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CALIBRATION OF OPHTHALMIC APPLICATORS

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## Calibration of Ophthalmic Applicators

### 1. Purpose and Scope

This document describes procedures used at NIST to calibrate beta-particle emitting ophthalmic applicators in terms of absorbed-dose rate to water at the source surface.

#### 1.1. Background and History

Applicators employing  $^{90}\text{Sr}/\text{Y}$  beta particle sources for the treatment of benign eye diseases (pterygia) were introduced in the 1950s. Between then and the 1990s, about 10 different manufacturers marketed such sources, and it is estimated that on the order of several hundred units were produced (Soares 1995). Manufacturing of planar  $^{90}\text{Sr}/\text{Y}$  ophthalmic applicators ceased in the 1990s. However, due to the long half life of the radioisotope employed (30 y), some devices are still being used for therapy.

The NIST calibration service for the calibration of  $^{90}\text{Sr}/\text{Y}$  ophthalmic applicators was inaugurated in 1977 by J.S. Pruitt. In this initial format, the service provided surface absorbed dose rate to water calibrations determined with an extrapolation chamber equipped with a 30 mm diameter collecting electrode. The measured current per unit air gap was used divided by the effective source area, determined by mapping the source area using a 1 mm diameter collecting electrode (probe). This procedure (Pruitt 1987) was followed until 1989, when problems with the method were discovered. These problems had to do with the normalization method using the source effective area, which is a poorly-defined quantity for some sources. The calibration service was closed down for 12 months while a new method was developed. In 1990 the service was restarted using a new procedure (Soares 1991) involving measurements with a collecting electrode smaller than the source area to allow a more precise specification of the measurement area. In addition, a smaller range of air gaps was introduced to minimize the effects of curvature in the measured current versus air gap function. In 1996, the present level of automation was completed with the addition of a four dimensional positioning system.

The calibration volume for these sources has never been great (see Fig. 1), and plummeted dramatically after 1996 when the University of Wisconsin Accredited Dosimetry Calibration Laboratory (ADCL) received accreditation for calibrations of planar  $^{90}\text{Sr}/\text{Y}$  ophthalmic applicators. In 2003, a change in the calibration service was introduced involving the addition of a new correction and the refinement of another correction. The overall change in the quoted absorbed dose rate was about 6.5 % and is nearly independent of source type, unlike the changes introduced in 1990 which were strongly dependent on source type.

One handicap the calibration service has always suffered under was the lack of interlaboratory comparisons with other primary standards laboratories. It has been only within the last few years that the Physikalisch Technische Bundesanstalt (PTB) in Germany has introduced a service even remotely similar to that employed at NIST, and only informal interlaboratory comparisons have occurred to date. In the late 1990s, NIST organized an interlaboratory comparison of ophthalmic applicator dosimetry (Soares et

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al., 2001) that involved the National Physical Laboratory (NPL) in Great Britain as well as several hospitals and secondary laboratories. At that point, the NPL standard was still under development and this development has not (yet) been completed. It is anticipated that, in future years, there will be comparable measurement capabilities available at other primary standards laboratories allowing more formal interlaboratory comparisons to take place.

### 1.2. Introduction to Ophthalmic Applicators

The typical ophthalmic applicator consists of a cylindrical radioactive core encapsulated in a cylindrical housing with a thin metallic "window" to allow the beta radiation to exit. The housing is mounted on a handle, sometimes with a pivot to allow the source to be used at an angle from the handle. The user is protected by a plastic shield mounted on the handle. All ophthalmic applicators have these same basic features. The source elements are either porous ceramic slugs impregnated with a radioactive liquid and then fired to seal in the activity, or metal foils on which the radioactivity has been electroplated. Source diameters are on the order of 5 mm to 10 mm and are usually only a few mm smaller than the source housings. The windows and the housings are usually stainless steel, although silver is sometimes used. Window thicknesses are usually on the order of 0.1 mm, which is thick enough to nearly stop all the low energy  $^{90}\text{Sr}$  beta radiation, but allows most of the higher energy  $^{90}\text{Y}$  beta radiation to exit the housing. Handles are 5 mm or so in diameter and usually 10 cm or so in length. The clear plastic shields are on the order of 5 mm thick and are either square or round with 10 cm being a typical dimension. The shields often are removable and frequently free to rotate about the handle. There is usually a flat place on the handle on which source information such as model, serial number and activity are engraved. Ophthalmic applicators invariably are supplied in a wooden box for storage. This box usually contains some metallic shielding in which the source head is placed. On some source models, there is a removable cap that goes over the source window, providing extra shielding when the source is being stored. A schematic diagram that illustrates the parts of the typical source is shown in Figure 2.

### 1.3 Introduction to the Extrapolation Chamber

The extrapolation ionization chamber ("NIST chamber") is a device designed to achieve a continuously variable air volume. This volume is defined by two electrodes and an insulating ring that separates the collecting region from the guard region. A potential is placed between the two electrodes that causes ionization products to be swept out (collected) of the defined volume. The radiation enters the chamber through a thin (0.006 mm thick) aluminized polyethylene terephthalate (PET) window that also serves as the "high voltage" electrode by having a voltage placed upon it. The radiation passes through the air in the gap between the electrodes, striking the other (collecting) electrode that is held at ground potential. The sign of the voltage placed on the high voltage electrode determines the sign of the ionization products collected by the collecting electrode. Since the beta particles are also stopped in the collecting electrode material, there is always a negative current being measured and recourse must be made by performing measurements at both polarities in order to remove this unwanted "parasitic" current from the desired ionization current. A schematic diagram illustrating the basic parts of the

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extrapolation chamber is shown in Figure 3. The current from the collecting electrode is measured with a high-impedance electrometer. Even though the air volumes are small (on the order of  $0.001 \text{ cm}^3$  to  $0.002 \text{ cm}^3$ ), the measured currents are moderate, on the order of 10s of pA, because the dose rates are high (100s of mGy/s); thus, an extremely sensitive electrometer is not required. The high voltage supply must be bipolar since measurements are made at both positive and negative polarities. It is convenient to use an electrometer with a built-in high voltage supply. The voltage gradient used is large, 100 V/mm, however, the recommended air gaps are very small ( $< 0.2 \text{ mm}$ ), so only modest voltages are required.

The remaining components of the extrapolation chamber are for mechanical motion (namely, to vary the air gap and to move the source relative to the collecting electrode). Unlike most extrapolation chambers, the collecting electrode is stationary and everything else (the source and the entrance window) moves relative to it in the NIST chamber. This has the disadvantage that extra motion control is required, but this is decidedly outweighed by the fact that, in the NIST chamber, the collecting electrodes can be easily removed. This allows the use of collecting electrodes of different diameters to make measurements on the same source without source realignment.

In the current version of the NIST extrapolation chamber, all motions and the data collection are computer controlled. Four high precision stepping motors are used; three to translate the source in three dimensions and the fourth to drive a rotating stage to move the entrance window. Data is collected from the electrometer and, since ionization chamber measurements must be corrected to reference conditions of temperature and pressure, from a thermometer and a barometer. The polarity and magnitude of the voltage applied to the entrance window is also under computer control. A schematic diagram showing the components and interconnections of the extrapolation chamber is given in Figure 4.

The polarizing voltage is delivered to the aluminized surface of the entrance window via a depth gauge that is mounted on the collecting electrode housing. The depth gauge also serves as a very rough indicator of the air gap. The aluminized side of the PET entrance window faces the collecting electrode. It has been found that the chamber operates with more stability when the source under measurement is kept at the same electrical potential as the high voltage electrode. Therefore, an electrical connection is made between the source and the high voltage supply. Care must be taken that all other surfaces and components are at ground potential (see Section 5.4). Photographs of the NIST extrapolation chamber are shown in Figure 5.

There are several crucial pieces of equipment necessary to have at hand when measuring ophthalmic applicators with the extrapolation chamber. A hand-held digital voltmeter is often necessary to verify that the voltage is being delivered where it should be and that grounding is properly maintained. Double sided adhesive tape is necessary to perform many of the measurement tasks outlined in this document and to temporarily affix sources and radiochromic films. A source of compressed air is often necessary to remove

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dust from surfaces, particularly the collecting electrode surface. Since air gaps down to 50  $\mu\text{m}$  are recommended, a little dust in the wrong place can prevent one from achieving these conditions. Plastic spacers are commonly used to mount some sources in the extrapolation chamber to provide electrical isolation of the source from ground. Finally, a good supply of unwrinkled aluminized PET should be maintained when the inevitable occurs and it is necessary to replace the entrance window (see Section 4.2).

## 2. Health and Safety

Radiation safety and training services are provided by the NIST Health Physics Group. Ophthalmic applicators contain activities on the order of 1 GBq to 4 GBq (20 mCi to 100 mCi) and are capable of producing very high absorbed dose rates, even considering the fact that only beta particles with limited ranges are produced. Dose rates on the order of 1 Gy/s are present at the surface of the source, and dose rates remain high even several cm from the source surface. Great care in handling such sources must be taken to minimize absorbed dose to the skin of the whole body and especially the extremities since the dose gradients are very high. Finger rings must be worn during all handling operations to monitor extremity dose, and dosimeter badges containing an open window element must also be worn to monitor whole body skin dose. Quite modest shielding (1 cm of plastic) is capable of stopping the beta-particle radiation; shielding with high atomic number (Z) materials such as Pb should be avoided because of increased bremsstrahlung production. Sources should be handled only behind plastic shielding, either portable ones available in the laboratory or the shielding box within which the extrapolation chamber is mounted.

## 3. Administrative Procedures

### 3.1 Source Acceptance

Once a customer has contacted NIST and indicated that a source is being shipped for calibration, a NIST 364 form ("Radioactive Material Request") must be completed and submitted to Health Physics. The source is then assigned an RS# that will be used in future source inventories. The source will be removed from inventory when it is returned to the customer. (See Section 3.6).

### 3.2 Opening a Test Folder

In recent years, this has been the responsibility of the Group secretary. It involves filling out a form that gives the secretary the necessary information to contact Test Administration which then issues a Test Folder.

