Purpose

The purpose of this procedure is to describe all steps involved in the measurement of air-kerma produced from electronic brachytherapy sources using the Lamperti [1-3] standard free-air ionization chamber. The details of the calibration service listed as 46012C are included.

Scope

The calibration of well-type ionization chambers instruments that measure x rays from electronic brachytherapy sources are performed in terms of the physical quantity air kerma in units of gray (Gy) [4,5]. The process for establishing calibration coefficients for well-type ionization chambers is explained in this procedure. Calibrations are performed by comparing the well-type ionization chamber response to air kerma realized by a NIST primary x-ray standard. The NIST calibration coefficients of a well chamber have units of Gy/(A s) normalized to reference conditions of 295.15 K and 101.325 kPa.

Referenced documents

NIST Special Publication 250-58 Calibration of X-ray and Gamma-ray Measuring Instruments
NIST Calibration Services (http://www.nist.gov/calibrations)
NIST Technical Note 1297 Guidelines for Evaluating and Expressing the Uncertainty of NIST

Measurement Results Records

Electronic files

Definitions

air kerma - the quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all electrons liberated by photons in a volume element of air and dm is the mass of air in that volume element. The SI unit of air kerma is the gray (Gy).

beam quality - used to refer to a specific x-ray beam with a characteristic half-value layer and produced by a constant potential kilovoltage.

calibration - the process whereby the response of a dosimeter or measuring instrument is characterized through comparison with an appropriate national standard.

calibration coefficient - the quotient of the air kerma in the absence of the chamber and the charge generated by that radiation in the well-type ionization chamber, expressed in units of Gy/(A·s) normalized to reference conditions of 295.15 K and 101.325 kPa.

electronic brachytherapy source - insertable, low-energy, miniature x-ray tubes for interstitial radiation therapy

exposure - exposure (X) is the quotient of dQ by dm, where dQ is the sum of the electrical charges on all the ions of one sign produced in air when all the electrons are completely stopped in air of mass dm. The

SI unit of exposure is the coulomb per kilogram (C/kg); the special non-SI unit of exposure, the roentgen (R), is equal to exactly 2.58E-4 C/kg.

half-value layer - (HVL) the thickness of the specified material added as a beam attenuator that reduces the air-kerma rate by one half of the unattenuated-beam air-kerma-rate value.

x-ray unit - system compred of a high-voltage generator, an x-ray tube and an x-ray controller.

Key words

air kerma; calibration; exposure; free-air chamber; electronic brachytherapy; well- ionization chambers; primary standard; standard; uncertainty estimate; x rays.

Background information and traceability of measurements

The quantity kerma characterizes a beam of photons or neutrons in terms of the energy transferred to any material. For the calibration procedures described in this document, consideration is limited to photon beams in air. A complete description of the determination of air kerma and the traceability of the standards is found in sections 4.1, 6.2 and 6.8 of NIST Special Publication 250-58 [2] and Refs [1,3].

Requirements of instruments to be calibrated

Only well-ionization chambers known to be stable and reproducible are accepted for calibration in this program. Facilities submitting well-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. The appropriate chamber insert must be provided by the customer. Instruments submitted for calibration, and material submitted for irradiation, must be shipped in reusable containers.

Explanation of calibration service offered

The increased use of limited-lifetime electronic brachytherapy sources which are low-energy, miniature x-ray tubes for clinical applications resulted in the need of a measurement of air-kerma dose from NIST. The type of electronic brachytherapy sources, Axxent S700, used thus far at NIST operates at tube potentials of 50 kV and anode currents of 300 μA. The millimeter sized anode is shown in Figure 1a revealing the tip detail of a source. Figure 1b shows a typical source in a water-cooling catheter and the high voltage (HV) connector. The calibration service determines the air-kerma rate in terms of Gy/s for each source at a distance of 50 cm using the Lamperti free-air ionization chamber [3]. A customer-provided well chamber is used to measure the stability of the source output and serves as a transfer instrument. A NIST-maintained well chamber is also calibrated to provide quality assurance to the process. The measurement process results in a NIST calibration coefficient for the well chambers for each source in units of the NIST air-kerma rate (Gy/s) at 50 cm per ampere, Gy/(A s) normalized to 295.15 K (22 ^{o}C) and 101.325 kPa (1 atm).

Design philosophy

The air kerma in units of gray (Gy) or air-kerma rate (Gy/s) is determined at a source to detector distance of 50 cm using the NIST primary standard. After determining the air-kerma rate of the electronic brachytherapy source, the source is then placed in the NIST well chamber for a series of measurements in units of ampere followed by the customer's well chamber. Ionization currents in air-kerma-standardization measurements are produced by the irradiation of a gas in an ionization chamber. The ionization chamber may be a free-air chamber, such as one of the national standard chambers, or a cavity chamber, where the gas is surrounded by the wall material. Ionization chambers, regardless of type, consist of electrodes that are insulated from one another and that are polarized in order to collect charge produced in the gas. The ions produced in the air by the beam are swept from the chamber volume by the electric field between the electrodes. Included in the measurement of these currents are currents not produced by the radiation of interest, but by background radiation and insulator leakage, referred to as background current.

X-ray range features

The NIST Electronic Brachytherapy Facility is located in the Radiation Physics Building 245, Room B24. It was designed with a walk-in shielding enclosure to provide personnel safety during measurements. The leaded-glass shielding maze entrance and leaded-glass walls, allows observation of the source and instruments during measurements. Figure 2a is a schematic of the design and Fig. 2b is a photograph of the clear leaded glass walls showing the maze entrance, the radiation area and the operator's control area. Figure 3 shows the essential equipment located inside the leaded glass enclosure. The source is surrounded on three sides by a leaded glass surround which reduces scatter. The water cooling pump for the source catheter, the HV cable, and the well chamber are mounted on a shelf above the source holder, Fig. 4. This positioning was selected since the length of the high voltage connector between the source and the power supply is limited, which is shown in the smaller insert picture in Fig. 4. The source alignment apparatus is also mounted above the source holder. The high-purity germanium detector and the cooling liquid nitrogen Dewar are shown in Fig. 5. The equipment to power, communicate with and control the x-ray sources, Lamperti chamber and well ionization chamber are located outside the leaded-glass shielding enclosure, in the control area of the facility, are shown in Figures 6-8 and identified in Table 1. Figure 6 shows the x-ray controller, the HV controller, the power supply for the Lamperti chamber and the data acquisition computer control equipment. Figure 7 shows the barometer, thermometer and the well-chamber electrometer. Figure 8 is the electrometer used for the Lamperti chamber, with details of the back hook-up. All calibration work related to the electronic brachytherapy sources is contained in room 245/B24, as there is sufficient setup area for the storage, preparation and maintenance of the sources.

Equipment

The temperature probes, pressure transducers and electrometers are considered essential support equipment to allow routine calibrations of ionization chambers. The maintenance and calibration of this support equipment follows. All equipment is listed in Table 1 and seen in Figures 3-15.

The temperature sensor in the electronic brachytherapy facility is the Fluke/Hart Scientific 1504A meter with a 5611 thermistor, used to determine the temperature of the air in the calibration area. The

thermometer calibration correction is applied internally to the 15004A digital meter at the time of NIST calibration.

A Setra 370 barometer is interfaced through the data-acquisition software to monitor atmospheric pressure. Any necessary correction is applied directly through software as part of the air-kerma calculation.

The charge measurements for the Lamperti chamber are acquired through the use of a Keithley 6512 electrometer. The charge measurements for the well-ionization chambers are acquired through the use of the PTW Unidose electrometer. Upon initial use, the charge mode of the electrometers are calibrated according to the procedures outlined in NIST ID 46030S. Any necessary correction would be applied as part of the air-kerma calculation. The PTW Unidos E electrometer is also used to measure the charge collected in the PTW TN34013 ionization chamber for QA purposes.

Support equipment calibrations

There are no specified intervals for calibration of the critical support equipment because the equipment is calibrated using the in house reference standards described below anytime there is a question of reproducibility. Since the QA procedure requires the calibration of the well-ionization chamber, any change in the reproducibility of a single source measurement above 0.2 % 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 removed and its condition clearly marked. A calibrated, identical model replacement instrument would be used for calibrations to continue until the repair of the damaged equipment is completed. Any damage and repair to the critical support equipment should be recorded in the current databook for the calibration of support equipment, titled *Calibration of Auxillary Equipment* Number 914, located in 245/B019. All NIST calibration records for the critical support equipment are located in a file drawer in 245/B033. In house calibration records of the barometers and thermometers are maintained in electronic files in the folder named *supportequipqa* located on the group server in the OBrien directory.

Temperature indicator calibrations

A Fluke/Hart meter 1504 (SNA95694) with probe model 5610-5 SNA932006 will serve as the "in-house" temperature reference standard for x and gamma ray calibrations. The meter and probe combination was calibrated in June of 2009 at NIST to the reference standard and will be calibrated periodically as necessary. Various probe and meter combinations, dedicated for calibration measurements, are periodically directly calibrated at the NIST.

Pressure indicator calibrations

An aneroid barometer, Wallace and Tierman, Model FA 139, Serial Number XX11242, as well as various other laboratory reference barometers are periodically calibrated by the NIST reference standard. Calibrations of individual pressure indicators used in the various x-ray calibration ranges are made by placing the calibrated barometer alongside the instrument to be tested. The instrument readings are compared over a range of pressures. A correction factor is obtained from this data for each pressure

indicator, if required. This calibration procedure is conducted periodically and checks are made when the pressure deviates significantly from the reference value of 101.325 kPa.

Procedures

Administrative procedures

Customers request calibration services in a variety of ways. Typically, a new or first-time customer will establish contact with the Dosimetry Group by email requesting information regarding techniques offered, charges, turnaround time, and shipping information. At this stage, there is generally an opportunity to discuss with the prospective customer the type of service being requested and methods of shipment to reduce the risk of damage. The customer must provide to the NIST technical contact the following: a detailed description of the calibration request, instrument model and serial numbers, name and telephone number of a technical contactand the return shipping instructions, including the address, special handling, the specified mail carrier with account number for payment, the value of the equipment and instructions for the insurance amount, if any. Complete instructions and payment policies for calibrations are found on the NIST website.

After the customer follows the NIST policy for payment documentation, the division secretary requests a NIST test folder, using the check list found in Table 2 . Additional records are maintained in the Dosimetry group. A copy of the purchase order, the final copy of the calibration report, the calibration raw data and summary sheets and any documents of correspondence concerning thee calibration are maintained in the customer's calibration- report folder filed by the unique dosimetry group (DG) number.

When instruments arrive for calibration, they are unpacked and inspected for damage. 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. The instrument would be rejected if the chamber cable is damaged. If the shipping box is visually damaged this should be noted and the customer consulted.

After the instrument has been calibrated, the calibration report is generated. Templates, generated in Microsoft Word and Excel are available to simplify this procedure and to ensure consistency in the reporting format. The reports are printed on official NIST letterhead. A sample report is found as Appendix 1.

The final copy of the calibration report is reviewed and initialed by the preparer, the reviewer and then given to the Group Leader for review. After the Group Leader approves and initials the report, it is sent to the Division Office for signature. Upon return, two copies are made. The original is mailed to the customer often in the box with the chamber, one copy is filed in the customer DG folder, and one copy is added to the NIST test folder. After all requested calibration work is completed, the Division secretary completes the test folder closure process. The NIST technical staff signs the NIST test folder upon completion. The DG customer folder is filed in room 245/B033. Shipping request forms are

prepared and the instrument is packed either in its original container or in a more suitable one if necessary.

