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[1] of ionization chambers in a ^{60}Co beam 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.

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 with LabView absorbed-dose-to-water calibration program and appropriate boards to handle instrument control and data acquisition,
- Electrometer (may belong to NIST or customer) with suitable computer control,
- Computer-interfaced temperature probes for continuous temperature monitoring of both the air and the water in the phantom,
- Pressure gauge with computer readout capabilities,
- ^{60}Co source traceable to NIST primary standard,
- Water phantom with chamber mounting apparatus,
- The aluminum meter scale with 1 mm precision,
- An in-house secondary standard ionization chamber.

The temperature probes, pressure transducers and electrometers used constitute essential equipment used for the calibration service. The temperature probes are calibrated against a reference standard Taylor liquid-in-glass 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 measurements division. A NIST check chamber is used to decide when the calibration of the equipment used for calibration needs to be checked against reference standards calibrated by the process and measurements division.

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.

Electrical safety

To avoid possible shock, one should not touch any chamber or connector once voltage has been applied to the chamber when negatively biased. Certain chambers (for example, the Exradin A12) 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. As a good safety practice, the high voltage should be turned off before making a height adjustment.

Procedures

Acceptance of chambers and equipment

1. Ensure that all incoming support equipment has a current calibration or calibration check.

2. When calibrating a customer chamber, inspect for any shipping damage. If damage has occurred, follow the IRD Nonconformance Guide. If equipment has been damaged, customer will be notified immediately.

3. If the chamber has not been calibrated at NIST before, perform test to ensure that it is open to the atmosphere.

4. Obtain a DG (Dosimetry Group) number (unique to each calibration) from the current Calibration Logbook in the Group secretary's office and record.

5. Record in the absorbed-dose-to-water calibration log book the following:

   - DG number,
   - Owner of the chamber to be calibrated (if other than NIST),
   - Shipping address,
   - Contact person phone and fax numbers and e-mail address,
   - Make, model and serial number of the chamber,
   - Date received.

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, readjusting equipment where necessary.

Set-up

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 1to1.5 ^{o}C lower than room temperature. This can take up to 24 hours.

2. Turn on the source control panel. Set 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 followed 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 shouldn't exceed 25 C and shouldn't 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. Preferred humidity conditions are between 20% and 50% but calibrations still can be performed if humidity levels fall out of this range. It's preferred to calibrate instruments on days that the pressure is around 760 Torr 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 lay along the underside of chamber. Lower the chamber (by rotating the height adjustment dial) into the water to approximately the desirable depth, or at least to a depth such that the entire mounting block is under the water. Connect 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, align the front (south) edge of phantom with the center and remove the block when completed. This procedure places the front water surface at the focal plane of the telemicrocrope. Once this position is established, a physical mark of the phantom with respect to the fixed part of the platform can be used for repositioning in lieu of the plumb-bob centering device.

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 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 on in the scope. Always align with the bottom-most one.) Record the readings on the scale of the telemicroscope, h_1. This reading should be between 7 cm and 8 cm such that when performing step 7 the travel range is in the center portion of the scale (full scale 10 cm). Push the phantom away from the center (toward north).

7. Insert the meter scale onto the holders under the source opening such that it suspends under the source. Adjust the height of the entire platform using the wall-mount control unit such that the horizontal crosshair in the telemicroscope centers on 53.8 cm on the meter scale. In B036, this position corresponds to a distance of 95 cm from the source. Turn off the motor controller. Lower the telemicroscope by 5.00 cm from the recorded position to a new position $h_2 = h_1 - 5.00$ cm using the dial with a scale. Ensure that it reads 58.8 on the large scale suspended from the source opening. This position is the calibration distance of 1 m. 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. Push the interlock button on the source control panel to enable shutter control.

10. Apply voltage at the polarity and maximum allowable value as specified by customer. Allow time for 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-irradiation by manually 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 high voltage to chamber. Remove chamber from water. Compare calibrations to chamber history if available.