### 3.3 Source Leak Testing

Prior to being released by Health Physics, the source will have been checked for removable radioactive contamination. Since this test usually takes the form of swiping the inside and outside of the Type A container, and the outside of the wooden box, it is prudent to also perform a visual inspection of the source prior to use. This is done with the source behind a plastic shield (see Section 1.2). Things to look for are a smooth, shiny surface with no corrosion spots or foil kinks. If there is any doubt about how the source looks, a thorough leak test should be performed by rubbing a swipe with the source surface and having Health Physics count it. Any oddities about the source capsule should

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be noted by at least a sketch. It is recommended that a digital photograph of each submitted source be obtained and placed in the calibration record.

In the data book prior the start of the calibration the following information shall be recorded:

- 1) customer name, address and phone number
- 2) source RS#, assigned by Health Physics
- 3) source maker, model and serial number (located usually on a flat on the handle)
- 4) customer purchase order number (PO#), from customer
- 5) NIST test folder number (TF#), assigned by Test Administration
- 6) NIST Report of Calibration number (DG#), assigned by Group secretary

In addition, copy down any pertinent information that may appear on the box such as activity assays or absorbed dose rate (and dates). Such information may be useful for later comparisons (Soares 1995).

### 3.4 Generation of Report

Once the measurements have been completed and analyzed (see Section 4), a Word template is used to generate the final calibration report. Ensure that the appropriate fields are changed in the report, such as the DG number, RS# and dates in the footer, the customer and source information on the front page, the source ID and measured dose rate (quoted to only two significant figures) in Table 1, and with an isodose rate contour plot. Make sure the figure caption has the correct isodose rate contour interval. A sample of a calibration report is shown in Appendix A.

In addition, a copy of all pertinent raw and analyzed data results listed in the final calibration report is to be included in the test folder for the review process. These values should be highlighted for the reviewer to facilitate comparison with the final reported values.

### 3.5 Uncertainty of Calibration

The uncertainty budget that appears in the report is given in Table 1. Many of these components are common to ionization chamber measurements and are consistent with those of other Radiation Physics Division calibration service uncertainty budgets. A few, however, are particular to this service. Starting with the divergence correction, the figure of 0.5 % for the Type A correction was generated from a consideration of the uncertainty of the fitting parameters of the Monte Carlo results. The range in the results obtained by taking extrema of the fitting coefficients including fitting uncertainties was assessed and the effect of the terminal slope calculated. The Type A component on the rate of change of current was estimated from repeated measurements of the slope with the reference source, while the Type B component was estimated from the difference between terminal slopes obtained from linear and quadratic fits of the current versus air gap function. The uncertainty in the effective area was estimated by propagating the uncertainty of a single diameter measurement with the traveling microscope of 0.015 mm, estimated from

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repeated measurements of the same diameter. Since the effective area is taken as the average of the collecting electrode diameter and the insulating gap diameter, uncertainties in two diameter measurements must be considered in this propagation. The final combined, expanded uncertainty (k=2) is estimated to be 7 %.

### 3.6 Source Shipment

When the calibration has been completed satisfactorily, the source is repacked in the Type A package in which it arrived along with the final signed calibration report. In cases where there is a delay in obtaining the required signatures on the report and the customer has an urgent need for the source to be returned, the source may be shipped with only a draft, not fully signed report to be used by the customer in the interim until the final report is ready. In this case, it shall be clearly indicated in a note attached to the report that the report is a draft and that the final report will be sent separately. Shipping Radioactive Material (RAM) may be performed only by personnel appropriately trained every two years. The shipper shall fill out the NIST Form 796a, Shipper's Declaration of Hazardous Materials, and submit the packed source to Health Physics for checking, measurement of exposure rates, and proper labeling.

### 3.7 Records

The primary means of data retention is use of a sequentially numbered NIST data book. It shall contain all the items indicated in the above paragraphs. In addition, original calibration data records will be kept in a folder in the OA Calibration file drawer currently in 245/C211.

### 3.8 Customer Issues

It is Division policy that used ophthalmic applicators acquired by donation to NIST may not be sold for use in treating patients. NIST is currently in possession of several such used applicators, which are used for research purposes. An important cautionary note is that it is very unwise to base the applicability of a calibration procedure on the behavior of a single source.

Often a potential customer of the service will require help with shipping the source to NIST for calibration. To this end, NIST maintains a supply of Type A containers that are sent to customers upon request, along with an information package with advice and sample forms for source shipment.

Occasionally, NIST is presented with the offer to have an orphan <sup>90</sup>Sr/Y ophthalmic applicator donated free of charge. This offer is generally not accepted since a good supply of such sources was obtained in the 1990s and only a few have so far been calibrated and sold. Exceptions to this policy might be considered in the case of applicators with particularly desirable characteristics, such as source uniformity or high dose rate. Reference can be made to Soares 1995 for a guide to source characteristics specific to each manufacturer. One use for such donated sources is measurement assurance devices for checking traceability with the ADCL. These checks should be

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performed periodically as mandated by the American Association of Physicists in Medicine.

#### **4. Measurement Procedures**

##### **4.1 Determination of Source Location within Capsule**

This is the first step in the series of measurements that culminate in the calibration report. The object is to produce an indication of where the surface dose distribution lies relative to the source housing. While ideally this should be centered, it often is not, and it should be of interest to the user if this is not the case, particularly if Castroviejo masks are used in the therapy.

The general idea is to produce a contact autoradiograph of the source, with the outline of the source housing also drawn on the film, referred to as the "marked film". To do this, the source is mounted in a clamp on a ring stand with the source surface facing downward and well above (at least 30 cm) the ring-stand platform. The source should be oriented such that the angular reference point (usually the flat area on the handle) faces the user. Before mounting the source, a piece of radiochromic film is attached to a plastic backscatter block (usually A150 plastic) with the emulsion side facing up and the film identification number in the lower right. The block with the film is then attached to the ring-stand platform with double-sided adhesive tape to keep it from moving during the exposure. The source is then lowered towards the film block with contact made such that the source housing is centered within the film boundaries and is as level as possible. Be careful not to scratch the film surface with the source. Note the irradiation start time. Very carefully take an extra fine (0.3 mm or less) polymer point pen and draw an outline around the source housing on the film surface, being careful not to move either the source or the film in this process. If either moves, the irradiation must be repeated. It may be necessary to remove the source shield from the handle to make this outline (see Section 1.3). The irradiation time should be such as to produce a good image on the film. For GAFChromic Type HD-810 film, this is about 150 Gy. Usually there is some idea of the dose rate indicated on the box containing the source and this can be used to obtain a rough estimate of the time. If no dose rate information exists, but only an indication of activity, a rough rule of thumb is 7 Gy/s/Ci which implies that a 50 mCi source requires about 7 min to deliver 150 Gy. When the planned irradiation time has been reached, raise the source off the film, retrieve the film, examine for any damage, and, if it is in good condition with both a good image and a good outline, repackage the film and place it in storage to be read with the other films to be irradiated later. Remove the source from the ring-stand clamp and clean the source housing with alcohol to remove any ink that might have been transferred to the source during the outlining process.

##### **4.2 Current Measurements**

The basic measurement performed by all the data acquisition programs controlling the extrapolation chamber is the net current. In the present operating scheme, this is obtained from charge measurements across the internal capacitor of a Keithley 617 electrometer. Measurements at both positive and negative polarities (also supplied by the electrometer)

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are made. The time base of the electrometer is used and the data store feature of the electrometer is utilized to obtain readings of the charge at 10 s intervals after the electrometer is ungrounded. For the measurements, the second and fourth readings are utilized, and the current at a given polarity is calculated from the charge difference of these two readings and the time difference (20 s). The net (uncorrected) current is obtained from the average of the magnitudes of the currents at the two polarities.

#### 4.3 Mounting Source in Extrapolation Chamber

The source is mounted in the extrapolation chamber with a specified reference orientation of the source. This is usually taken as having some distinctive feature on the applicator handle facing the operator. On most applicators, this feature is the flat surface on the rod handle on which the source model and serial number are engraved.

It is extremely crucial that the source is mounted in the same fixed and immobile position during the entire course of the measurements. To do this, double-sided adhesive tape is used to securely attach the source shield to the adjustable-level source mounting platform. If the shield is not affixed to the handle so as to preclude rotation of the source with the shield fixed, the shield shall be affixed securely to the source handle with adhesive tape. On some sources, the pivot attaching the source to the handle may be loose and allow the source capsule to move. If this is the case, the pivot should be rendered immobile by very carefully wrapping the pivot with adhesive tape. When the source has been mounted, carefully attach the high voltage electrode to the source handle. If the source has been properly mounted and isolated from any grounded surface, the same potential should be on the source surface as is on the entrance window/high voltage collecting electrode.

#### 4.4 Irradiation of Scrap Film

A film scrap is irradiated for a sufficient time to develop a visible image. No backscatterer need be used for this irradiation since the main points of this irradiation are to have a record to place in the data book and to verify that there is a reasonable absorbed dose rate at the surface of the source. This film is not read out but merely taped in the data book. An indication mark is put on the film prior to irradiation to coincide with the source reference orientation, and attached in the data book with this mark down, which the convention is used throughout for source dose distribution images.

#### 4.5 Raising, Leveling and Centering Source

The mounted source is raised into near proximity to the entrance window by using the coarse height adjustment, i.e., loosening the platform holding screws and lifting the platform carefully until the source surface is just below (a few mm or less) the entrance window. The platform is then secured. The source surface should be as parallel to the entrance window as possible. To do this, a combination of the leveling screws on the source platform and the fine height adjustment are used. There are two leveling screws on the source platform. Turning one or the other alone causes tilts of the source surface towards or away from the front of the chamber housing. Turning both screws together in the same direction causes tilts to one side or the other of the chamber housing. Leveling

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should be done with the source less than 1 mm from the window by using the fine height adjustment, either by selecting the z axis on the controller and turning the adjustment knob, or by using the positioning program MOTOMOVE. Adjustments are made and then the leveling is assessed by looking from the side to see the relationship between the source surface and the window. Often, leveling adjustments cause the source to come into contact with the window. In this case, the fine height control is used to lower the source slightly. Once the desired degree of leveling is achieved, the source should be centered within the window area by using the x and y axis controls; this is best achieved by using the program MOTOMOVE. When the desired degree of centering is achieved, the x and y axis display values on the X-Y controller should be zeroed by cycling the power on this unit. It is important to remember during all these processes that the x-, y-, and z-axis linear translators have only a limited range of motion, 25 mm for the x-and y-axis and 12.5 mm for the z-axis. Therefore, particularly for the z-axis, care in selecting the coarse height should be taken such that, when the source is finally level and centered under the window, the translators are within a few mm of the center of their available range to give the maximum range of motion during the measurements that will follow. The position within its range is indicated on the side of each translator.