Laboratory procedures

Procedure for Cleaning and Lubricating the Source
Prior to connecting the source to the HV connector and cooling lines, the source must be cleaned and lubricated. Complete manufacturer's procedures are found in the glass cabinet with the cleaning supplies in B24, see Fig. 9 for cleaning supplies and general details. In summary, the process involves using alcohol and a lint free tissue to clean the HV connector, paying attention to any dark marks from arcing. After the alcohol has evaporated or air dried then the connector lubricant, MS-383H, should be applied with a swab or lint free tissue, using gloves and taking care not to add any dirt to the connector. If any hint of arcing occurred, then the HV connector socket, labeled in Fig. 4, should be inspected and cleaned with alcohol using the swab and/or a lint free tissue.

Procedure for Drying Source
The cooling medium must be removed from the cooling catheter in order to preserve the life of the source. Complete manufacturer's procedures, using the vacuum pump shown in Fig. 10, are found in the glass cabinet above the pump in 245/B24. Each source must be vacuumed after use. The source should be disconnected from the HV connector and cooling lines. The source is easily connected to the vacuum pump and dried. Select the "1hour" button on the electrical cord of the pump. The pump will automatically stop after one hour.

Procedure for Alignment and Positioning of the Lamperti chamber and the source

Source alignment: As seen in Figures 11 and 12, there are multiple mechanisms for the alignment of the equipment. Figure 11 shows the three alignment control stages for the source. Within the leaded glass surround, the source can be adjusted with the two stages for the horizontal and vertical source position to the lasers which are seen in the large photo in Fig. 12. The power switches for the lasers are on the back of each laser or the wall plugs can be used to energize the lasers. The lasers are mounted on custom alignment platforms and should never be realigned routinely unless there is a modification to the calibration facility. Once the laser mounted behind the Lamperti chamber is energized, the alignment to the scale on the "front" of the catheter is possible. The center of the source is visible through the catheter and is used as the alignment point for both the horizontal and vertical positioning. There is a third alignment stage, Fig. 11, which is used to change the angle of the "front" or scale portion of the source relative to the Lamperti chamber. This rotation stage has two etched marks which are to be aligned to the mark at the center of the stage to set the source at 0 degrees, 120 degrees and 240 degrees relative to the front of the Lamperti chamber. Once the laser mounted behind the Lamperti chamber is used to align the source horizontally and vertically, the second laser mounted perpendicular to the other laser can be used to verify the distance between the center of the Lamperti chamber and the center of the source. The distance between the center of the Lamperti chamber and the center of the source is 54 cm and should be established by a tape measure.

Lamperti chamber positioning: Figure 12 has three smaller inserted photos which show the knobs for the under mounted alignment slides which are used to align the Lamperti chamber for

various required measurements. The center photo and the one to the right show the knob in the back of the Lamperti chamber. This knob controls the horizontal positioning of the Lamperti chamber. Like the lasers, this alignment slide should never be realigned routinely unless there is a modification to the calibration facility. The knob for the slide used to adjust the distance of the source to the center of the chamber is located to the side of the Lamperti chamber. There are alignment marks, not visible in the photos, on the Lamperti support which are used to establish the various distances from the source. The alignment slide, with the knob to the side of the Lamperti chamber is used and the distance verified with the rulers, seen in Fig. 12. The center of the chamber is placed at 54 cm from the source for the air-kerma measurements and repositioned to 52 cm from the source, for the inverse square distance dependence of the air kerma rate. The Lamperti chamber is moved closer to the source by 2 cm to measure the scatter conditions of the points of measurements for the air attenuation measurement. Assuming a stable, geometrically centered and well-constructed source, the scatter conditions can be tested using the inverse square distance method over 4 cm, but the routine is to measure when the center of the Lamperti chamber is placed at 54 cm and at 52 cm. The fourth smaller inserted photo in Fig. 12 shows the front aperture of the Lamperti chamber. This tungsten aperture, having a diameter of 0.5 cm, is used for all measurements except the air-attenuation determination.

Lead shields

Figure 13 shows the lead shields that are used during the inverse square distance dependence of the scattered radiation test, angular and air attenuation determination. The air-kerma shield, placed at a nominal 40 cm from the source, has a hole with a diameter of 3.5 cm and does not impact the measurement of air-kerma. It is used to reduce the size of the x-ray beam incident on the Lamperti chamber. It must be removed for the air-attenuation measurements, for which the smaller shield with the hole of diameter 0.3 cm is used. The air-attenuation shield is positioned at 45 cm from the source.

Air-attenuation positioning

The Lamperti chamber tungsten aperture must be removed for the air-attenuation measurement. The air-attenuation shield should not be moved during the two measurements required to determine the air-attenuation ratio, one when the center of the chamber is at 54 cm and the second when the center of the chamber is at 52 cm from the source. The Lamperti chamber is not moved forward the full air-path length of 4 cm, to 50 cm, because moving that large of a distance disturbs the geometry and poor results are obtained. If the air-attenuation is measured over 2 cm and then calculated for the 4 cm air path, the measured results match the calculated results. The Lamperti chamber was not designed to allow direct measurement of the air-attenuation correction due to the original geometry of the imbedded tungsten aperture. Verification of the calculated value of the air-attenuation correction can be achieved with a simple measurement ratio over the 2 cm path-length. Figure 14 shows diagrams of the various measurement positons of the Lamperti chamber which explain the various positions used for measurements.

Safety for repositioning chamber

When entrance to the radiation area is required for the repositioning of equipment, for example during the inverse square and the air attenuation measurements, the source has to be de-energized. Guidance for this is described in step 14 of the XOFT Labview operating procedures on the Xoft control computer.

The high voltage, of 3000 volts, remains on the Lamperti chamber during movement of the chamber for the inverse square and the air-attenuation measurements. The voltage is interior to the surface of the Lamperti chamber and there is no risk of electric shock as long as the interior of the chamber is not touched.

Procedure for using the cooling medium flow pump
The source should be connected to the cooling medium, located in the hanging intravenous (IV) bag, through the red and blue cooling lines, Fig. 3. Once the tube connections are secure, the red flow clamp should be released prior to energizing the flow pump, Fig. 4. On the pump, the flow needs to be set to **forward** (button down) and the setting is ideally 3. When sufficient flow is achieved, the flow interlock will release and the source can be safely energized. The flow safety interlock light will illuminate on the Xoft interlock controller, Fig. 6. If the flow decreases such that the source is at risk of overheating, the interlock will switch off and de-energize the source. At the completion of use of the de-energized source, the pump should be de-energized, the red clamp secured and the tubes disconnected. If the red clamp is not secured fully, or clicked all the way shut, the cooling medium will leak on the table and floor.

Procedure for Energizing Source
1. Turn on the water pump, which cools the source, following cooling hook up procedures.
2. Turn on the power switch to the main controller.
3. Verify all interlocks are made on the control area, including a blank source in the well chamber during use of the Lamperti chamber for air-kerma measurements. Voltage will not be applied to thesource if the interlocks are not made.
4. Visually verify that no one is in the radiation area.
5. Visually verify that the radiation warning lights both at the control panel and the shielding wall are on.
6. Test the interlock barrier.
7. Reset interlocks.
8. Use control computer to ramp up tube voltage, filament current, and beam current using XOFT Labview procedure.
9. For the inverse square and the air attenuation measurements, entrance into the radiation area is required for repositioning of the Lamperti chamber. The source has to be de-energized for safe entrance. This is an option on the computer software.

Procedure for De-energizing Source
1. Use control computer to ramp down x-ray source tube voltage, filament current, and beam current.
2. Turn off the water pump.
3. Secure water-cooling line with clamp to prevent leakage.

Computer procedures and instructions for Labview and XOFT computer applications

Electrometer data acquisition procedures: The application WCCharge.vi collects data on the PTW electrometer, barometer and thermometer when the well ionization chamber or the PTW TN34013 QA chamber is in use. The blue signal cable is switched between the well chamber(s) and the PTW QA chamber to allow measuring the electrical charge produced in either of the two chambers. When the source is in the well chamber the blue signal cable is connected to the

appropriate well chamber. When the source is in the leaded glass surround, for air kerma measurements, made with the Lamperti chamber, the PTW Unidose electrometer is used to measure the charge collected on the PTW QA chamber. The Data Socket Server file must be open on the startup menu on the XOFT control computer for this program to work. The WCCharge.vi program allows the user to enter in the number of data points desired to collect and the collection time. Generally the data is collected every 6 seconds for 5 minutes. The data that is accumulated in rows includes columns with the following information: the uncorrected (for temperature or pressure) charge, the collection time, the date, the time stamp, the temperature, the pressure, the calculated temperature and pressure normalization factor, and finally the corrected charge. The output files are saved as ".txt" files and are imported to Excel spreadsheets for analysis. The text files are named using a nomenclature of date, source ID and some counter. The well chamber data is then saved with the Lamperti chamber data on a spreadsheet identified by the source identification number. The PTW QA data is saved on the spreadsheet which contains all measurements per source ID. The PTW QA data is compared for each source in a series of measurements.

The charge measurements for the Lamperti chamber are acquired through the use of a Keithley 6512 electrometer, using the data store option. There is no computer interface for this data collection. The charge data is entered by hand into Excel spreadsheets. The charge is collected, as well as the temperature and pressure, so that the air density and temperature and pressure correction can be applied. The charge is collected at a source to center of the Lamperti chamber distance of 54 cm and at 52 cm so that the inverse square difference can be determined. This agreement is ideally around 1 %, if it is greater than 2 % then the source needs to be realigned with the lasers. The distance of 52 cm is used because the air attenuation measurement is made at these two distances and the inverse square calculation between these two distances should be determined so that the geometry can be evaluated. The charge is also collected at angles of 0 degrees, 120 degrees and 240 degrees; see Fig. 11 for source rotation details. There are marks on the Lucite source holder which align the source at each position. The leakage electrical charge is determined in the Lamperti chamber at the beginning of the measurement set and the later charge collection measurement sets are adjusted for the leakage. The charge is also determined for the air attenuation determination measurements. See Appendix 2 for a sample spreadsheet of the data collected. This example shows only a small sample as a guide for the format. In addition to the data for the air kerma, air-attenuation determination, inverse square data and angular measurements, the well chamber and the PTW QA data is also maintained on the sheet identified by the source ID.

HPGe spectrometer

1. Open the Canberra software found on the desktop computer in B24.
2. Select Gamma Acquisition and Analysis in Startup.
3. Select file, open DATAsource, select detector, DET1USB, open, clear, preset 100 then start. Only use the SAVEAS when saving files.
4. On Exit, NEVER save changes. One spectrum is typically saved for each angle used. The output files are saved as ".cfn" files. The files are named using a nomenclature of date, angle and counter, for example 219901 means February 19, 90 degree position and the first file created.

