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**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**

This procedure covers the absorbed-dose-to-water calibration of ionization chambers in a  $^{60}\text{Co}$  beam<sup>1</sup> that is traceable to the NIST water calorimeter<sup>2</sup>. All chambers must be waterproof or able to be made waterproof as measurements are made with chambers submersed in a water phantom.

**Definition**

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

**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
- $^{60}\text{Co}$  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 constitute essential 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 Process and Measurements 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.

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## **Safety**

### Radiation safety

Rooms containing  $^{60}\text{Co}$  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 Health Physics Group.

### 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**

### Acceptance of chambers and equipment

1. Chambers received at NIST should be inspected visually for possible damage that could have occurred during shipment. Check with the customer to see if the instruments had been calibrated at NIST previously.
2. If the equipment received is found to be damaged, the customer should be notified.
3. Chambers are assumed to be open to the atmosphere unless informed otherwise by customers.
4. Obtain a DG (Dosimetry Group) number (unique to each calibration) from the current Calibration Logbook located in the office of the secretary of the group.
5. Record and file in the calibration folder the following:
  - DG number
  - Owner of the chamber to be calibrated
  - Shipping address
  - Contact person phone and fax numbers and e-mail address
  - Make, model and serial number of the chamber
  - Date received

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### Customer chamber set up and calibration

Follow the procedures for the setup and calibration sections below for one of the NIST secondary standard ionization chambers and then again for the customer chamber.

#### *Setup*

1. Set the water phantom on the moveable cart of the  $^{60}\text{Co}$  platform and fill approximately 2/3 full of water. Allow water to come to temperature equilibrium, which is usually 1 °C to 1.5 °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 °C. If the temperature is not stable during a single measurement, calibrations should be postponed. Also, the temperature should not exceed 25 °C and should not be lower than 19 °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 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.

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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  $^{60}\text{Co}$  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. 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 B036, 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.

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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 A 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 760 mm Hg). 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. In addition, 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 measurements should be made for each calibration point. The standard deviation of these 5 or more measurements should not be greater than 0.1 % for reference class chambers. If it is greater, additional time or pre-irradiation may be required to help the chamber settle.

For working chambers, a standard deviation of up to 0.20 % may be acceptable. For abnormally high standard deviations, the owner of the chamber should be contacted to verify that the chamber is acting in its “normal” manner.

Results for 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.

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### Uncertainty Analysis

The uncertainty analysis of the absorbed-dose-to-water calibration of ion chambers is outlined in the NIST Special Publication 250-74<sup>1</sup>. 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<sup>2</sup>
2. <sup>60</sup>Co 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 %

### Records

All information related to the calibration is stored in a calibration folder including calibration data, date the chambers were received and a copy of the signed calibration report (original sent to customer). The report is identified by a DG number.

### 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

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determined by the NIST water calorimeter in a  $^{60}\text{Co}$  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  $^{60}\text{Co}$  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  $^{60}\text{Co}$  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  $^{60}\text{Co}$  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  $^{60}\text{Co}$  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.

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## Appendix A

**Sample Uncertainty Analysis**

	Type A (%)	Type B (%)
Absorbed dose rate at 5 cm in water <sup>1</sup>	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
<sup>60</sup> Co decay constant <sup>5</sup>		0.05
 quadratic summation	 <u>0.19</u>	 <u>0.43</u>
 <b>Relative combined standard uncertainty</b>		 0.47
 <b>Relative expanded uncertainty, k = 2</b>		 0.94



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## Appendix B

**Sample of Calibration Report**

**National Institute of Standards and Technology**

**REPORT OF ABSORBED-DOSE-TO-WATER  
CALIBRATION**

FOR

Calibration Laboratory  
100 Calibration Street  
San Diego, California

**Radiation Detection Chamber:** The Chamber Company Model T10, SN ABC

Calibrations performed by Ronaldo Minniti

Report reviewed by Michelle O'Brien

Report approved by Michael G. Mitch

For the Director  
National Institute of Standards and Technology  
by

Lisa R. Karam, Chief  
Ionizing Radiation Division  
Physics Laboratory

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. The results provided herein were obtained under the authority granted by Title 15 United States Code Section 3710a. As such, they are considered confidential and privileged information, and to the extent permitted by law, NIST will protect them from disclosure for a period of five years, pursuant to Title 15 USC 3710a(c)(7)(A) and (7)(B).

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National Institute of Standards and Technology

**REPORT OF ABSORBED-DOSE-TO-WATER  
CALIBRATION**

FOR

Calibration Laboratory  
100 Calibration Street  
San Diego, California

**Radiation Detection Chamber:** The Chamber Company Model T10, SN ABC

**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 faced the source of radiation.

**Environmental conditions:** The chamber is assumed to be open to the atmosphere.

**Waterproofing sleeve:** Used as described in the section entitled "Explanation of Terms Used in the Calibration Procedures."

**Depth in water:** 5 cm.

**Average background current:** 0.01 % of the collector current.

**Field size:** 15 cm x 15 cm.

**Calibration dates:** March 30, 2010.

**Current ratio at full to half collection potential:** 1.000 for an absorbed-dose-to-water rate of 3.00 E-03 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)
<sup>60</sup> Co	14.9	2.000 E+7	3.00 E-3	100

## ABSORBED-DOSE -TO-WATER CALIBRATIONS FOR IONIZATION CHAMBERS

### Explanation of Terms Used in the Calibration Procedures and Tables

**Absorbed-Dose-to-Water:** The absorbed-dose-to-water rate at the NIST calibration position is measured by a water calorimeter. The  $^{60}\text{Co}$  gamma-ray rate 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,  $N_{D,w}$ :** 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. 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).

**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.

**Beam Code:** The beam code identifies important beam parameters and describes the quality of the radiation field. For gamma radiation, the beam code identifies the radionuclide.

**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  $^{60}\text{Co}$  half-value layer (HVL) is 14.9 mm of copper which has been determined from calculations.

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**Uncertainty:** The expanded, combined uncertainty of the absorbed-dose-to-water calibration described in this report is 1.0 %. 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 of a typical uncertainty analysis are given in reference [1].

#### 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 <sup>60</sup>Co Gamma-Ray Beam," NIST Special Publication 250-74 (2007).

[2] 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 <sup>60</sup>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**

## Absorbed Dose Calibration Program

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Table	◆	Chamber owner	
Operator	t	Chamber make	t
Measurement type	absorbed dose t	Chamber model	t
Room	B036 t	Seial #	t
Source	Co-60 t	Applied voltage	◆ 300 Volts
Distance	1 meter t	Polarity	Negative t
Aperture	10.75 x 10.75 t	Time HV set	
Air Kerma rate	(internal reference)	Equil/waterproffing	Inherent t
Absorbed dose rate	(internal reference)	Rotation	white line t
Measurement method	Computer t	Orientation	Perpendicular t
Electrometer owner	NIST	Pressure	mmHg
Electrometer make	t	Temperature	deg C
Electrometer model	t	Humidity	◆
Electrometer serial #	t	DG Number	
Electrometer address	27	TF Number	

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.