#### 4.6 Height Checking Source using HEIGHT

To achieve the proper position of the source below the extrapolation chamber window, the source is raised in small increments towards the window and the signal assessed. Expected response is a gradually increasing signal as the source approaches the window followed by a sharp drop in signal when the source reaches contact and begins to change the air gap. These measurements are made conventionally at the starting air gap, which is 0.15 mm. The program HEIGHT is designed to do all these procedures automatically, making a reading at positive and negative polarity, then raising the source by 0.01 mm and repeating. The program looks for two successive signals that are lower than the previous ones and then assumes that the optimum position is with the source 0.03 mm lower than the last measurement made. When multiple series of measurements are needed, the program averages the results of each series to determine the optimum height of the source. As a final step, the program moves the source to the determined optimum height. A screen print of the HEIGHT program should be made for retention in the data book when the program has executed successfully.

#### 4.7 Installation of Collecting Electrodes

The greatest challenge in using the extrapolation chamber is determining the air gap since there are no direct displays of this parameter. This is a direct result of the design flexibility which allows the collecting electrodes to be easily removed and replaced. It is therefore up to the user to keep careful records of the use of the chamber, which electrode was last used and the motions made when the electrode was changed. There are some gross indications can be used for estimates of the air gap, the first being the depth gauge that gives an indication of the distance between the window plane and the extrapolation chamber top mounting plate. This is only a very rough estimate and should be used with care. For the two electrodes commonly used for ophthalmic applicator measurements (see Fig. 6), the depth gauge readings for 0.15 mm air gaps are shown in Table 2.

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Collecting electrodes are stored in plastic holders inside sealed glass jars with a castle nut on the microdot signal connector. Care should be taken never to touch the surface of a collecting electrode to anything since dust or dirt can cause leakage paths across the insulator which will degrade signal stability. In addition, anything on the electrode surface may impede the ability of the system to achieve small air gaps. Compressed air can be used to clean the electrode surface and the connectors prior to installation. To install a collecting electrode, attach brass posts to the threaded holes on the back of the electrode. Although the collecting areas are well centered within the electrode hole, it is good practice to always insert the collector in the extrapolation chamber in the same orientation. Conventionally, the number is inscribed on the bottom of the collecting electrode oriented towards the front of the chamber. The brass post which has tape on it is usually placed in the hole to the right of this number to aid in keeping this orientation during installation. The orange microdot to BNC cable is then connected to the collecting electrode, and the posts are used to guide the electrode down into the hole in the chamber. There is a shelf at the base of this hole that catches the outer brass diameter of the electrode, letting the surface protrude below the end of the hole in the direction of the entrance window. Care must be taken that the collecting electrode is properly seated on this shelf. Finally, the BNC end of the orange cable is connected at the top of the extrapolation chamber.

Prior to making measurements, the condition of the high voltage electrode/entrance window foil should be assessed and the window replaced if necessary. Also, the presence of the polarizing voltage on both the source and high voltage electrode mounting wing should be verified with a portable voltmeter since sometimes the depth gauge plunger that carries the voltage will stick a little and not have good contact.

#### 4.8 Source Mapping using MAPOAC

Since the sources being measured are small and usually not very uniform, the position of the collecting electrode relative to the center of the surface absorbed dose rate profile is critical. To determine this positioning with high precision, a map of the dose distribution is made using the 1 mm collecting electrode as a probe. A fixed air gap of nominally 0.15 mm is used; the source is stepped around in the x-y plane and readings of net current are made. These tasks are performed by the program MAPOAC, which takes readings, translates the source, determines when enough data have been acquired, analyzes the data to determine the central position, and finally translates the source to this determined position. The user must select the stepping increment, which for most ophthalmic applicators should be 1 mm. For smaller sources (less than 30 mm<sup>2</sup> active area, for instance) smaller sizes like 0.5 mm might be chosen, but MAPOAC has limitations in the grid size it will handle, being limited to 20 by 20, so smaller step sizes should be used with caution. The position the source is in at the start of the measurements will be used as the reference position during the series. After every five measurements, the program returns the source to the reference position and makes a reading; these are averaged and the standard deviation displayed to monitor measurement stability. Standard deviations of more than 2 % indicate unstable operation and should be investigated. In the BASIC

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version of this program, the reference position value is displayed on the grid in white, while values above half the maximum value are displayed in red. Values of less than half the maximum are displayed in light blue for ease in determining from a glance at the monitor the progress of the measurement. The program steps is a spiral pattern out from the reference position until there are values less than half the maximum value at the extremes of all columns and rows.

The program uses the acquired data to determine the center of the dose distribution (Soares and McLaughlin 1993). The center is defined as the center of the 50 % isodose contour (i.e., the center of the area where the relative dose rate is 50 % or more of the maximum dose rate). Mathematically, it can be calculated from the grid of values obtained by MAPOAC (see an example in Fig. 7 and Table 2). The coordinates of the field center ( $x_c$ ,  $y_c$ ) are given by

$$x_c = \left(\frac{1}{n}\right) \sum_{i=1}^n \frac{x50_i^- + x50_i^+}{2}, \quad y_c = \left(\frac{1}{m}\right) \sum_{j=1}^m \frac{y50_j^- + y50_j^+}{2}, \quad (1)$$

where  $n$  is the number of rows and  $m$  is the number of columns containing dose-rate values larger than or equal to 50 % of the maximum dose rate;  $x50_i$  and  $y50_j$  are the x or y positions of the 50 % of maximum dose rate determined by linear interpolation for the  $i$ th row or the  $j$ th column, right of, or above (+), and left of, or below (-) the center.

When MAPOAC operates to completion, the source is at the proper centered position. A screen print should be made for retention in the data book. In addition, the output of the centering calculation (see Table 3) should be retained for the data book record, as well as the result of the reproducibility measurements made at the reference position.

#### 4.9 Extrapolation Measurements using EXTRAP

The actual calibration of the source is made with the 4 mm diameter collecting electrode, 4C. The source is first moved away from the window by 2.585 mm using MOTOMOVE, then the air gap (theta) is increased by 2.585 mm. When the theta move is completed (this takes several minutes), the smaller collecting electrode 1C can be replaced by electrode 4C. The program EXTRAP is used to control the chamber and acquire data for the extrapolation measurement. The user has the option of checking the source surface/window positioning ("height") prior to measurement. Alternatively, this can be done outside of the program using the HEIGHT program again. EXTRAP assumes an initial starting air gap of 0.15 mm and performs net current measurements over a range of air gaps set by the user. For ophthalmic applicators, the default set of air gaps is 0.15 mm to 0.07 mm in 0.01 mm steps. At the end of the series, the program returns the chamber to the initial, 0.15 mm air gap, and repeats the measurement at this air gap for a consistency check. The program moves the source in the z-axis direction commensurate with the changes in air gap to keep the distance between the source surface and the entrance window constant. In addition, it varies the high voltage applied to the entrance window so

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as to keep a constant voltage gradient of 100 V/mm. At each air gap, a series of measurements are performed at positive polarity. Sufficient measurements are performed so that the final 5 measurements in a series have a range of values within a specified value, the default being 0.00041 nC. When this has been achieved, the polarity is reversed and the process is repeated at negative polarity. When the condition has been satisfied for this polarity, the corrections (see below) are applied and the net current is calculated and stored. After all air gaps have been measured, the program iteratively fits the measured data to obtain the terminal slope and hence the absorbed dose rate, as well as the intercept of the linear fit of the data. Iterative fitting is necessary since some of the corrections applied to the measured currents are strong functions of the air gap. Therefore the data are fit to a linear function, and the x intercept is calculated from the fitting parameters and used to correct the air gaps. These new air gaps are used to calculate new corrections that are applied to the currents and the data are fit again. This process is repeated until the x intercept is nearly zero (0.001 mm), at which time the result is printed and saved to a disk. Note that the iterative fitting can also be done off-line with the program OFIT2003.BAS. This is often necessary if there are data that should be rejected from the fit due to obstructions or shorting at small air gaps; EXTRAP has no data rejection criteria.

Often there will have been a considerable offset determined by the fitting routine. If the absolute value of the offset is more than 0.01 mm, then the user must use the offset value to move the theta and z axes an appropriate amount using MOTOMOVE to account for this zero position determination. The program EXTRAP is then run again with the new conditions. After successful completion, a screen print should be performed for the data book. The program output to the printer showing the data at each air gap should also be part of the data book record. The program saves a file containing the nominal air gaps and corresponding currents which can be used for offline editing and re-fitting.

#### 4.10 Extrapolation Chamber Constants & Corrections

Corrections applied to extrapolation chamber current measurements fall into two classes: those that depend on the air gap and those that do not. At present, the following air gap dependent corrections are made to the measured currents:

##### 4.10.1. Correction to reference conditions of temperature and pressure, $k_{Tp}$ .

While not strictly speaking air gap dependent, these corrections can vary during the course of the measurement due to changes in ambient conditions. Temperature and pressure measurements are acquired by HEIGHT, MAPOAC and EXTRAP, and the correction  $k_{Tp}$  calculated from

$$k_{Tp} = [(T+273.15)/(T_0+273.15)][p_0/p], \quad (2)$$

where  $T$  is the measured ambient temperature in °C,  $T_0$  is the reference temperature of 22 °C,  $p$  is the ambient pressure in mm Hg and  $p_0$  is the reference pressure of 760 mm Hg.

##### 4.10.2. Recombination, $k_{recom}$ .

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Current losses, caused by ions being lost due to recombination before they can be collected, are dominated by the diffusion of ions against the electric field for the small air gaps used for ophthalmic applicator measurements. This correction is calculated from

$$k_{recom} = \left(1 - \frac{0.04554}{\sqrt{(X \ell^2)}}\right)^{-1}, \quad (3)$$

where  $X$  is the electric field in V/mm, and  $\ell$  is the air-gap width in mm (Loevinger and Trott, 1966). (The constant 0.04554 carries the units to make the quantity dimensionless).