XOFT Labview operating procedures on the Xoft control computer

1. Secure source in the appropriate measurement position, either in the well chamber or the air-kerma position, which is in the leaded glass enclosure.
2. Follow the procedures for cooling and energizing the source.
3. Open the Labview application named EXPERT, which is located on the desktop in the upper right corner.
4. Open the datasocket server on the desktop in the upper right corner.
5. Once the Expert icon is clicked then the Manufacturing Test Fixture application opens to the MTF Logon window.
6. Enter Username: Expert and Password: XOFTexpert not case sensitive, then log on
7. Then numerous Manufacturing Test Fixture Administrator windows will open. The EXIT and TEST button should be selected on most.
8. Select YES for the zero electrometer; the PTW will take about 1 minute to zero
9. STOP at the MTF V&V Test C Setup and select MTFV&V test C setup MM10 hrs
10. Verify that the interlocks are all illuminated to left of screen and on the control box.
11. On final window select Test Type: select V&Vtest C
12. Enter Tube ID.
13. Toggle between Set ID and type for Test and Run Test to energize source.
14. If entrance to the radiation area is required for repositioning of equipment, for example during the inverse square and the air attenuation measurements, the source has to be de-energized or ramped down for safe entrance. This is accomplished by selecting Abort Test. The selection will allow voltage to be removed from the source and a safe entrance, without exiting the entire Labview program. Once the repositioning is complete then repeat step 13.
15. If the source is being de-energized and no additional source will be used and the software is being exited then the Abort Test button should be selected twice and the Exit option should be selected.

Procedure for charge collection in a well chamber

1. Connect the blue tri-axial signal lead to the correct well chamber and the Unidose electrometer.
2. Connect a prepared source to the cooling tubes and HV connector. Insert in the well chamber.
3. If the well chamber in use is NOT the NIST QA (A080851) well chamber then verify that the safety interlock is made for the NIST QA well chamber. This means place a voided source in the NIST QA well chamber.
4. Follow procedures for using the cooling medium flow pump.
5. Follow procedures for energizing the source.
6. Run the application WCCharge.vi as directed in the electrometer data acquisition procedures.
7. Use the average charge collection to determine the NIST calibration coefficient in units of Gy/(A s) normalized to reference conditions of 295.15 K and 101.325 kPa.

Environmental parameters procedures

During all calibrations the laboratory temperature must be maintained between 22°C ± 2°C and stable to ± 0.1 °C for typical measurement sets of 10 minutes. If the temperature is unstable during a typical

measurement set, calibrations should be postponed. The laboratory humidity should be maintained between 20 % and 50 % relative humidity. Since the pressure is monitored and the charge data is normalized to pressure it is good laboratory practice to postpone data collection and calibration work during sudden changes in pressure due to storms or weather fronts. If the pressure reading is stable during the calibration collection time, the measurements can continue. The pressure should be monitored and the influence on the normalization factor should be considered.

Uncertainty Analysis

The method of uncertainty assessment follows the NIST policy of expressing uncertainty, as outlined in the NIST Technical Note 1297 [6]. Conventional statistical estimates are given as standard deviations of the mean, and are designated as "Type A", which can be considered to be objective estimates based on statistical analysis. All other uncertainty estimates, which are designated "Type B", are subjective estimates, based on extensive experience and scientific judgment. The "Type B" uncertainties are estimated so as to correspond approximately to one standard deviation. The Type A and Type B estimates are combined according to the usual rule for combining standard deviations, by taking the square root of the sum of the squares, the quadratic sum. The quadratic sum of the two types of uncertainty is then considered to be the combined standard uncertainty, which is in turn multiplied by a coverage factor, of two, to give the expanded uncertainty. This expanded uncertainty is considered to have the approximate significance of a 95 % confidence limit. Table 3 lists the details of the assessment of uncertainty for the air kerma rates determined for the Xoft S700 x-ray beams by the free-air ionization chamber. No uncertainty component is provided for the distance since the air kerma measurement is made at a fixed distance and the uncertainty in the determination of that distance is considered negligible. The positioning of the source is determined by the laser and the ability to align the source to the laser, the uncertainty of which is also considered negligible. Table 4 lists the details of the assessment of uncertainty of the calibration coefficient determined with the calibration of a typical well-ionization chamber. No uncertainty component is included for the positioning of the source inside the well chamber. This uncertainty is considered to be negligible as any positioning variation is determined by the source positioning insert. As the estimates of uncertainty vary lightly with sources, methods of measurement, and rate, in each case the largest value is used for the estimate. In an official calibration, measurements could be repeated to maintain optimal conditions.

Safety

The main safety consideration is radiation protection as the typical air-kerma rate at the front face of the Lamperti Chamber is 2×10^{-4} Gy/s. As described below, every effort is made to avoid any possibility of radiation exposure, even though it would be highly unlikely that serious exposures could occur accidentally. All radiation areas in the building are marked with striped tape and dosimeters must be worn by all personnel. Another safety consideration is exposure to high voltage, such as exists on the standard chamber during calibration. There is no danger of high voltage related to the x-ray generator because the equipment in use has no exposed high voltage in a normal operating mode. Another safety concern, for which there is a separate safety protocol, is the risk from the liquid nitrogen used to cool the high-purity germanium (HPGe) detector.

Radiation safety

The electronic brachytherapy calibration facility was designed to eliminate any possible exposure to x radiation. Details are listed in the safety protocols posted in the facility. The miniature x-ray tube is interlocked with its power supply in such a way that if the tube is removed from the well chamber measurement position, the high voltage will not be applied. A red light signal illuminates when the power is on the x-ray source. An interlock barrier prohibits entry into the radiation area. If the electronic eye is tripped, the voltage is removed from the source. Both of these safety features are seen in Fig 15. A radiation warning light at the control panel turns on when voltage may be applied to the source. The entrance and shielding walls separating the control area from the radiation area, where the x-ray tube is located, are clear, leaded glass, providing radiation shielding while allowing for verification that no person is inside the radiation area.

High-voltage safety

The only danger that exists from high voltage comes from the free-air ionization chamber which operates at 3000 volts and the PTW QA and well chamber, which operate at 300 volts. To prevent dangerous electric shock, almost all power supplies contain current-limiting resistors in the high-voltage circuit. Common sense and education is dictated when working around chambers that have exposed high-voltage electrodes.

Cryogenic safety

The safety protocol, *Operation of High-Purity Germanium (HPGe) spectrometer liquid nitrogen cooling systems*, is posted in the facility. HPGe spectrometers are cooled by liquid nitrogen auto-fill systems. These systems include a cryogenic storage tank, fill timing device, overflow sensor, and solenoid valve. The posted protocol describes the safety and operational procedures to be followed when using the liquid nitrogen cooling systems of the HPGe spectrometer in 245/B24.

Filing and Retention

The RPD Quality Manager shall maintain the original and all past versions of this RPD 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 RPD 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 RPD Quality Manager.

Table 1. Essential equipment to conduct calibrations in the electronic brachytherapy calibration range

Description	Model	Serial number
Lamperti free-air chamber		
Fluke(Hart) thermometer	1504A	9A183

Thermistor probe	5611	071030708
Keithley electrometer	6512	0664954
Setra barometer	370	3781741
Bertan high-voltage power supply	230-03R	73031-1-A05384
Axxent HVPS		040108-006
NI controller	NI PXI-1033	136B8AD
Xoft high-voltage power supply	StellarTech	888-0431-000
Xoft controller	XTC-03	7(M-0803)
Xoft interlock controller		9
Canberra HPGe spectrometer	ULD010010FG	12088412
PTW Unidos E electrometer	T10010	00456
PTW ionization chamber	TN34013	00115
Axxent vacuum pump	E500	800193
HDR Axxent x-ray sources	S700	various
Connector lubricant	MS-383H	
Variable flow chemical pump	Fisher Scientific	111681331
Standard Imagining well-chamber	HDR 1000Plus	A080851
Xoft source holder		V050640

Table 2. Example of checklist to be completed prior to requesting a test folder

Test Folder Request Form			
Required Dates		**Optional Dates**	
PO received		Estimated job start	
Estimated completion		Equipment arrival	
Report mailed		Inspection complete	
Equipment returned			

Contact Information
NIST Technical Contact: **Michelle O'Brien x2014**
Company:
Technical Contact:
DG Number:

Instrument Description		
Manufacturer	Model	Serial Number

Calibration Request and Cost				
SP 250 Cal ID **460XXC**	Item Description **X-Ray Calibration**	Qty	Cost for this Cal ID **$**	**TOTAL**

Table 3. Estimated relative standard uncertainties for the determination of air kerma with the Lamperti chamber for the Xoft Axxent source at 50 kV, shown in %

Component	For:	Relative standard uncertainty, %	
		Type A	Type B
Q_{net}, I_{net}	net charge or current	s_Q[a], s_I[a]	0.06
	typical value	0.14[b]	
W/e	mean energy per ion pair	-	0.15
ρ_0	air density	0.01	0.07
V_{eff}	effective volume	0.04	0.01
k_{ion}	ion recombination	0.03	
$k_{humidity}$	humidity of air		0.04
k_{att}	attenuation	-	0.11
k_{el}	electron loss	-	0.06
k_{sc}	photon scatter	-	0.03
k_{fl}	fluorescence reabsorption	-	0.05
k_{br}/(1-g)	effects of bremsstrahlung	-	0.02
k_{ii}	initial ion	-	0.04
k_{dia}	diaphragm scatter	-	0.10
k_d	electric field distortion	-	0.20
	aperture penetration	negligible	
	chamber face penetration	negligible	
	polarity difference	0.02	
Combined	air kerma	0.15	0.321

[a] Determined as the standard deviation of the mean of the measurement.
[b] Typical value for numerous S700 sources measured in 2013/2014.

Table 4. Estimated relative standard uncertainties for well chamber calibrations, shown in %

Components	For:	Relative standard uncertainty, %	
		Type A	Type B
Q_{net}, I_{net}	net charge or current	s_Q[a], s_I[a]	0.06
	typical value	0.10[b]	
ρ_0	air density	0.01	0.07
$k_{humidity}$	humidity of air		0.03
	uncertainty of air kerma from Lamperti chamber	0.15	0.321
combined	air kerma calibration coefficient	0.178	0.335

[a] Determined as the standard deviation of the mean of the measurement.
[b] Typical value for numerous S700 sources measured in 2013/2014.

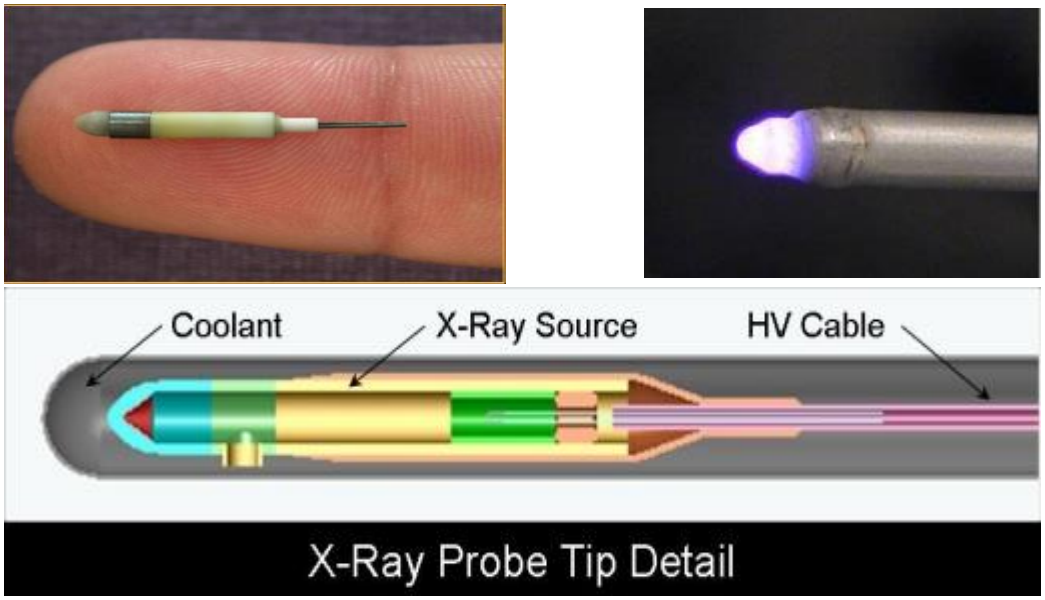


Figure 1a. The Xoft Axxent miniature x-ray source tip detail.