Analysis and Report

The average current, in the unit of A, or C/s, measured in the above procedures is normalized to reference environmental conditions (22°C and 760 mmHg). It is divided by the decay corrected absorbed dose rate (traceable to NIST primary standard), in the unit of Gy/s, to obtain a calibration coefficient, C/Gy. 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 total measurements should be made for each calibration point. The standard deviation within these 5 or more measurements should not be greater than 0.05% 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.

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.

Uncertainty Analysis

The bases for the determination of uncertainties associated with the absorbed-dose-to-water calibration of ion chambers are the ISO Guide to the Expression of Uncertainty in Measurement[3] and the Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results[4]. The purpose of this section is to explain the various components of uncertainty for absorbed-dose-to-water calibrations.

Absorbed-dose-to-water rate – this was determined earlier[2] and will not be revisited here.

^{60}Co decay constant – a type B uncertainty of 0.03%, obtained from the literature[5].

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.

Recombination loss – as NIST does not report recombination correction, there is no uncertainty.

Timing – shutter control reproducibility, a type B uncertainty.

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.

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.

Leakage – The leakage is determined to be less than 0.02% of the dose readings, and therefore is not included in the uncertainty statement.

Radiation background – the effects of any radiation background are so small that there is no uncertainty in the measurement from them.

Field size – this is estimated to be a type B uncertainty of 0.40%.

Beam uniformity – this effect on the measurement is estimated to be no more than 0.20%. It is a type B uncertainty.

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

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

Records

The dates that the chamber is received from and returned to the customer are entered into the absorbed-dose-to-water calibration logbook along with the other information pertaining to the chamber, identified by the DG number.

Copy of signed calibration report (original sent to customer) along with calibration data printouts are stored in folders identified by DG numbers and dates.

Traceability

The SI unit of absorbed dose is the Gray (Gy), which is 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. More detailed information concerning traceability and uncertainty analyses is summarized in references 1 and 2.

References

1. Shobe, J. and Domen, S.R., Absorbed Dose to Water Calibration of Ionization Chambers in a 60Co Gamma-Ray Beam, NIST Special Publication 250-40 (in WERB process), 2003.
2. Domen, S.R., A sealed water calorimeter for measuring absorbed dose, J. Res. Natl. Inst. Stand. Technol., 99, pp. 121 – 141, 1994.
3. ISO Guide to the Expression of Uncertainty in Measurement. International Organization for Standardization, Geneva, 1995.
4. NIST Technical Note 1297, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results.
5. The Evaluated Nuclear Structure Data File, Nuclear Structure and Decay Data, National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973, 2003

Filing and Retention

The IRD Quality Manager shall maintain the original and all past versions of this IRD Procedure. Copies of the current revision of this Procedure shall be placed in controlled Quality Manuals. Electronic copies of this Procedure are uncontrolled versions.

All deleted Procedures (including old revisions) shall be maintained by the IRD Quality Manager. All old revisions shall be maintained until such time as it is decided to delete the Procedure. Once the decision has been made to delete the Procedure, only the last revision shall be maintained by the IRD Quality Manager.

Appendix A

Sample Uncertainty statement

	Type A (%)	Type B (%)
Absorbed dose rate at 5 cm in water[1]	0.16	0.32
^{60}Co decay constant[5]		0.03
Measurement repeatability	0.05	
Timing		0.01
Air density	0.01	0.10
Humidity		0.15
Leakage		N/A
Field size		0.40
Beam uniformity		0.20
Positioning at 5 cm depth in water	0.05	
Positioning at 1 m source distance	0.02	
Relative standard uncertainties in **Calibration coefficient**		
quadratic summation	0.18	0.58
Relative combined standard uncertainty		0.61
Relative expanded uncertainty, k = 2		1.22

Appendix B

Calibration Report Template

National Institute of Standards and Technology

REPORT OF CALIBRATION

ABSORBED-DOSE-TO-WATER CALIBRATION FOR IONIZATION CHAMBERS

FOR

Customer Address
Customer Address
Customer Address

Radiation Detection Chamber: Manufacturer name, Model xxxxxx, SN xxxxxx

Calibrations performed by Scientist(s)