#### 4.10.3. Divergence, $k_{div}$ .

Close to the source surface, the function of chamber current vs. air-gap width exhibits curvature. This curvature is stronger for larger air gaps, smaller source areas, and smaller collecting electrode areas (Soares et al., 1992). It can be minimized by selecting air gaps as small as possible, but, without corrections, it can never be entirely removed. The curvature can largely be explained by geometrical considerations of the measurement of an extended source with a parallel plate chamber (Deasy and Soares, 1994). The curvature was ignored when calibrations with air gaps of 0.15 mm or less were performed at NIST before 2003 but, starting in that year, results of Monte Carlo calculations of the divergence correction began to be applied. The correction is calculated from

$$k_{div} = c_{div}/(a_{div} + b_{div}e^{-\ell}), \quad (4)$$

where  $\ell$  is the air-gap width in mm, and  $a_{div}=5.713$ ,  $b_{div}=4.074$  and  $c_{div}=9.787$ .

#### 4.10.4 Backscatter correction, $k_{back}$ .

The only correction that is independent of air gap that is now applied is for the difference in backscatter between the collector material, carbon, and the reference material in which the dose rate is quoted (water). The value used since the beginning of July 2003 for this factor,  $k_{back}$ , is 0.990.

#### 4.10.5 Calculation of absorbed dose rate.

Absorbed dose rate to water,  $\dot{D}_w$ , is given by the Bragg-Gray relationship

$$\dot{D}_w = \frac{(\bar{W}/e)s_{w,air}}{\rho_0 a} (\Delta I / \Delta \ell)_{\ell \rightarrow 0} k_{back}, \quad (5)$$

where  $\bar{W}/e$  is the average energy in joules needed to produce one coulomb of charge of either sign in dry air ( $33.97 \pm 0.05 \text{ JC}^{-1}$ ) (Boutillon and Perroche-Roux, 1987),  $s_{w,air}$  is the ratio of the mean mass-collision stopping power of water to that of air,  $\rho_0$  is the density of air at the reference temperature and pressure ( $T_0, p_0$ ),  $a$  is the effective area of the collecting electrode,  $(\Delta I / \Delta \ell)_{\ell \rightarrow 0}$  is the rate of change of current (normalized to a reference temperature

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and pressure) with extrapolation chamber air-gap width as the width approaches zero, and  $k_{back}$  is a correction factor that accounts for the difference in backscatter from the collecting electrode compared to that of water. A value of 1.12 is used for  $s_{w,air}$ , while  $1.197 \text{ kg/m}^3$  is used for  $\rho_0$ . The effective collecting area,  $a$ , is determined from measurements of the collecting electrode surface performed with a travelling microscope. Values for the two electrodes used at NIST are given in Table 1.

Excel templates are used to perform final calculations of the absorbed dose rate for the calibration report. The raw data from the EXTRAP program are pasted into the template at the proper location as well as the output to the iterative fitting done on the selected subset of the raw data. Current versus air gap curves are produced, as well as a plot of current per unit air gap as a function of corrected air gap. This latter curve is useful to assess the remaining curvature in the current versus air gap function as well as the smoothness of the data since neither one of these features is apparent in the current versus air gap plot. This plot is inserted in the data book as well as the final dose rate calculation, which is done in the Excel template, that shows all corrections applied to the data. The absorbed dose rate is quoted at a depth of  $0.9 \text{ mg/cm}^2$  (not the surface but very near it) and represents an average over the central 4 mm diameter of the source.

#### 4.11 Using Radiochromic Film

Radiochromic film irradiations are used to check the validity of the extrapolation chamber measurements of customer sources. Radiochromic film is also used to supply the customer with an isodose rate contour map of the source surface, which also shows the area over which the extrapolation chamber averaged the absorbed dose rate, and where the physical margins of the source lie relative to the dose distribution. There are several types of GAFChromic dosimetry media now available, but the one preferable for beta particle dosimetry measurements is the oldest, now denoted as Model HD-810. This material consists of a nominal 0.007 mm thick sensitive emulsion coated onto the surface of a 0.1 mm thick PET backing. The emulsion is initially nearly colorless but turns blue upon exposure to ionizing radiation. No processing is required, but sufficient time between irradiation and readout should be allotted to let the image stabilize. A roll of this material was purchased by NIST in 1989 and this roll is still in use. The film should be stored in a dark, cool area since it is slightly sensitive to ultraviolet light. The film is calibrated using the NIST reference ophthalmic applicator New England Nuclear (NEN) S/N 0258 (or equivalent). The film batch is recalibrated every 2 to 3 years, although the only change noticed over the years has been a slight increase in unirradiated film density. A delay time between irradiation and readout of no fewer than 3 and no more than 7 days is used for both calibration and customer source films. This form of the medium is preferable for beta-particle dosimetry because of the thinness of the emulsion and the fact that the emulsion is on the film surface. Other models feature thicker emulsions (and hence more sensitivity) that are sandwiched under layers of PET. Since surface dose rate is being measured, a thin, surface detector is required. One caveat in the use of the film is that the emulsion side of the film must be towards the source. It is not easy without practice to determine this by eye; fortunately, the emulsion turns temporarily cloudy when wet. This allows one to determine the emulsion side by wetting a corner of one side

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of a film. For measurements of ophthalmic applicators, pieces of film 1.5 cm by 1.5 cm are used. The four digit film serial number is written on the emulsion side of the film in the lower right corner.

#### 4.12 Dosimetry Film Irradiations

Every customer source is used to irradiate (besides the marked and scrap films described above) six calibrated HD-810 films. These irradiations are performed at the same depth of measurement (the entrance window thickness of  $0.9 \text{ mg/cm}^2$ ) as was performed with the extrapolation chamber. The film dimensions currently being used are 1.5 cm by 1.5 cm, cut (usually) from the same 12.5 cm column from the HD-810 roll. Films are irradiated in the extrapolation chamber with the source in the same location as it was during the ionization measurements. To perform these measurements, the electrode 4C is removed from the extrapolation chamber and the program MOTOMOVE is used to raise the source and decrease the air gap by 0.7 mm. The dummy electrode 30E is then installed. This electrode is constructed from A150 tissue-equivalent plastic and has the same geometry as the electrode that was used for dosimetry measurements prior to the 1990 revision of the calibration service. To test that the proper air gap has been set, a scrap piece of HD-810 film is taped to the center of the dummy electrode 30E that is inserted into the extrapolation chamber. If the air gap is set properly, the edges of the film are just visible on the entrance window. If they are not visible, the air gap must be reduced (and the source raised accordingly) until they become visible. Do not change the air gap with the dummy electrode installed since the film and tape rubbing on the inside of the window could cause damage to the window. When the proper air gap is achieved, the dosimetry films are irradiated one at a time with the customer's source. The target dose in the film should be around 150 Gy, and the necessary irradiation time is calculated using the dose rate indicated by the extrapolation chamber measurement. Films should be oriented on the face of the dummy electrode with the emulsion side up and the identifying mark on the film (number or dot) in the lower right corner such that this mark will be towards the user during the irradiation. This is important to assure that the same orientation convention is used for both extrapolation chamber and film measurements. For most applicators, irradiation times are on the order of 5 to 10 min so hand timing is sufficiently accurate. Having an alarming watch is useful for these irradiations. The film number, as well as start and stop times, are recorded in the data book. After irradiation, all films are taken to the exposed film storage drawer in B140 to await readout.

#### 4.13 Readout of Dosimetry Films on LKB Densitometer

Radiochromic films are read out using a high resolution two-dimensional scanning system. Any of the three scanning systems available in the Division may be used, although there must be a calibration for the film-densitometer system. In the following, use of only one of the systems, the LKB Pharmacia, will be described. This densitometer uses a 0.1 mm diameter laser light source at 633 nm to step over the film sample in two dimensions in step sizes as small as 0.04 mm. For readouts of ophthalmic applicator films, a step size of 0.16 mm is used, with readout field sizes of 12.0 mm x 12.0 mm. This results in 75 x 75 pixel images. To set up the densitometer for these readouts, first power on the system and let it warm up for at least 90 min. To set up the field from the

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LOG-IN MENU shown when the unit is powered up, first select 7, SETUP MENU. On the STARTUP MENU make sure that “2-dimensional scanning, spot, RS-232, and baud 9600 D=8 P=N S=1 no echo” are selected, then select 7 PLOT MENU. On the PLOT MENU, make sure that ABSOLUTE ASCII is selected, then select 7, MAIN MENU. The MAIN MENU is where the remainder of the session will be spent. From here, one starts readouts and also enters the defined field menu. Make sure that only one field is defined at a time or the device will read the sample over all the fields defined unless special precautions are taken. When one field is defined, the selection 5 indicates START/STOP #= 1/1. To define a field, select 7, DEFINE FIELD. There will already be a field stored from the previous session; to access it hit F2, 1 to set the ruler to the start of the stored field. Note the “x” location of the field is shown where the vertical ruler bar intersects the axis at the bottom of the scanner bed. Note also that this bar is not quite straight and reads a mm or two greater than the indicated start position. Most ophthalmic applicator films can be read with a 12 mm by 12 mm field. It is good practice to read the films on the same area of the scanning bed each time, so for these films a field of x-start = 56.0 mm, x stop = 68.0 mm, y start = 89 mm, y stop = 101 mm, x step size = 4 and y step size = 4 is used. This yields a 75 by 75 pixel array since each step is 0.16 mm. The center of this field is thus at 62, 95 mm. To set a new field, hit the START button and use the motion arrows adjacent to the FAST button to move the bar until the display says it is at 56.0. Note that faster movement can be obtained by holding down the FAST button while pressing a direction arrow. Enter the y-start location with the key pad; your response will be indicated in the NEW PARAMETER VALUE line. To set the stop location of the new field, hit the STOP button and use the direction arrows to move the vertical bar to 68.0 mm, then enter 101 for the desired y-stop location. Finally, the step sizes are entered by pressing first the X-STEP button and entering 4, then the Y-STEP button and again entering 4. Press the START button again to place the bar at the start location, then the ESC button to get out of the NEW PARAMETER VALUE entry. Save the field you just defined by pressing the SAVE button. You will now have two fields defined and the old one must be removed. To do this, hit either the NEXT or LAST buttons to highlight the field number of the field you want to delete, then press the DELETE button to remove it. To restore the field you just defined, hit either NEXT or LAST to highlight the field number (there should be only one now). You are now ready to mount the film. Before placing any film in the densitometer, dim the fluorescent lighting behind the scanning bed by pressing the dimming button located at the upper left corner of the button array. You will see the light get dimmer as you do this. Let up after a few seconds when the light no longer gets any dimmer. You will repeat this last procedure every time the roll top is opened to access a film. To aid in proper film alignment, hit START and use the arrows to place the vertical indicator at the center of the defined field, 62.0 mm. The film should be placed with the center of the image at a vertical position of 95 mm as indicated on the bar. It is sufficient to eyeball center the circular image between the 90 mm and 100 mm rules on the vertical scale. When the film is correctly placed, check the position by hitting ESC, F2, 1 and then START and STOP to see that the line on the vertical bar encloses the limits of the image. When complete, hit ESC until you return to the MAIN MENU. Orient the film such that the film serial number is right side up and located in the lower right corner.