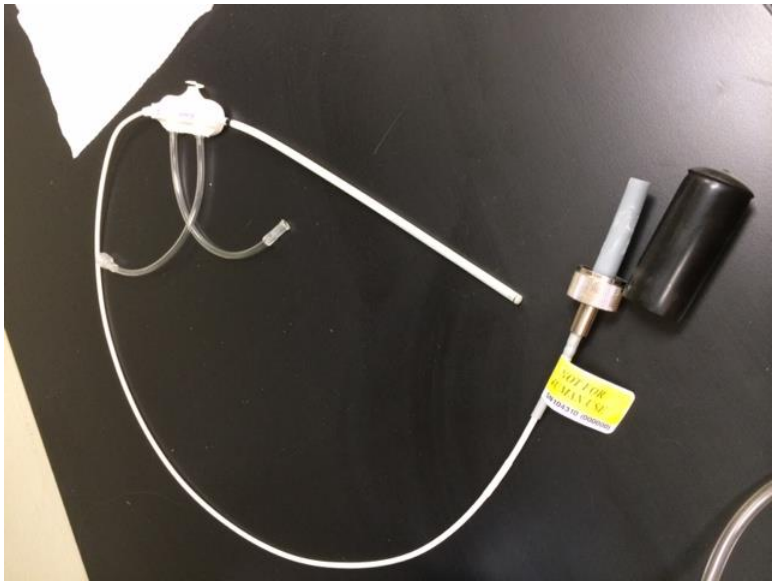


Figure 1b. The Xoft Axxent miniature x-ray source catheter enclosed and HV connector.

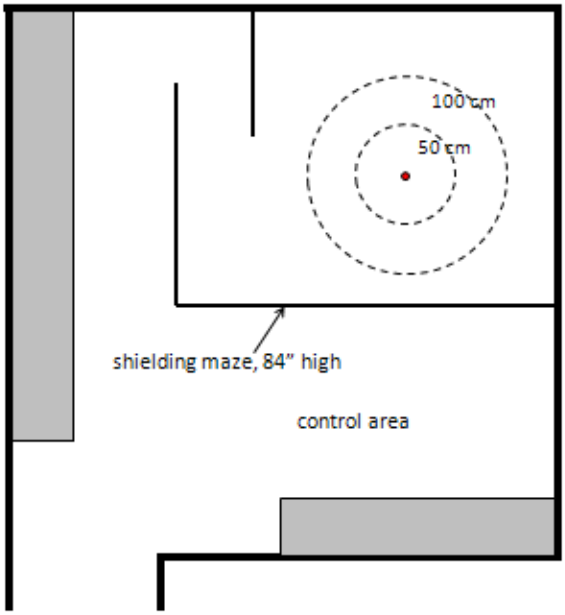


Figure 2a. Layout of the NIST electronic brachytherapy dosimetry facility.

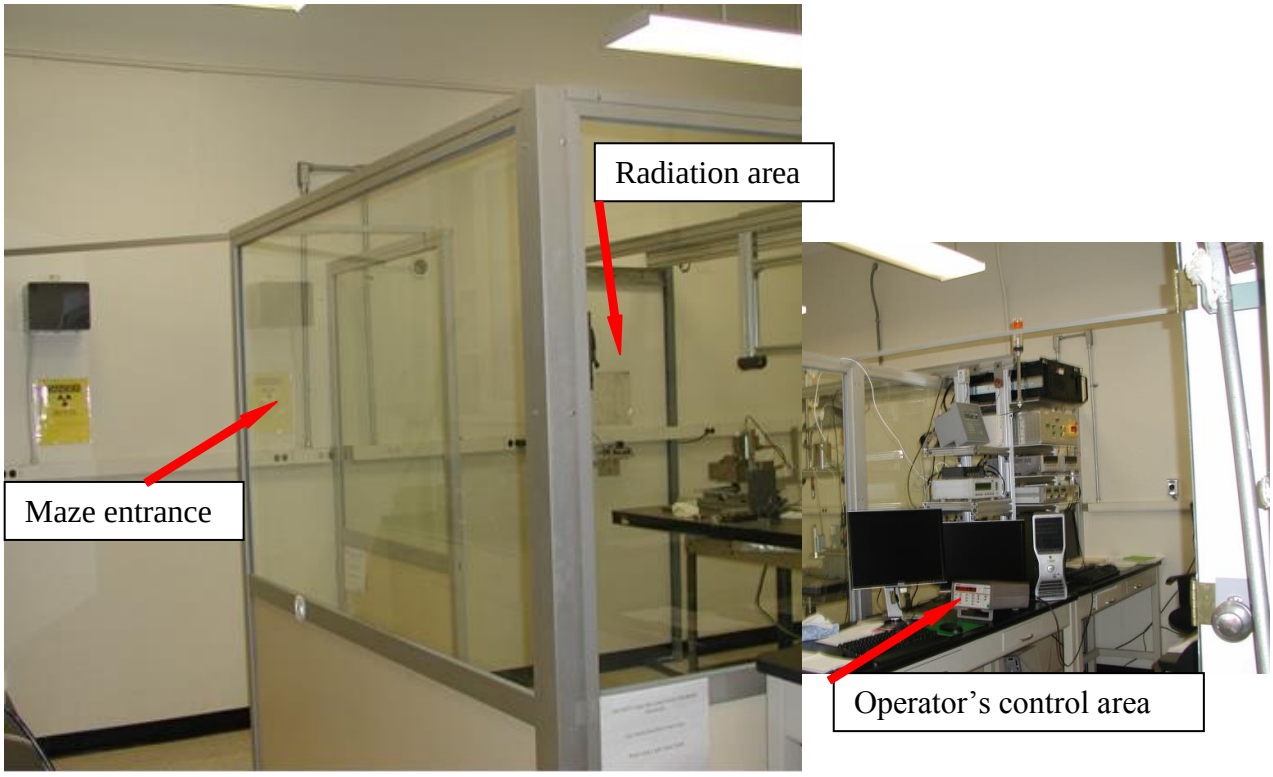


Figure 2b. NIST facility showing lead glass enclosure.

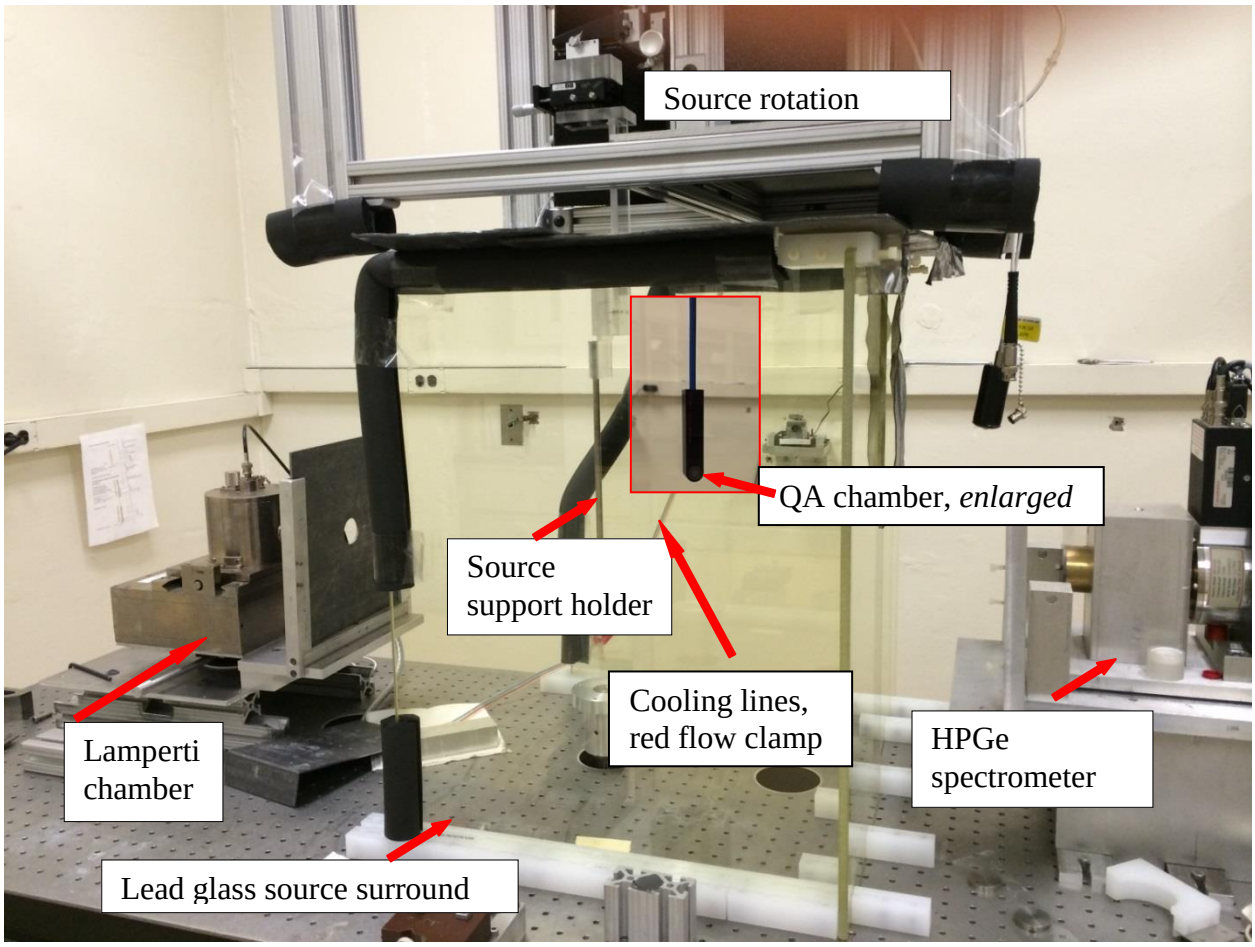


Figure 3. Low Scatter Measurement set-up with the Lamperti FAC.