Report reviewed by Fellow Scientist

Report approved by Group Leader

For the Director
National Institute of Standards and Technology
by

Division Chief
Ionizing Radiation Division
Physics Laboratory

Information on technical aspects of this report may be obtained from H. Chen-Mayer, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460,Gaithersburg, MD 20899, (301)975-5595, chen-mayer@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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REPORT OF CALIBRATION

ABSORBED-DOSE-TO-WATER CALIBRATION FOR IONIZATION CHAMBERS

FOR

Customer Address
Customer Address
Customer Address

Radiation Detection Chamber: Manufacturer name, Model xxxxxx, SN xxxxxx

Report of Calibration

Beam Code	Calibration Performed	Distance (cm)	Beam Size (cm) S: square C: circular	Current ratio (at full to half collection potential)	Dose Rate (Gy/s)	Calibration Coefficient (Gy/C) (22 °C and 1 atm.)
^{60}Co	Absorbed dose	100	S15.4			
^{60}Co	Air-kerma*	100	S14.0			

*Air-kerma calibration coefficient is provided as a courtesy to customers. For calibration procedures for air-kerma calibration, please see IRD-xxx.)

Conditions of Calibration

- ***Chamber orientation:*** The cavity is 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. The collecting electrode is kept at ground potential. With this arrangement negative charge is collected.
- ***Chamber rotation:*** The white line faces the source of radiation.
- ***Average leakage:*** less than 0.00% of the radiation measurement current.
- ***Waterproofing sleeve:*** not used, as chamber is inherently waterproof.
- ***Environmental conditions:*** The chamber is assumed to be open to the atmosphere.
- ***Ion recombination:*** A detailed study of ion recombination has not been performed and no correction is applied to the calibration coefficient(s). The ratio of currents measured at full and half voltages is being supplied for reference purpose only. If the chamber is to measure absorbed-dose-to-water rates significantly different from that used for the calibration, it may be necessary to correct for recombination loss.

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REPORT OF CALIBRATION
ABSORBED-DOSE-TO-WATER CALIBRATION FOR IONIZATION CHAMBERS

FOR

Customer Address
Customer Address
Customer Address

Radiation Detection Chamber: Manufacturer name, Model xxxxxx, SN xxxxxx

Explanation of Terms Used in the Calibration Procedures and Tables

Absorbed-Dose-to-Water: The absorbed-dose-to-water rate at the calibration position has been determined by a water calorimeter at the reference date, the NIST primary standard for absorbed-dose-to-water in a ^{60}Co. The dose rate on the date of calibration is decayed corredted from that on the reference date using a half-life of 5.27 years.

Air Kerma: The air-kerma rate at the calibration position has been determined by graphite cavity ionization chambers that are NIST primary standards for ^{60}Co gamma radiation. For details of air-kerma calibration procedures, please see IRD-XXX.

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.

Beam Size: The beam size is the perpendicular distance from the centerline of the calibration beam to the fifty-percent intensity line. For circular fields, the letter C precedes the dimension; for square fields, the letter S precedes the dimension and the chamber axis is perpendicular to a side of the square.

Calibration Coefficient.: The calibration coefficients 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 calibration coefficient is reference 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, computed as follows: $F = (273.15 + T)/(295.15H)$ 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).

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REPORT OF CALIBRATION

ABSORBED-DOSE-TO-WATER CALIBRATION FOR IONIZATION CHAMBERS

FOR

Customer Address
Customer Address
Customer Address

Radiation Detection Chamber: Manufacturer name, Model xxxxxx, SN xxxxxx

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.

Equilibrium Shell: Material added to the nominal wall thickness of the chamber to ensure electronic equilibrium.

Half-Value Layer (HVL): The thickness of a material that attenuates the radiation intensity by a half. The HVL for copper used in a ^{60}Co source is 14.9 mm based theoretical calculations.

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.

Sleeve for Waterproofing: 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.

Uncertainty: The expanded combined uncertainty of the air-kerma calibration described in this report is 1.4% and the expanded, combined uncertainty of the absorbed-dose-to-water calibration described in this report is 1.2 %.