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Data acquisition is obtained using the program SCANIN.BAS on the host computer. Execute the batch routine B.BAT. When you are ready to read a film, type RUN; the program will prompt you for a filename. Use G####.ASC where #### is the film serial number. The program will check that the file does not already exist; if it does not, then it will wait for data to start coming from the densitometer. To start the read out, select 6 from the main menu. The reader will initiate the readout process and, after 10 seconds or so, data will start to appear on the host computer monitor. This will continue until several minutes after the completion of the readout by the densitometer. It takes about 15 minutes to read an ophthalmic applicator film. A typical readout session starts with the readout of the base plate alone, with the output file named (by convention) noMMDDYY.ASC where MM, DD and YY are the month, day and year. The readouts of the six dosimetry films follow and then, at the end, a readout of a reference optical density filter is performed to monitor the stability of the absorbance scale of the instrument. For this test, one of the filters of an SRM 2031 is used. The filter used is the nominal 10 % transmitting one (the darkest of the set). It is indicated in the set as the one with an Allen wrench with it in its holder. The Allen wrench is used to remove the filter from the spectrophotometer cell holder. Do this very carefully, never touching the filter surface. The filter is mounted in the densitometer in a horizontal orientation centered in the standard 56-68, 89-101 field. The data from this scan are conventionally named G1MMDDYY.ASC. An average of these data can be performed with the program HISTER.BAS. The average should be  $396 \pm 5$  scanner density units in order for the readings to be valid. The scale of this instrument has been quite stable since its acquisition in 1989 and has yet to stray from this range. In addition to the six dosimetry films, the marked film is also read at this time. Note that since this film includes the circle (or portion thereof) delineating the outside of the source, a larger field will often be needed. A field of 54-70, 87-103 mm step 4 (100 by 100 pixels) is usually sufficient for this. When the readout session is complete, the densitometer is switched off.

#### 4.14 Analysis of Dosimetry Films using FILMANAL

The raw ASCII files from the densitometer are converted to absorbed dose rate and analyzed by the program FILMANAL.BAS. This program reads in a file in LKB ASCII file format, converts each pixel value to absorbed dose rate using the calibration curve and the user-input irradiation time, and outputs the data to disk in the SURFER GRD file format for plotting isodose curves. It also saves a file containing the dose rate data in a two dimensional array for printing. The image center is then determined using exactly the same algorithm as that used by MAPOAC (see above) and this information is also saved for printing. Finally, some dose rate averages are calculated for various diameters using the determined source center. Of particular interest is the calculation for the  $14.681 \text{ mm}^2$  area, which corresponds to the area of the 4C electrode. This value, along with the determined 50 % isodose source area, is recorded in the data book along with the other film irradiation data. Each film image is also printed out using the GRD file in SURFER to verify the readout quality. The average value of the absorbed dose measured by the radiochromic films must be within  $\pm 5 \%$  of that measured with the extrapolation chamber or the cause of the discrepancy must be investigated.

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#### 4.15 Measurement of Source Holder Diameter

Before the source is taken from the extrapolation chamber, it is necessary to record the physical source diameter. This is obtained by carefully measuring the source diameter near the source surface using Vernier calipers. Care should be taken to minimize dose to the fingers in this measurement. The measured diameter is recorded in the data book for use in the report generation.

#### 4.16 Creation of Report Figure

A difficult aspect of this whole set of procedures is the generation of the figure that appears in the report. This figure gives the isodose rate contour map of the source surface with the collecting electrode diameter and outer source diameter superposed on it. No single graphing package seems to be able to provide the same level of accuracy as the set of procedures described below. The figure starts with the selection of one of the six dosimetry films for the report. Selection criteria include centering of the image, absence of any extraneous artifacts (dust, specks, film markings) and nearness of the average dose rate of the film to that given by the extrapolation chamber. Once the film has been selected, its dose rate values are normalized to the extrapolation chamber reading using the program GRIDNORM.BAS. A line is edited in that program to read in the file G####DOS.GRD, where #### is the film number, and output file OA%%%.GRD, where %%% is the 4-digit source identifier. Another line is edited such that the dose rate value written out to the OA file is multiplied by the ratio of the extrapolation chamber dose rate to that of the uncorrected film. The program then runs until out of data and then stops. The user then CLOSEs the file. The file OA%%%.GRD is then read into SURFER Version 4. An appropriate contour interval is selected such that there are usually no more than 10 contours on the plot. Every other contour level is labeled. Axes are labeled X Position, mm and Y position; mm and 0.5 mm between ticks are selected with every fourth tick labeled. The plot is then output to disk in HPGL format as OA%%%.PGL. Circle data for overlay on this plot are created by MAKECIRC.BAS (for the inner circle representing the collecting electrode) and MAKECIRR.BAS (for the outer circle representing the physical source edges). Input to MAKECIRC.BAS are the x- and y-centers calculated by FILMANAL.BAS for the film being considered. Since FILMANAL.BAS outputs the centers in 0.16 mm steps, counting from the second step in each row and column, the step centers are converted to mm via

$$\text{mm} = (\text{steps}-2)*0.16$$

This calculation is entered in the data book and the output of MAKECIRC.BAS is named OA%%%.CI.DAT. Getting the appropriate center of the outer circle is trickier since one cannot assume that the dose rate distribution is centered within the source area. This is where the readout of the marked film is used. Using an isodose rate contour plot of this film created by SURFER and a transparency of some polar coordinate graph paper, determine the center of the physical source by aligning the circles on the graph paper with the image of the outer circumference on the marked film. Mark this center using the hole at the center of the transparency and then use a ruler to pick off the x- and y-

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coordinates of the source center from the graph axes. Record this center on the plot. Next, calculate the center of the dose rate distribution for this film using the FILMANAL.BAS values converted to mm per the above formula. Record these data on the plot, and then subtract these latter values from the coordinates of the source center. The result represents the displacement of the source center from the dose distribution center. If both values are less than 0.01 mm, consider the distribution centered within the source. Otherwise, add these coordinates to the center coordinates of OA% % % .GRD and enter them when prompted for a center by MAKECIRR.BAS. Also input the measured physical source radius when prompted by this program, and output the data as OA% % % OC.DAT. Now use GRAPHER Version 1.79 or the equivalent to create a graph with the same scale (6inch sides with 0 to 11.68 mm axes) as the SURFER plot, but with no tick marks or labels (blank axes). Use a dashed line to connect the points of the inner circle and small points for the outer circle. Output the plot file in HPGL format as OA% % % CI.PGL. The two files, OA% % % .PGL and OA% % % CI.PGL, can then be concatenated in DOS to produce the file OA% % % C.PGL which, if properly aligned and scaled, will contain the isodose rate plot with the two circles and no evidence that it is actually two separate plots. Rename this file OA% % % C.PLT since this is the modern extension for HPGL files, and import the file into a drawing program that accepts HPGL files (such as COREL) and that allows one to modify the pen colors of the plot upon input. The resulting plot can then be cut and pasted into the appropriate place in the calibration report. A copy of the isodose plot of the marked film, including the center calculations, should be made and placed in the data book.

#### 4.17 Quality Assurance Measurement of Reference Source NEN 0258

Quality assurance for this calibration service is maintained by application of the two dimensional model shown in Figure 8. The model employs two checks of the measurement quality of the unknown source: a check on the primary standard instrument using a known source (see below) and an independent measurement of the source with a secondary measurement system (radiochromic film, see above). Before the result of the extrapolation chamber measurement of the customer source can be considered final, a measurement of the NIST reference source NEN 0258 must be performed. This may be performed either before or after the customer calibration or series of customer calibrations but can never be performed more than two weeks before or after to be considered valid for measurement assurance. Since this source is known to be very uniform over the source area, positioning is not as critical and the source does not have to be mapped with 1C and MAPOAC. However, eyeball leveling and centering as with a customer source needs to be carefully performed, as well as the HEIGHT procedure. The EXTRAP program is then run on the properly mounted source with electrode 4C installed. Telling the program OA when it asks for a source identifier will automatically generate a decay correction to January 1, 1990, which is the reference date for this source. The measurement is performed using the standard air gap range of 0.15 mm to 0.07 mm in 0.01 mm steps and the terminal slope calculated. The result of this calculation must be within  $\pm 5\%$  of the reference value of 0.254 nA/mm for the measurements to be considered valid. The result shall be entered into the control chart for these measurements which is kept in the data book.

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**5. Equipment****5.1 List of critical equipment**

A list of the critical equipment used in this calibration service is given in Table 4. Calibrations were initially performed on each piece of equipment when it was brought into service by comparison against local standards. Calibration frequency is as needed, based on control charts. Measurements using the extrapolation chamber are performed in Building 245, Room B06. All equipment is located in Building 245.

None of the devices receive routine calibration. The uncertainties of the measurements are such (see Table 2) that the small corrections introduced by routine recalibrations would not influence the overall results. Furthermore, the consistency of the measurement system as a whole is routinely monitored via measurements with the reference source.