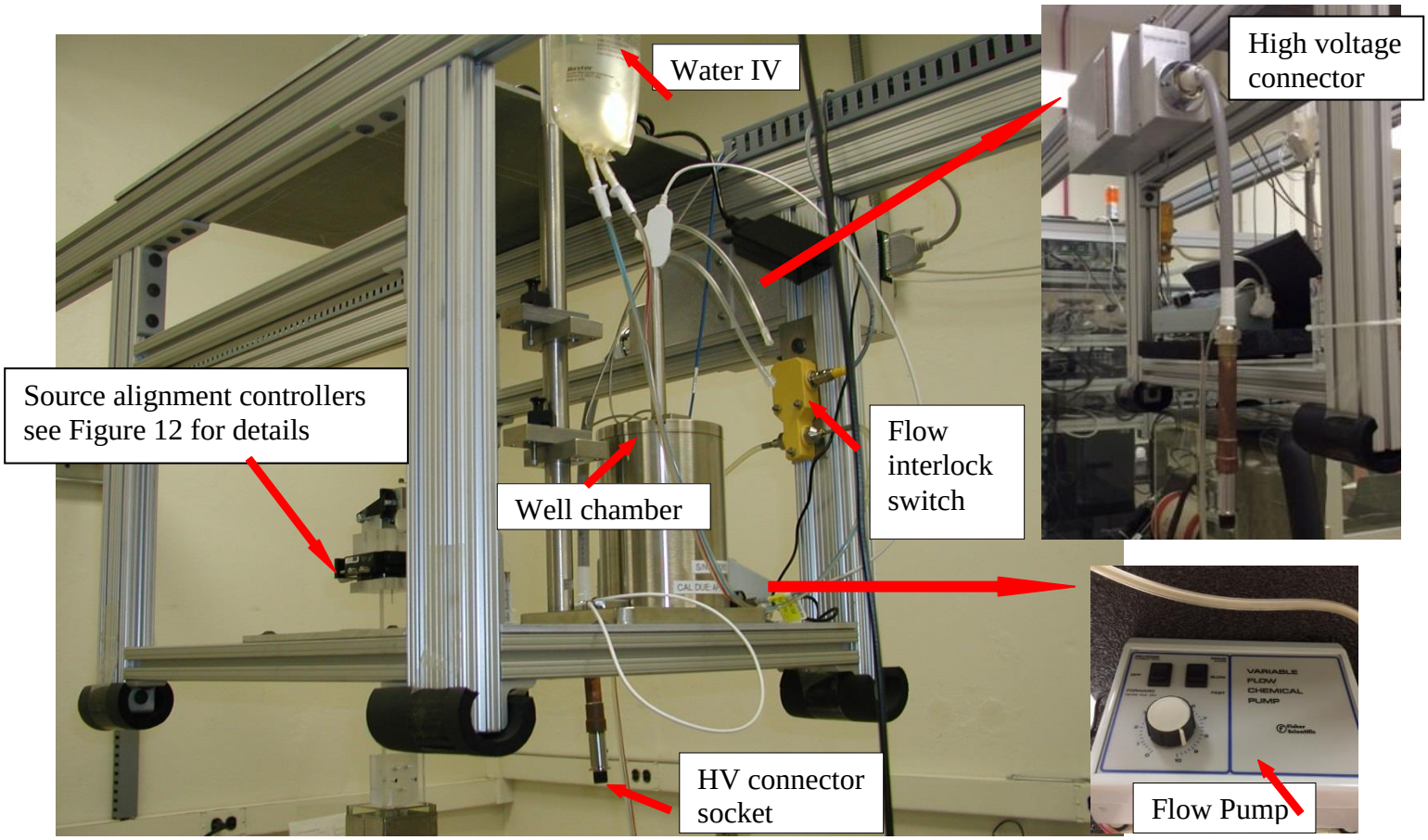


Figure 4. Well chamber platform with water IV bag, flow pump, which is hidden behind well chamber in large picture so shown in smaller picture, flow interlock and HV connector, also hidden so shown to right.

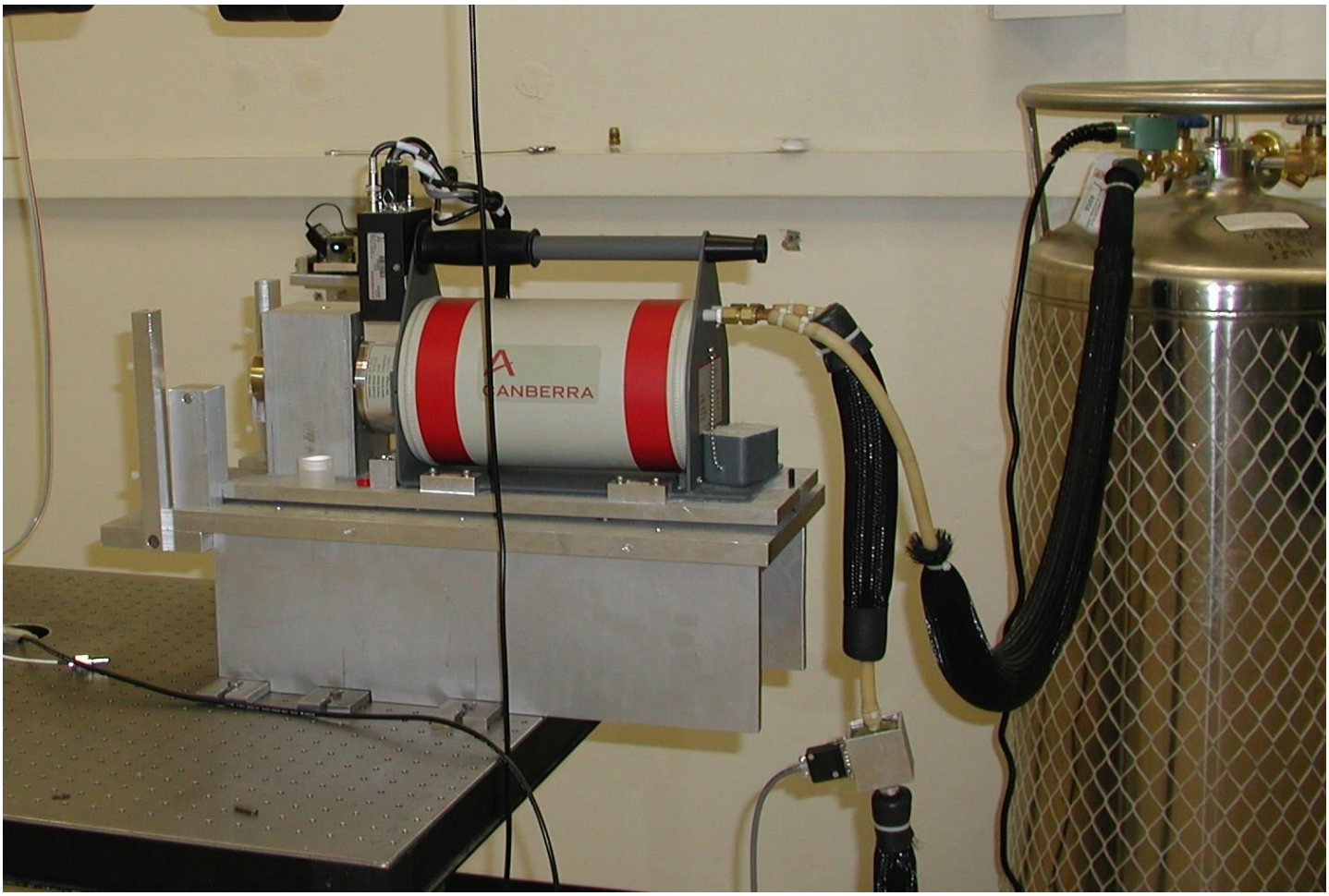
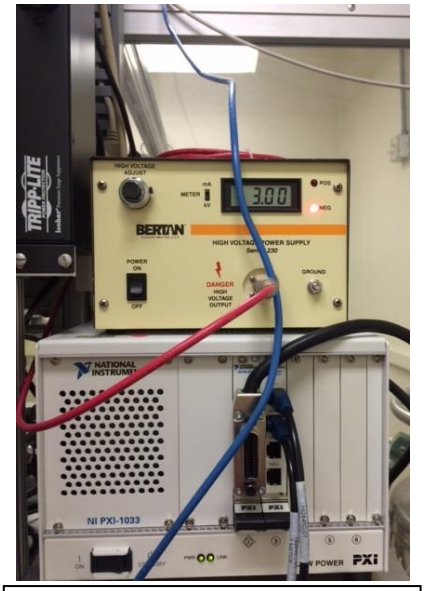


Figure 5. High-purity germanium detector with cooling Dewar.



Bertan HV supply (top)
Labview controller (bottom)

Figure 6. Essential rack mounted equipment.

Figure 7. Barometer, thermometer and well-chamber electrometer.

igure 8. Front and back view of the electrometer used with the Lamperti chamber. Back view shows required tri-axial hook up.