- Expanded combined uncertainty = 2 times combined uncertainty.
- Combined uncertainty = $\sqrt{\Sigma_i(\sigma_i^2)}$, where σ_i is the standard deviation of the mean for component i.

For a measurable component, σ_i is determined by the uncertainty associated with replicate measurements; for all other components, σ_i may be assumed approximations of standard deviations. An expanded combined uncertainty is considered to have the approximate significance of a 95% confidence limit. Details of the uncertainty analysis can be obtained by request.

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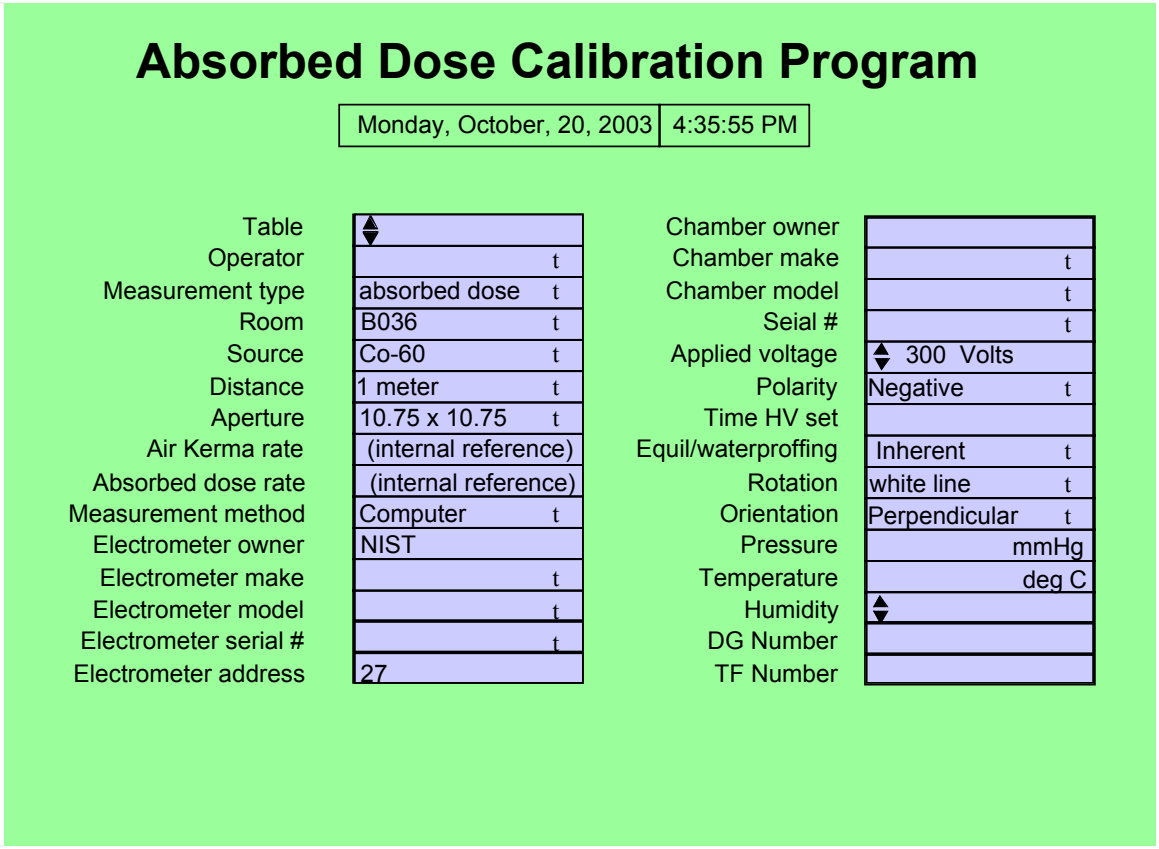
Appendix C

Calibration Program Control Panel



Notes:

- Fields with ▲▼ on the left is a "counter" which accepts either manual input or incremental input from the counter.
- Fields with ▼ 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.