**5.2 Changing Entrance Foils/HV Electrodes**

Entrance foils should be replaced when they show any sign of wear, such as tears, stretch marks or clear areas where the aluminization has been removed. To replace the foil, mounted sources should either be removed (preferably) or shielded with low-Z materials. The window mounting ring is removed from the chamber by removing the four plastic screws that attach it. Note that there is a thin plastic insulating ring that keeps the window mounting ring isolated from ground; keep it inside the extrapolation chamber housing during the following procedures. Take the mounting ring to a desk or other smooth work surface and remove the four screws that attach the window mounting plate to the mounting ring. Set the mounting ring aside, and remove the eight small screws that hold the tension ring in place and remove the old entrance window. Cut a fresh piece of aluminized PET (Mylar) from the stock supply, making sure it contains no creases or other flaws and is sufficiently large to cover the entire mounting plate with a few cm to spare; a size of 15 cm square is sufficient. Place the PET with the aluminized side downward, which will put it on the inside of the chamber. The side that is aluminized is somewhat shinier than the unaluminized side but you may confirm the orientation by checking the conductivity with a portable ohmmeter; the aluminized side is conducting, the other side is not. Use pieces of adhesive tape to stretch the window over the mounting ring and hold it in place; taping in 8 places is sufficient to remove all wrinkles in the foil. While doing this, it is useful to use a finger to press in the foil over a hole in which one of the eight screws holds the tension ring, making a circular mark on the foil. This will make it easier to properly orient the tension ring during mounting. Mount the tension ring, which stretches the foil tight; use a sharp object to punch holes in the foil where the tension ring mounting screws will go, and attach the screws, working in a 180° pattern and keeping pressure on the tension ring until it has been securely attached. Use a knife or scalpel to cut the foil around the outer edge of the tension ring. The finished product should be mirror-like with no wrinkles evident. Reattach the window mounting plate to the holding ring with the four metal screws, and then attach the holding ring to the extrapolation chamber with the plastic screws, being sure to put the insulating ring on the

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holding ring before fastening it down. Care should be taken in all the screw tightening to not slip and punch a hole in the window.

### 5.3 Collecting Electrode Fabrication

It may occasionally be found to be necessary to refabricate one of the collecting electrodes due to damage or the development of unacceptably high leakage currents. Useful details for the construction of electrodes is given in Pruitt 1987 as well as in some of the NIST data books involving the service. Figure 9 is a reproduction from one of these data books (DB 793/113; in this document, references to NIST data books are given in the format DB###/### where ### is the data book number and ### is the page number). In 2003, a new 1-mm diameter collecting electrode made from the conducting tissue equivalent plastic D400 was successfully fabricated and tested.

### 5.4 Troubleshooting the Extrapolation Chamber

Problems with the NIST medical extrapolation chamber are most often indicated by evidence of signal drift or noise, and often seem to be associated with conditions of low humidity. In 2002, humidity and temperature controls were implemented in B06, which have alleviated some of these problems. Acceptable ranges of ambient conditions under which calibrations may be performed are humidity between 20 % and 70 %, and temperatures between 20 °C and 24 °C. There are no restrictions on barometric pressure. In addition, temperature changes must be limited to less than 1 °C/h **during measurements**. One of the most common problems is the absence of polarizing voltage on the high voltage electrode. Always check this with a digital voltmeter when electrodes are changed out and there are concomitant large changes in the window positioning. Also note that, if the high voltage supply from the electrometer is shorted to ground, there will be no indication other than a blinking light on the electrometer display and an absence of voltage. Check that there no high voltage leads touching ground and that the source is also isolated from ground. Grounding loops are sometimes a problem with the system and will cause noise or drifts. Check continuity to ground of the various components and use shorting leads liberally as needed to maintain solid connections to ground. Floating elements can collect charge that will cause measurement drifts, so avoid these. Since there is no positive indication of air gap, it is possible to be very far off in the estimation of the true air gap. It is possible, if the air gaps are large enough, to actually observe negative slopes in the current versus air gap. When grossly incorrect slopes are suspected, reorient with the reference source and the 4C collector since, at an air gap of 0.15 mm with this source and electrode, one should read a decay corrected (to 1/1/90) current of about 36 pA. The current scale on the electrometer can be used for this determination. Noisiness is sometimes a symptom of dirt in one of the connectors. Use compressed air to dust off connectors, preferably from the laboratory supply in B06 rather than canned compressed air that contains propellants. Another cause of noise is excessive leakage current caused by a compromise in the insulation between the collecting and guard regions of the collecting electrode. Resistance between the collector and ground can be checked either directly with a source-meter capable of very high resistance measurement ( $>10^8 \Omega$ ) or indirectly with an electrometer using the circuit constructed for the purpose by Pruitt and detailed in DB 889/144. Values measured previously for the electrodes used

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in the calibration service are given in Table 1. As mentioned earlier, it is a good idea to blow out the chamber volume with compressed air whenever the electrode is changed to remove any dust or other particulates that may have entered. Never leave the hole in which the electrodes are placed in the chamber uncovered for any length of time; use the Teflon disk to cover the hole when an electrode is not installed. Never leave a source up with an electrode installed for an extended period of time, *e.g.* over the weekend. While very radiation resistant, the electrodes are not radiation proof and high doses may degrade the material used in the construction, such as the insulating epoxy. Use the z-axis translator to move the source away from the collector by 5 mm or so to reduce dose rates when leaving the device unattended for an extended period of time with an electrode mounted. Leaving the source and electrode in place overnight is acceptable practice, in fact, as it is common to start an automated measurement sequence to run in the overnight hours. One final problem that will occur occasionally is the translator motors hanging up for no apparent reason during the MAPOAC procedure. There is no known fix for this, and the motors have to be power cycled and then returned to home position and the measurement begun again.

## 6. References

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Soares, C. G. and W. L. McLaughlin, "Measurement of Radial Dose Distributions Around Small Beta-Particle Emitters Using High-Resolution Radiochromic Foil Dosimetry", *Radiat. Prot. Dosim.* **47**, 367-372 (1993).

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**CALIBRATION OF OPHTHALMIC APPLICATORS**

Soares, C.G., Vynckier, S., Järvinen, H., Cross, W.G., Hokkanen, J., Sipilä, P., Flühs, D., Schaeken, B., Mourtada, F.A., Bass, G.A., Williams, T.T., “Dosimetry of beta-ray ophthalmic applicators: Comparison of different measurement methods,” *Med. Phys.* **28**, 1373-1384 (2001).

**7. Uncertainty Analysis**

See Table 1.

**8. Documentation**

N/A

**9. Definitions**

N/A

**10. Filing and Retention**

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

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## CALIBRATION OF OPHTHALMIC APPLICATORS

Appendix A. Sample Calibration Report

**National Institute of Standards and Technology****REPORT OF CALIBRATION**

OF

**<sup>90</sup>Sr+<sup>90</sup>Y Beta-Particle Source****New England Nuclear Model NB-1 S/N #####**

FOR

#####

#####

Calibration was performed by Jason S. Walia  
on March 8, 2010

Report reviewed by Ronaldo Minniti

Report approved by

Michael G. Mitch, Leader  
Radiation Interactions and Dosimetry Group

For the Director  
National Institute of Standards and Technology  
by

Lisa R. Karam, Chief  
Radiation Physics Division  
Physics Laboratory

Information on technical aspects of this report may be obtained from Jason S. Walia,  
NIST, 100 Bureau Drive Stop 8460, Gaithersburg, MD 20899, 301-975-5592

*Report format revised 4/00*



REFERENCE DG11890/03  
RS# 03-0133  
NIST DB 968/180  
October 16, 2003  
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Beta-particle sources are calibrated in terms of the absorbed-dose rate to water. Absorbed-dose rate very near the source surface averaged over the central 4-mm diameter area is determined from current measurements with an extrapolation ionization chamber that has a graphite electrode. The absorbed-dose rate to water in Gy/s is given by

$$\dot{D} = \frac{33.97 \times 1.12 \times B}{1.197 \times A} \left( \frac{\Delta I}{\Delta d} \right)_0$$

where  $(\Delta I/\Delta d)_0$  is the rate of change of current (normalized to a reference temperature and pressure) with extrapolation chamber air-gap thickness as the thickness approaches zero, in units of nA/mm, 33.97 is the average energy in joules needed to produce one coulomb of ions of either sign in air, 1.12 is the ratio of the mean mass stopping power of water to that of air, 1.197 is the density of air at the reference temperature and pressure (22 °C and 1 standard atmosphere) in kg/m<sup>3</sup>, **B** is a correction for reduced backscatter from the collecting electrode, and **A** is the area of the collecting electrode in mm<sup>2</sup>. For the source submitted, one calibration was made, to determine the average absorbed-dose rate to water across the central area of the source, at the high voltage electrode/entrance window depth of 0.9 mg/cm<sup>2</sup>. For the calibration, the rate of change of current with air-gap thickness was measured with a 4 mm diameter graphite collecting electrode. Currents were measured at nine air gaps from 0.07 mm to 0.15 mm and were corrected to the reference temperature and pressure, for source field divergence and for recombination losses; these data yield a linear relation between corrected current and air gap. The location of the center of the source was determined by mapping the dose rate across the source surface with a 1 mm diameter probe electrode. In addition, a two-dimensional scan of a calibrated radiochromic dye film was made. The results of this scan were used to construct a dose-rate contour map of the source surface, shown in Figure 1. The dashed line on this plot represents the area averaged over by the extrapolation chamber equipped with the 4-mm diameter collecting electrode. The dotted line at the periphery represents the physical edge of the source. The figure shows the dose-rate distribution that would be produced by an application with the flat of the applicator handle facing downward. The numerical data from this scan are available upon request. The absorbed-dose rate to water at a depth of 0.9 mg/cm<sup>2</sup> as determined from the extrapolation measurement is given in Table 1 in SI units (gray per second). This rate is considered to be an average of the dose-rate across the central area of the source surface. The combined, expanded uncertainty of the calibration is estimated to be  $\pm 7\%$  (see Table 2). The random uncertainty components are calculated as standard deviations of the mean of replicate readings; other components are estimated so that they can be assumed to have the approximate character of standard deviations. The combined, expanded uncertainty is two times the square root of the quadratic sum of all the component uncertainties; it is considered to have the approximate significance of a 95 % confidence limit.