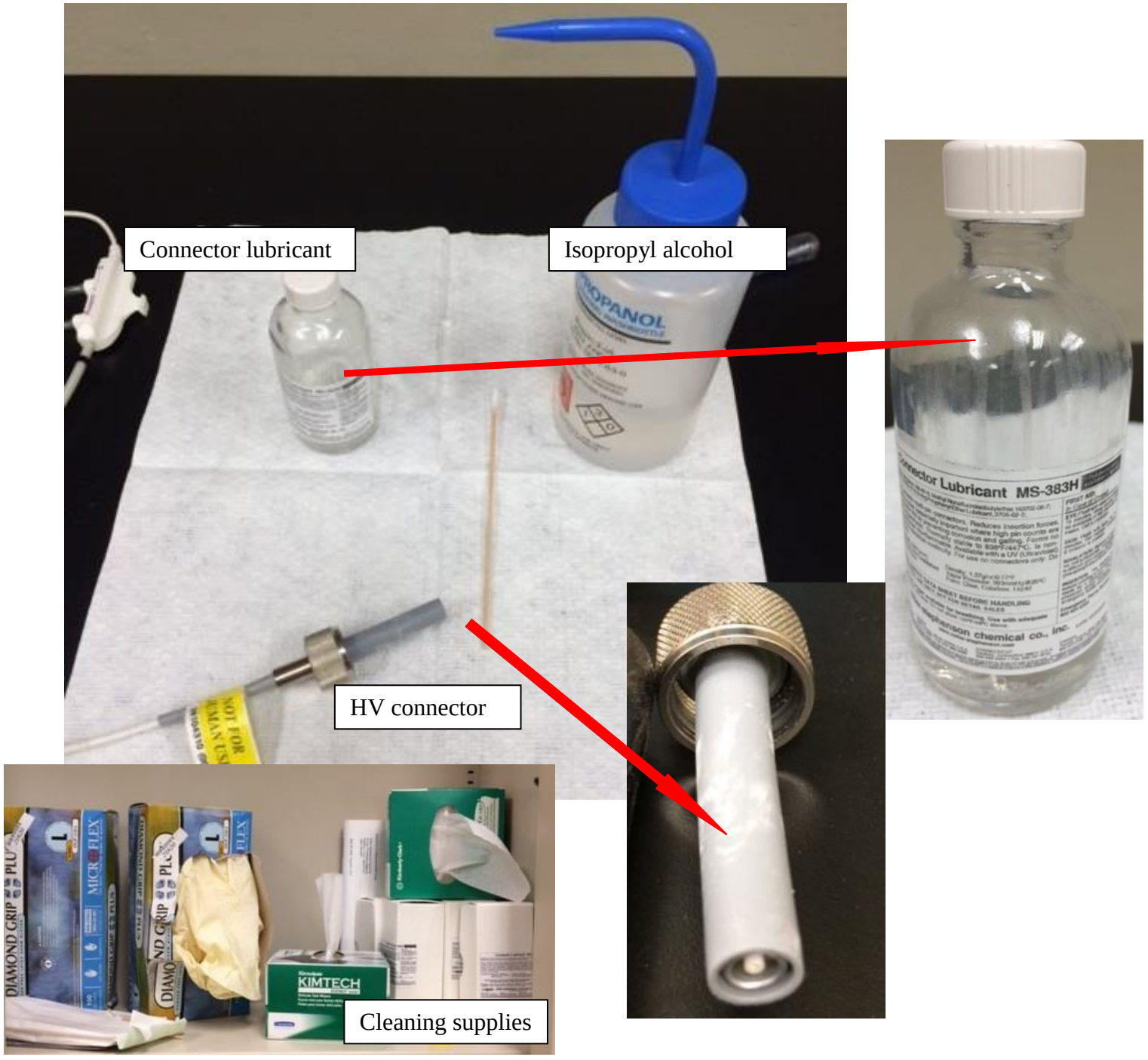


Figure 9. Supplies for cleaning HV connector

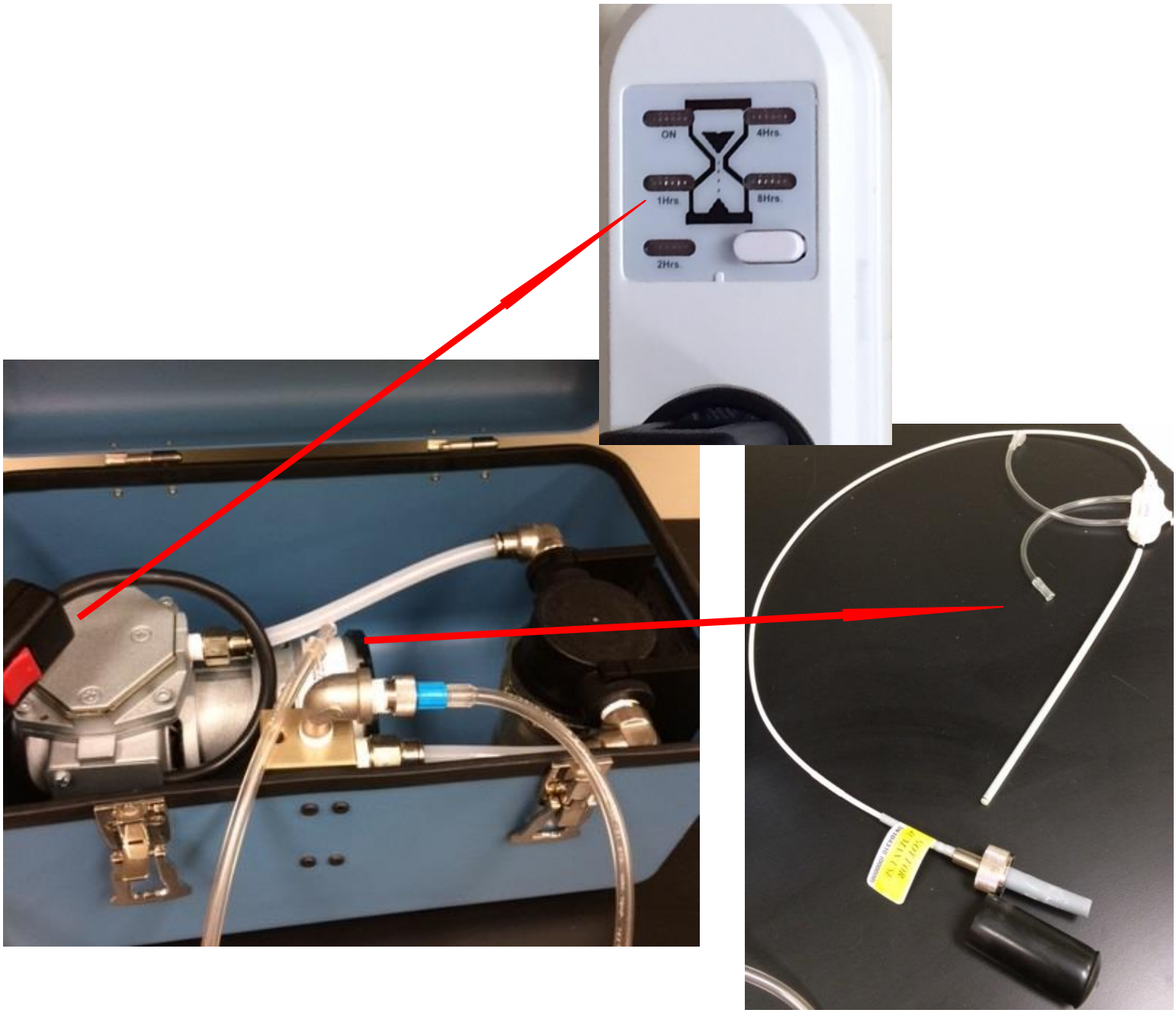


Figure 10. Vacuum pump and drying details.

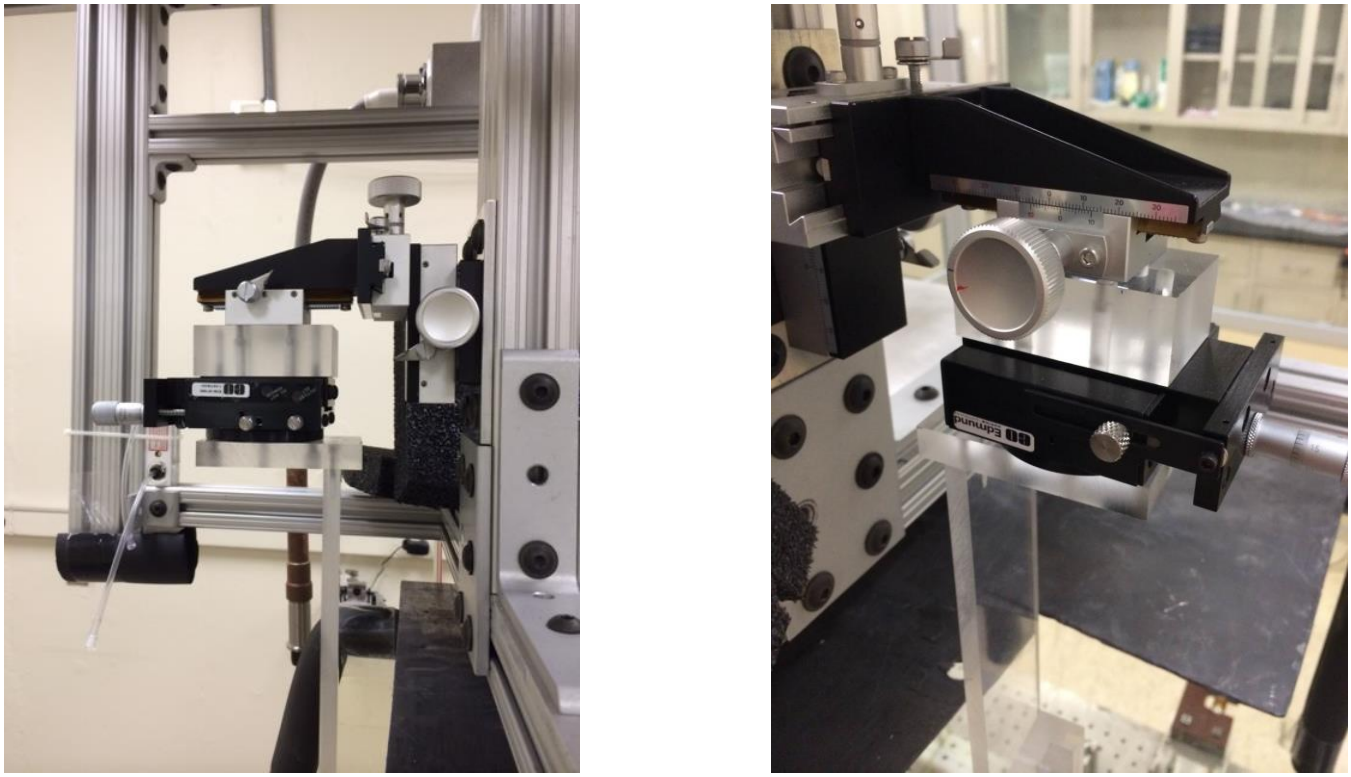
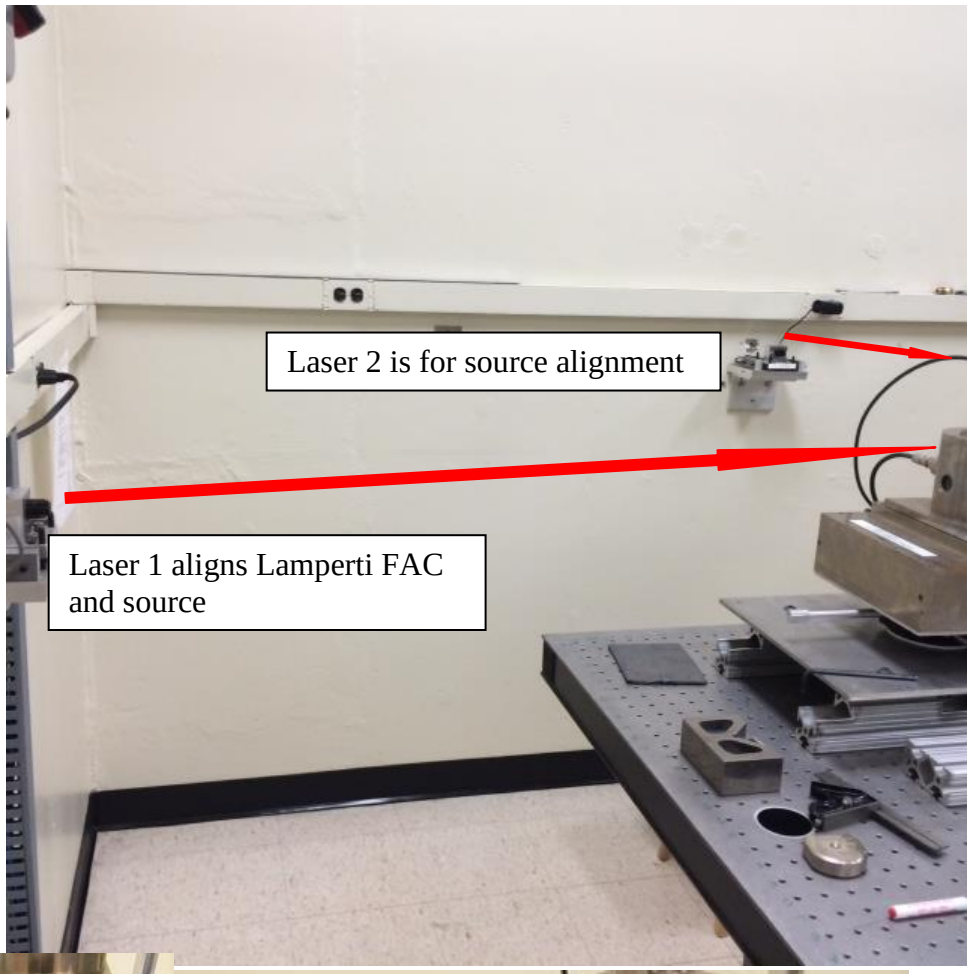
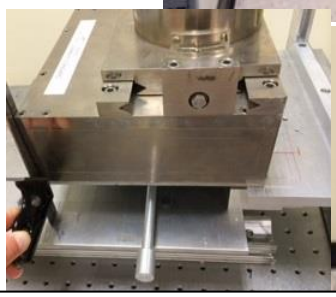
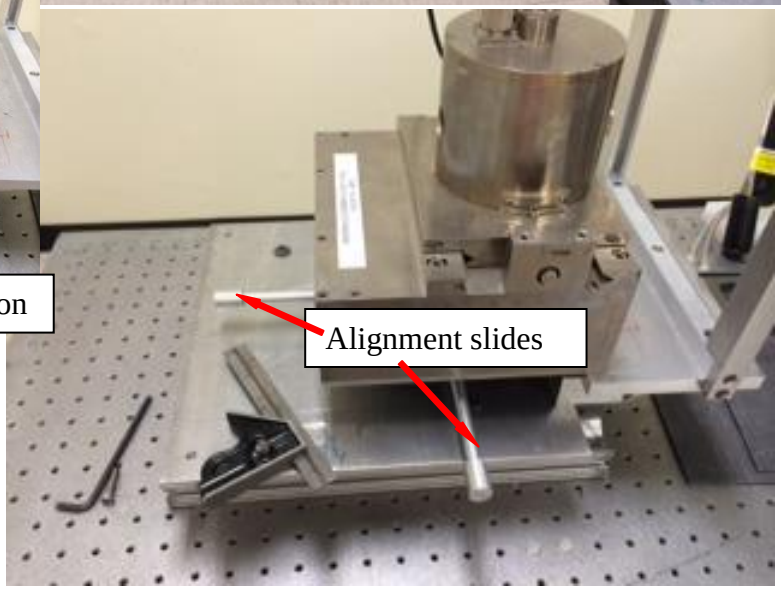


