mercury).

Waterproofing Sleeve: For the case of non-waterproof chambers, NIST uses a commercially available waterproofing sleeve made of 1 mm PMMA over the collecting volume of the chamber. A latex sleeve is attached to the back of the PMMA sleeve to ensure no water seepage to the chamber.

Calibration Distance: The calibration distance is that between the radiation source and the detector center or the reference line. For thin-window chambers with no reference line, the window surface is the plane of reference. The beam size at the stated distance is appropriate for the chamber dimensions.

Beam Size: The collimator defines a square field of 15.4 cm x 15.4 cm (50 % intensity line), perpendicular to the centerline of the calibration beam.

Half-Value Layer: The calculated ^{60}Co half-value layer (HVL) used here is 14.9 mm of copper.

Uncertainty: The expanded, combined uncertainties of the NIST reference absorbed-dose-to-water rate and the absorbed dose to water calibration described in this report are 0.8 % and 1.0 % respectively. The expanded, combined uncertainty is formed by taking two times the square root of the sum of the squares of the standard deviations of the mean for component uncertainties obtained from replicate determinations, and assumed approximations of standard deviations for all other uncertainty components; it is considered to have the approximate significance of a 95 % confidence limit. Details are given in: Minniti R., Shobe J., Seltzer S. M., Chen-Mayer H. and Domen S. R. "Absorbed Dose to Water Calibration of Ionization Chambers in a ^{60}Co Gamma-Ray Beam," NIST Special Publication 250-74 (2007).

Measurement Results: The results relate only to the instrument calibrated and/or tested in this report.

References

Minniti R., Shobe J., Seltzer S. M., Chen-Mayer H. and Domen S. R., "Absorbed Dose to Water Calibration of Ionization Chambers in a ^{60}Co Gamma-Ray Beam," NIST Special Publication 250-74 (2007); http://www.nist.gov/calibrations/upload/sp250-74.pdf

Minniti, R., Chen-Mayer, H., Seltzer, S.M., Saiful-Huq, M., Dewerd, L., Micka, J., Bryson, L., Slowey, T., Hanson, W., Wells, N., "The US radiation dosimetry standards for ^{60}Co therapy level beams, and the transfer to the AAPM accredited dosimetry calibration laboratories". Med. Phys. 33 (4), 1074-1077 (2006).

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