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## CALIBRATION OF OPHTHALMIC APPLICATORS

Table 1. Source Measurement Results

Reference Date: October 8, 2003

Source	Measurement		Correction Factor <b>B</b>	Average Water Absorbed-Dose Rate (Gy/s)
	Distance (mm)	Depth (mg/cm <sup>2</sup> )		
####	0	0.9	0.99	0.51

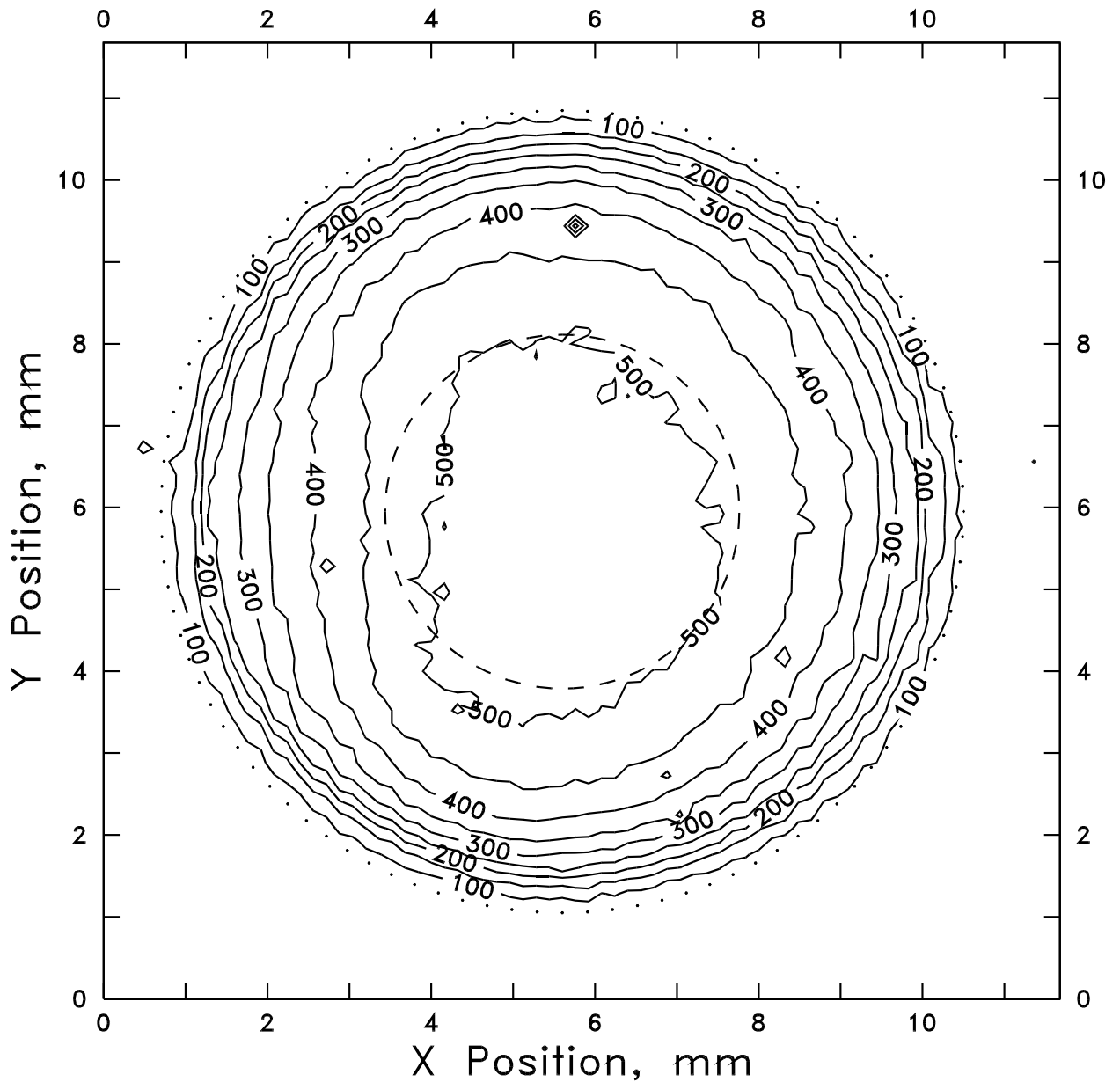
Table 2. Estimated Uncertainties in Source Calibration  
Using the Extrapolation Chamber

Component of Uncertainty	Uncertainty (%)	
	Type A	Type B
Net current	0.1	0.1
Air density correction		0.1
Recombination correction		0.1
Divergence correction	0.5	
Rate of change of current, $(\Delta I/\Delta d)_0$	2	2.6
Average energy per ion pair		0.15
Stopping power ratio		0.6
Backscatter correction, <b>B</b>	0.6	
Collecting electrode area, <b>A</b>	0.6	
Combined uncertainty (quadratic sum)		3.5
Expanded uncertainty (combined x 2)		7

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Figure 1. Isodose Rate Contour Map of Submitted Source  
(50 mGy/s contour intervals)



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**CALIBRATION OF OPHTHALMIC APPLICATORS****List of Tables**

1. Estimated uncertainties in source calibration using the extrapolation chamber
2. Characteristics of the collecting electrodes used for measurements of ophthalmic applicators
3. Data that accompanies Fig. 7 illustrating a determination of the source center.
4. List of critical equipment

**List of Figures**

1. Calibration volume
2. Details of a typical  $^{90}\text{Sr}$ - $^{90}\text{Y}$  planar (“ophthalmic”) applicator construction
3. Schematic of the extrapolation chamber
4. Schematic of components and interconnections of the NIST Medical Extrapolation Chamber
5. Photographs of the NIST extrapolation chamber
6. Photographs of collecting electrode surfaces
7. Sample data set for illustrating the concept of source center
8. Two dimensional MQA Model applied to the calibration of ophthalmic applicators
9. Collecting electrode fabrication

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## CALIBRATION OF OPHTHALMIC APPLICATORS

Table 1. Estimated uncertainties in source calibration using the extrapolation chamber

Component of Uncertainty	Uncertainty (%)	
	Type A	Type B
Net current	0.1	0.1
Air density correction		0.1
Recombination correction		0.1
Divergence correction	0.5	
Rate of change of current, $(\Delta I/\Delta \ell)_0$	2	2.6
Average energy per ion pair		0.15
Stopping power ratio		0.6
Backscatter correction, $k_{\text{back}}$	0.6	
Collecting electrode area, $a$	0.6	
Combined uncertainty (quadratic sum)		3.5
Expanded uncertainty (combined x 2)		7

Table 2. Characteristics of the collecting electrodes used for measurements of ophthalmic applicators

Name	Use	Material	Collecting Area, mm <sup>2</sup>	Insulator thickness, mm	Resistance, $\Omega$	Depth Gauge reading for 0.15 mm air gap
1C	Source mapping	carbon (graphite)	0.6482	0.30	$3 \times 10^{12}$	3.77
4C	Absorbed dose measurement	carbon	14.681	0.27	$1.6 \times 10^{10}$	2.86

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Table 3. Data that accompanies Fig. 8 illustrating a determination of the source center.

i	y value	$x50_i^-$	$x50_i^+$	$(x50_i^- + x50_i^+)/2$
1	39.2	28.3	34.6	31.4
2	41.2	27.3	35.2	31.3
3	43.2	27.5	35.1	31.3
4	45.2	29.7	33.1	31.4
Average $\pm 1\sigma$				$31.3 \pm 0.07 = x_c$
j	x value	$y50_j^-$	$y50_j^+$	$(y50_j^- + y50_j^+)/2$
1	28.2	39.3	44.0	41.7
2	30.2	38.1	45.6	41.9
3	32.2	38.1	45.9	42.0
4	34.2	38.9	44.3	41.6
Average $\pm 1\sigma$				$41.8 \pm 0.20 = y_c$

Table 4. List of critical equipment

Device	Manufacturer	Model	S/N <sup>†</sup>	NIST #	Location
Extrapolation chamber*	NIST			569833	B06
Electrometer <sup>§</sup>	Keithley	617	0566351	562175	B06
Thermometer	Hart	1502	48155	none	B06
Barometer	Setra	370	505118	none	B06
Digital volt meter	Hewlett-Packard	34401A	3146A24057	560992	B06
Motion controllers	Oriel				B06
Radiochromic film	International Specialty Products	HD-810			B003
Scanning densitometer	LKB	Ultrosan XL	90 02 4940-01437	541890	B140

<sup>†</sup> Or equivalent

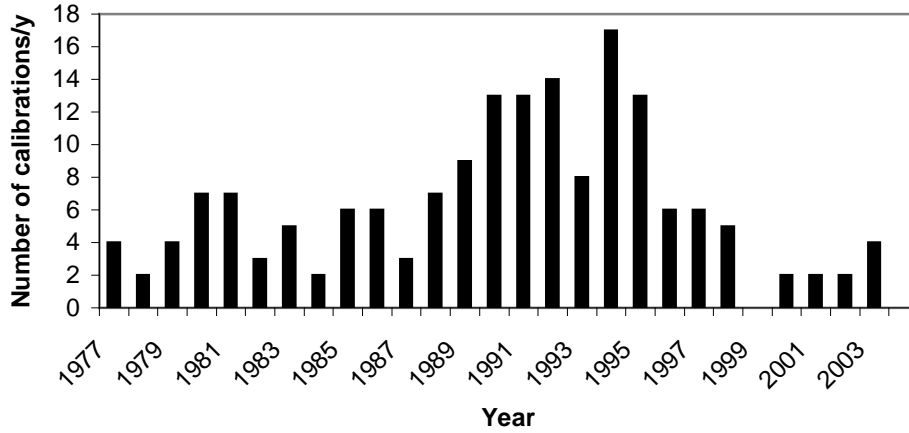
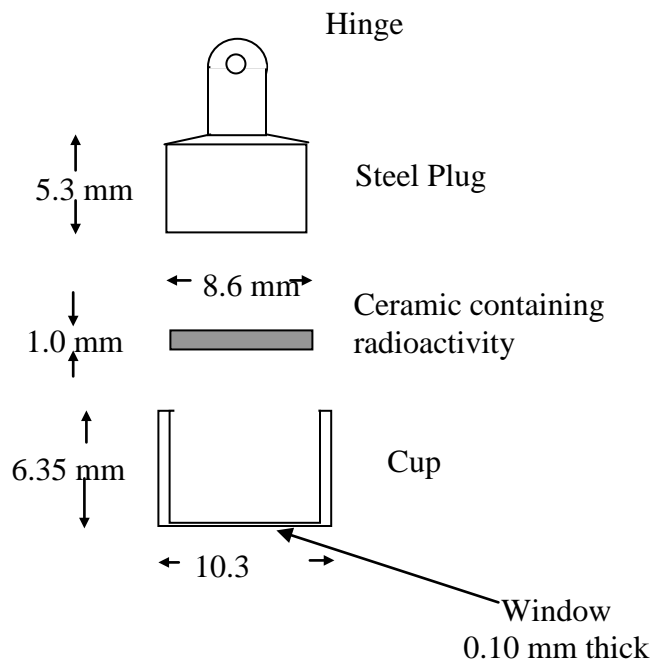
\* Includes removable collecting electrodes, motorized source translation stage, source leveling device, shielding/housing