Figure 11. Side views of alignment and rotation adjustments for the source holder.







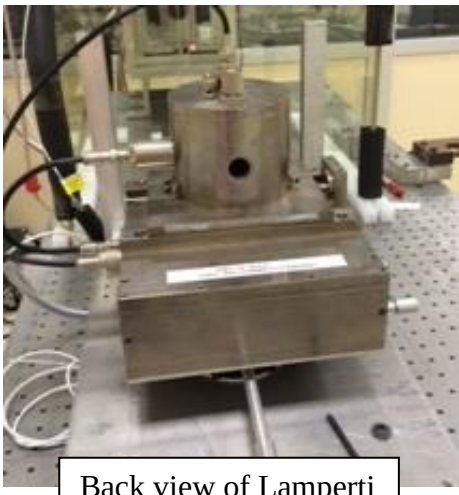


Figure 12. Techniques for Lamperti chamber and source alignment

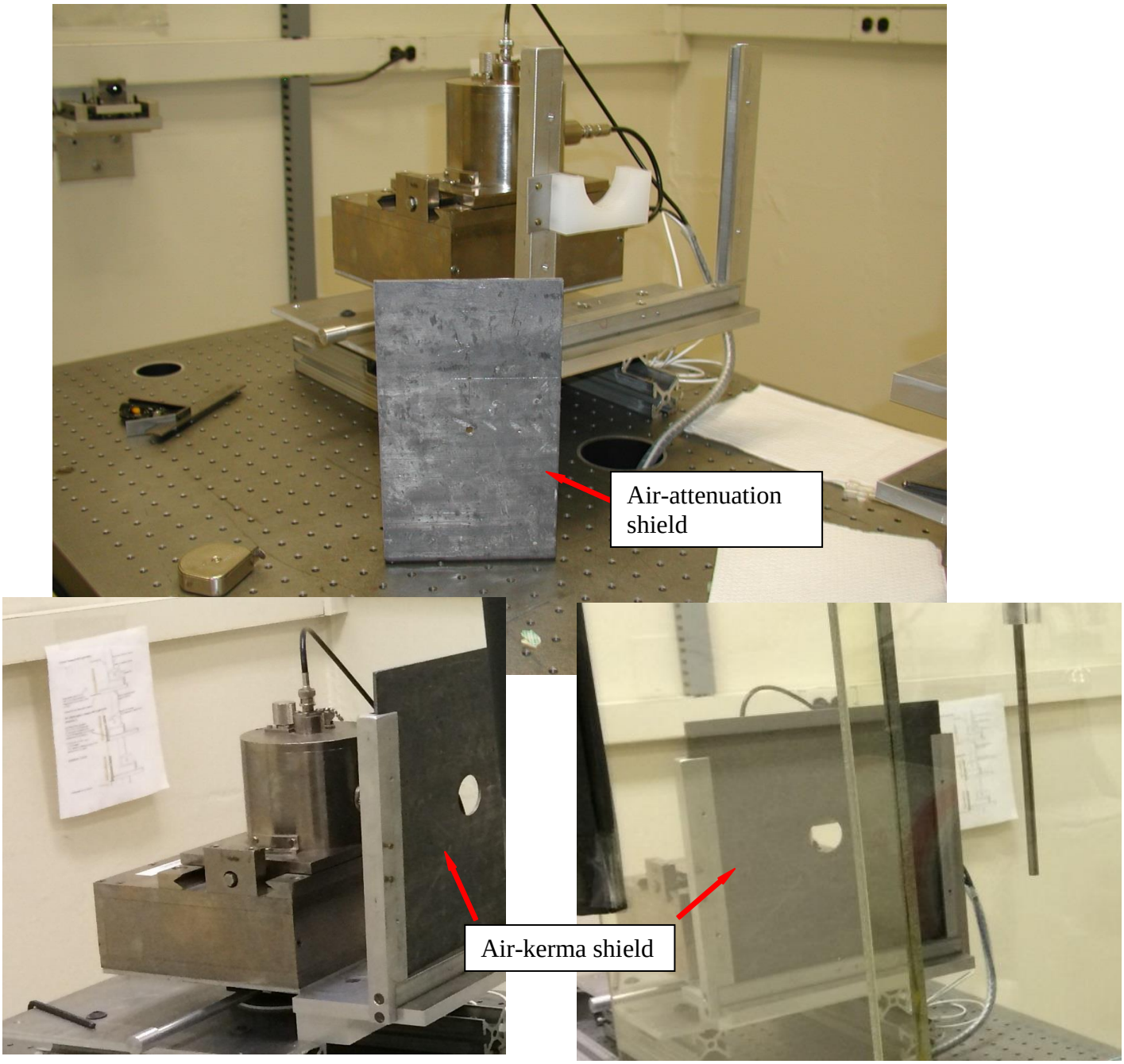


Figure 13. Lead shields used for air-kerma and air-attenuation measurements

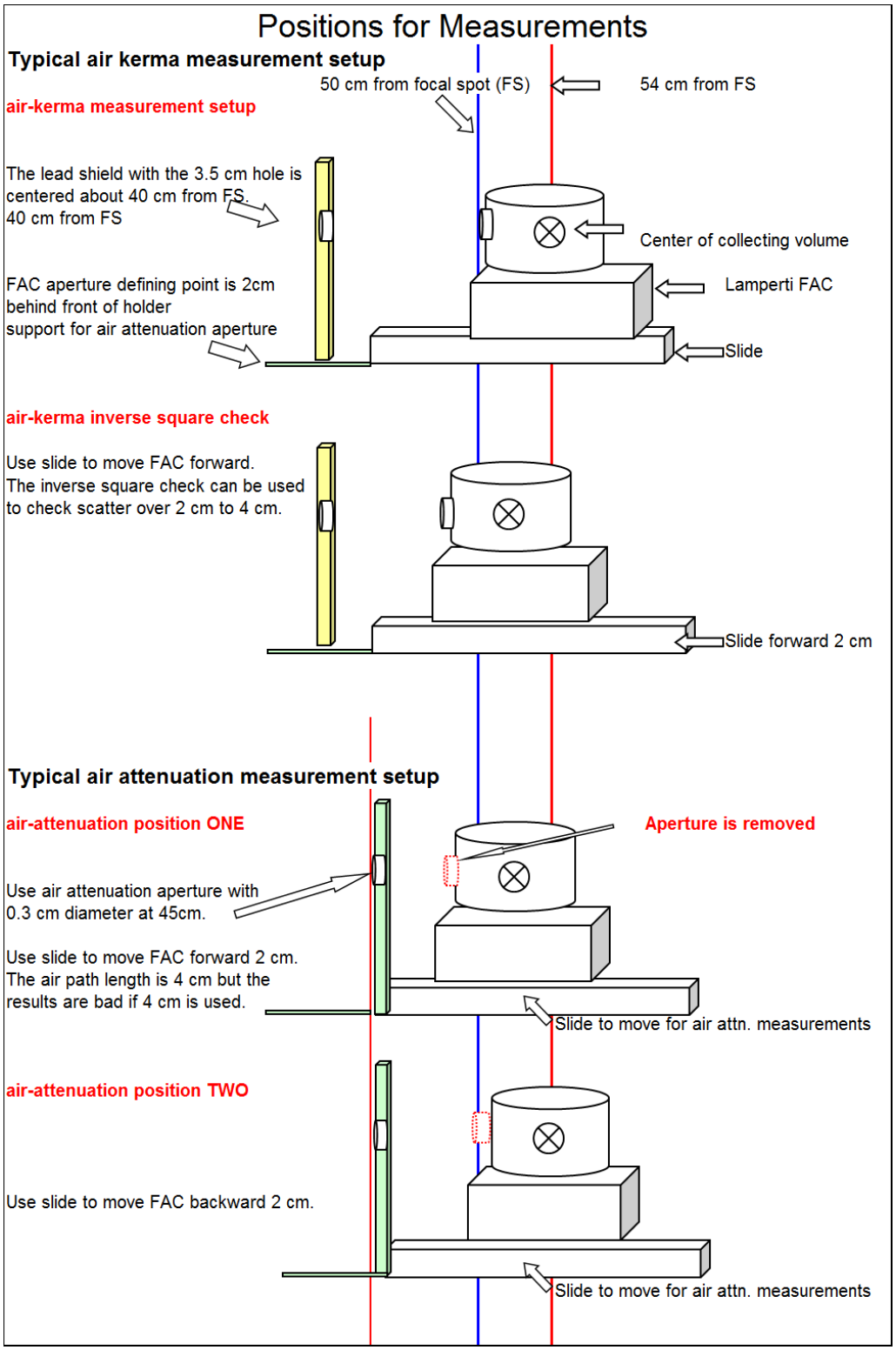


Figure 14. Positions for the Lamperti Chamber for different measurements

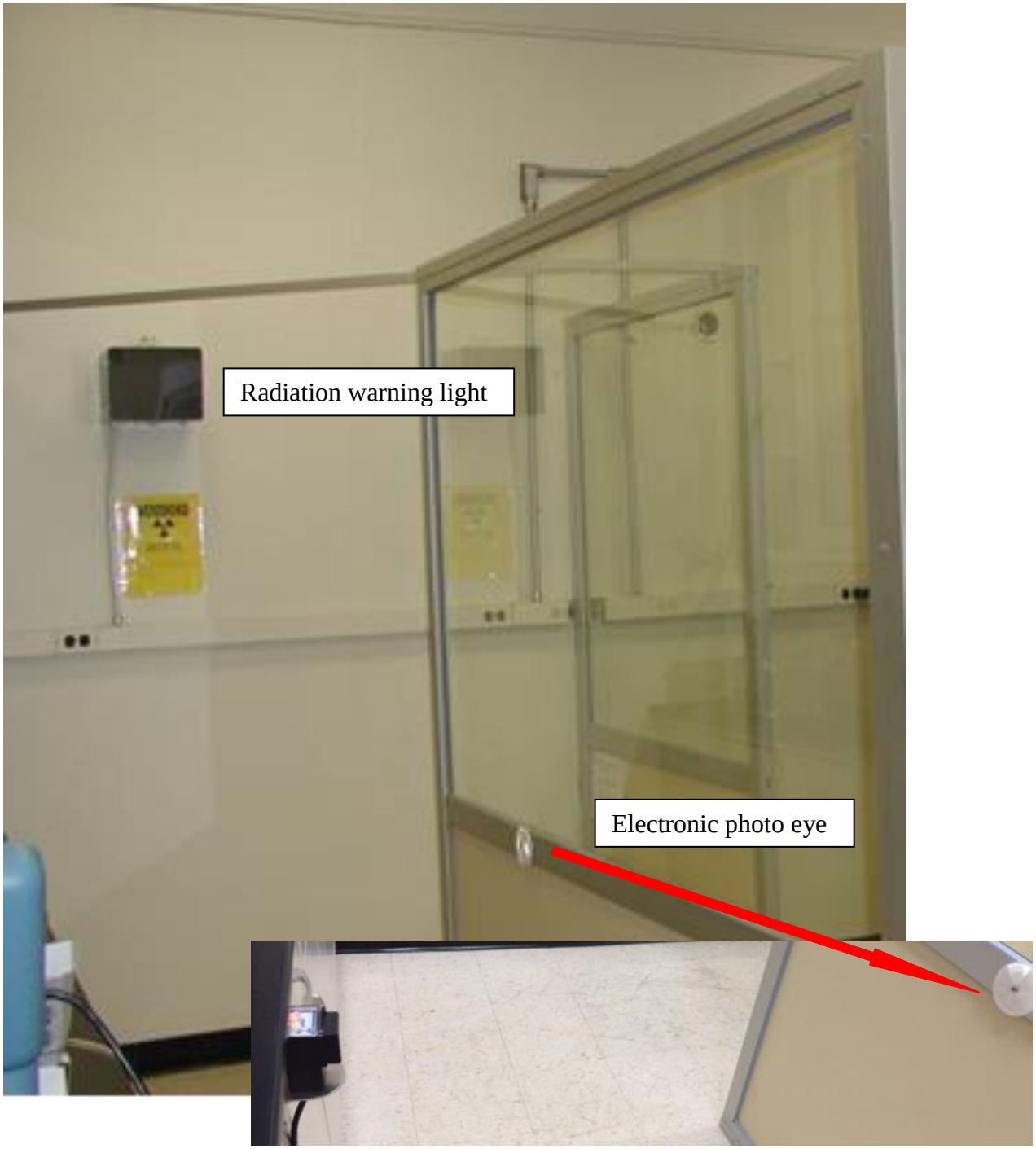


Figure 15. Two radiation safety interlocks.

Appendix 1: ***Sample Report***

REPORT OF AIR-KERMA CALIBRATION

OF
address

Radiation Detection Chamber: Standard Imaging Model HDR1000 Plus (S/N A######)
with the Xoft Source Holder (V######) Ref #####
Xoft Axxent S700 Sources: #####

Calibrations performed by Michelle O'Brien

Report reviewed by Ronaldo Minniti

Report approved by Michael G. Mitch

For the Director
National Institute of Standards and Technology
by

Lisa R. Karam, Chief
Radiation Physics Division
Physical Measurement Laboratory

Information on technical aspects of this report may be obtained from Michelle O'Brien, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460, Gaithersburg, MD 20899, michelle.obrien@nist.gov, or (301)975-2014. 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).

Report format revised 8/14

DG: #####/14
NIST ID 460##C TF:#####
00/00/2015

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

REPORT OF AIR-KERMA CALIBRATION

OF
address

Radiation Detection Chamber:
Standard Imaging Model HDR1000 Plus (S/N A######)
with the Xoft Source Holder (V######) Ref #####
Xoft Axxent S700 Sources: #####

Well Chamber: Standard Imaging Model HDR1000 Plus (S/N A043636) with the Xoft Source Holder (V112651) Ref 70088 at a collection potential = + 300 V to measure negative current.
Electrometer used for well chamber at NIST: PTW Unidos E SN T10010-00456
The following conditions were used when the sources were energized. All conditions were set and controlled automatically by the Xoft control software.
Xoft Controller settings*:* Tube voltage was 50 kV and the beam current was 300 µA.
Date of calibration: Month year

Xoft Axxent Source Conditions (Data presented here as examples of quantity.)

Xoft Source	**NIST Air-Kerma Rate at 50 cm** (Gy/s)	**Xoft Controller Filament Current** (A)	**NIST Calibration Coefficient** **295.15 K (22 °C) and 101.325 kPa (1 Atm)** (Gy/s/A)	**Uncertainty Type A** s_Q [a]
#####	1.95E-04	1.403	1.713E+03	0.14[b]
#####	1.67E-04	1.335	1.674E+03	0.14[b]
#####	2.11E-04	1.367	1.754E+03	0.14[b]

[a] Determined as the standard deviation of the mean of the charge measurement.
[b] Typical value for numerous S700 sources measured in 2013/2014.

Explanation of Terms Used in the Calibration Procedures and Tables

Air Kerma: The air-kerma rate at the calibration position is measured by a free-air ionization chamber for x radiation and is expressed in units of grays per second (Gy/s). For a free-air ionization chamber with measuring volume *V*, the air-kerma rate is determined by the relation:

$$\dot{K} = \frac{I}{\rho_{\text{air}} V} \frac{W_{\text{air}}}{e} \frac{1}{1 - g_{\text{air}}} \prod_i k_i$$

where

$I / (\rho_{\text{air}} V)$ is the ionization current, measured by the standard, divided by the mass of air in the measuring volume

W_{air} is the mean energy expended by an electron of charge e to produce an ion pair in dry air; the value used at NIST is W_{air}/e = 33.97 J/C

g_{air} is the fraction of the initial kinetic energy of secondary electrons dissipated in air through radiative processes; the value is 0.0 (negligible) for x rays with energies less than 300 keV, and

$\Pi\, k_{\text{i}}$ is the product of the correction factors to be applied to the standard.

Calibration Coefficient: The calibration coefficients given in this report for the well chamber are quotients of the air-kerma rate (Gy/s) per ampere collected in the well chamber. The measurements are normalized to a pressure of one standard atmosphere (101.325 kPa) and a temperature of 295.15 K (22 °C). No correction is made for the effect of water vapor on the instrument being calibrated. The average current used to compute the calibration coefficient is based on measurements with the well chamber at the stated polarity and potential.

Uncertainty: The expanded, combined uncertainty of the calibration described in this report is 0.86 %, of which 0.71 % is assigned to the uncertainty in the air-kerma rate of the NIST beam. 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.

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

Appendix 2: *Sample Calibration Spreadsheet*

Calculation of Air-Kerma with the Lamperti Chamber

DATE:	
xoft value U:	
amps	
inverse square difference	
NIST WC	
%stdev	
customer WC	
%stdev	
air kerma 0 degree	
120 degree	
240 degree	
AVG air kerma	
%stdev	
AirKerma/NIST WC	
AirKerma/white WC	
%stdev on charge	

Dimensions

FAC center (cm):	54
Airpath (cm):	**4**
Aperture Diam. (cm):	**0.5**
Collector (cm):	**1.01346**

ka: **u:** **u/p:** measured and calculated values

corrections	
ka:	1.0087
u/p:	1.8500
Kp:	0.9987
Kbr:	1.0000
Kh:	0.9980
Kfl:	0.9979
ke:	1.0008
Ks:	0.9996
kii	1.000
Kl	1.000
Kpen	1.000

typical entered data in purple

typical calculated values in blue

Date	air kerma (C/s)	Temp	Pres	density	1/poV	exp(u/p*p*x)	corrections	Units -R/s	R/s	Gy/s no Ks	Ks	Gy/s
DATE	1.1381E-12	21.4867	751.914	1.19E-03	**4238.1**	1.0088	0.995007	3.8760E+06	0.0188	1.64E-04	0.9997	1.644E-04

ID	hand entered data					
54cm	**charge/60s**	**C/60 s**			**FAC 3000 volts**	
	0.2055				leakage	
	0.2738	0.0683	0.00114		1.04	
	0.3415	0.0677	0.00113		1.44	0.4
	0.4093	0.0678	0.00113		1.85	0.41
	0.4771	0.0678	0.00113		2.22	0.37
	0.545	0.0679	0.00113		2.52	0.3
	0.613	0.068	0.00113		2.91	0.39
			1.1381E-12		3.28	0.37
			0.0011		3.69	0.41
			0.17%		4.11	0.42
This type data collection is repeated multiple times for each source and type c					4.36	0.25
air-kerama, each of three angles(0, 120 and 240), inverse square calculation and air attenuatio						-6.148E-15

All data is kept on one spreadsheet per source ID.

Example of inverse square calculation, shown with typical data:

This is a good predictor of adequate source geometry. The agreement should be around 1%.

dist	airkerma	dist2	ratio dist	inverse	ratio kerma	Agreement
51.5	1.46E-12	2652.25				
54	**1.31E-12**	2916	0.90955	1.09944	1.11	-1.29%

Example of air attenuation calculation, shown with typical data:

	Temp 20.88		**density of air** 1.203E-03		
	Pres 761.39				
dist. FAC center to Sourc	**(C/s)**	**time (s)**	**T&P Cor**	**Charge T & P**	
51.5	3.528E-13	60	1.074	3.79E-13	
54	3.511E-13	60	1.074	3.77E-13	
			Ka	1.0047	
			U	0.00189	
			U/p	1.574E+00	

References: NEW

[1] P. J. Lamperti and H. O. Wyckoff, "NBS free-air chamber for measurement of 10 to 60 kV x rays," J. Res. Natl. Bur. Stand. 69C, 39 – 47 (1965).

[2] P. J. Lamperti and M. O'Brien, *NIST Measurement Services: Calibration of X-Ray and Gamma-Ray Measuring Instruments*, NIST Special. Publication 250-58, National Institute of Standards and Technology, Gaithersburg, MD (2001).

[3] Seltzer, S.M., O'Brien , M. and Mitch, M.G., "*New National Air-Kerma Standard for Low-Energy Electronic Brachytherapy Sources*," J. Res. Natl. Inst. Stand. Technol.Volume 119 (2014). http://dx.doi.org/10.6028/jres.119.022

[4] International Commission on Radiation Units and Measurements, *Fundamental Quantities and Units for Ionizing Radiation*, ICRU Report 85a (International Commission on Radiation Units and Measurements, Bethesda, MD) (2011).

[5] Bureau International des Poids et Mesures, *Le Systéme International d'Unités (SI), The International System of Units (SI)*, 8th Edition (Bureau International des Poids et Mesures, Sèvres) (2006).

[6] NIST Technical Note 1297, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, (1994). Edition. http://www.nist.gov/pml/pubs/tn1297/index.cfm

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