<sup>§</sup> Operated on the appropriate coulomb scale

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## CALIBRATION OF OPHTHALMIC APPLICATORS

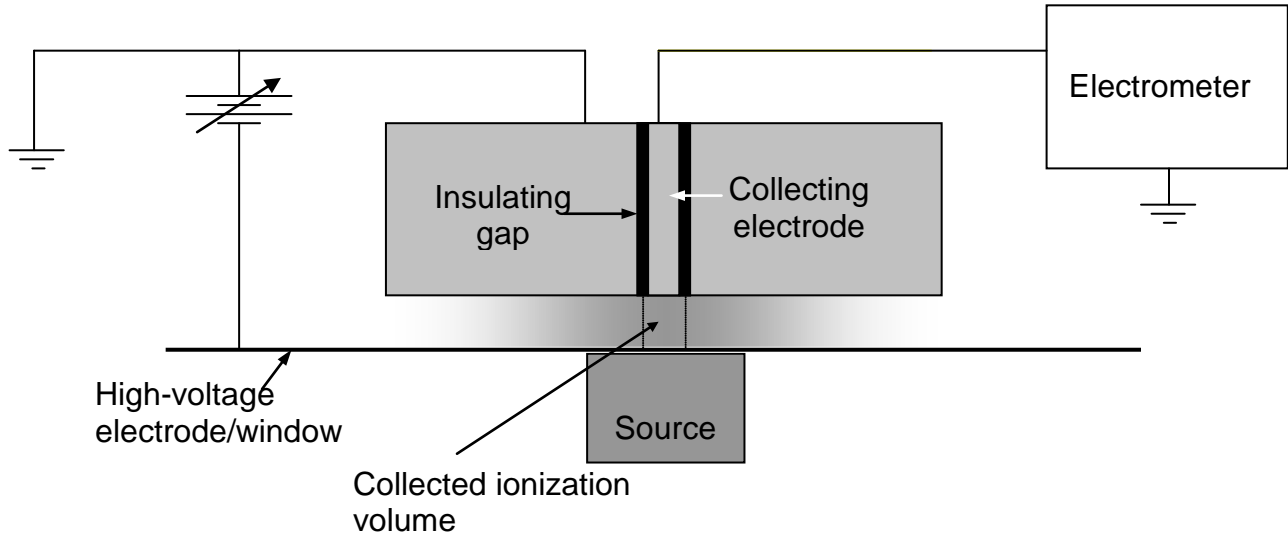
Figure 1. Calibration volume

Figure 2 Details of a typical  $^{90}\text{Sr}$ - $^{90}\text{Y}$  planar (“ophthalmic”) applicator construction

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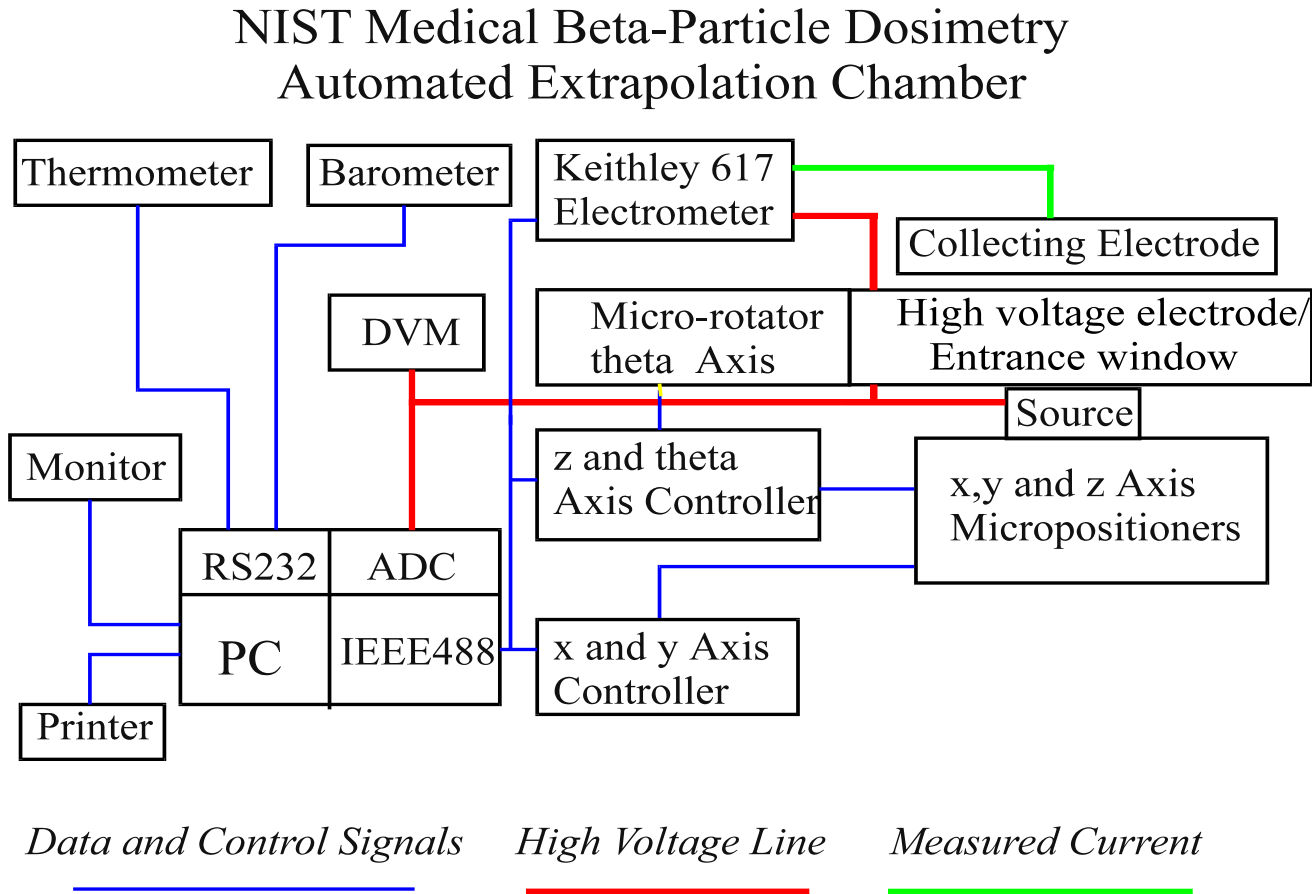
Figure 3. Schematic of the extrapolation chamber



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## CALIBRATION OF OPHTHALMIC APPLICATORS

Figure 4. Schematic of components and interconnections of the NIST Medical Extrapolation Chamber

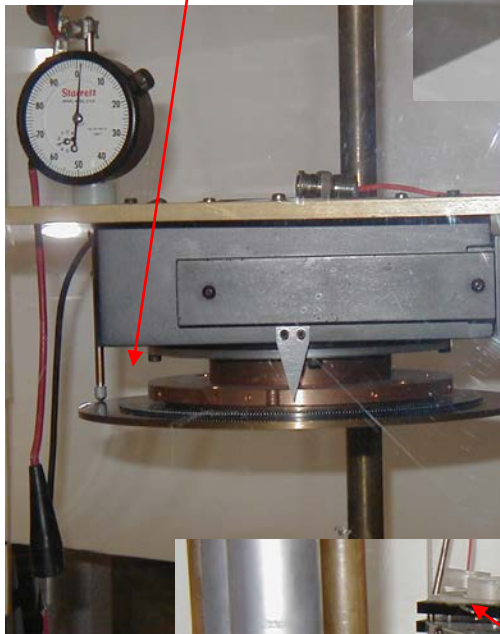
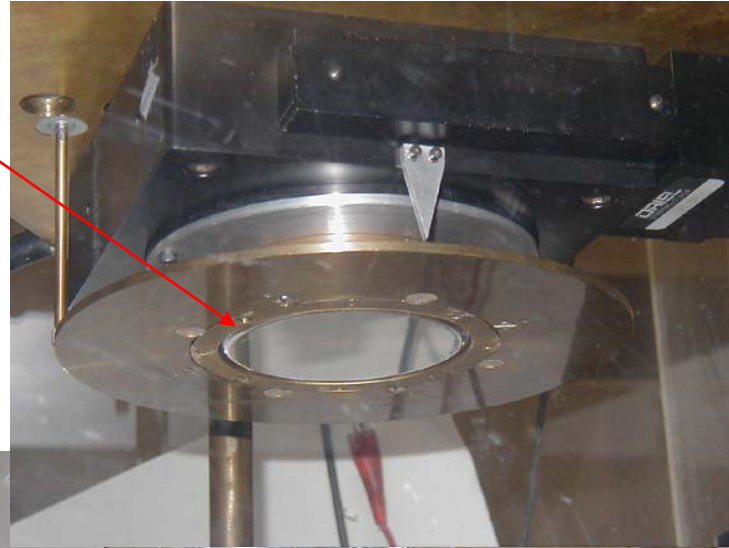


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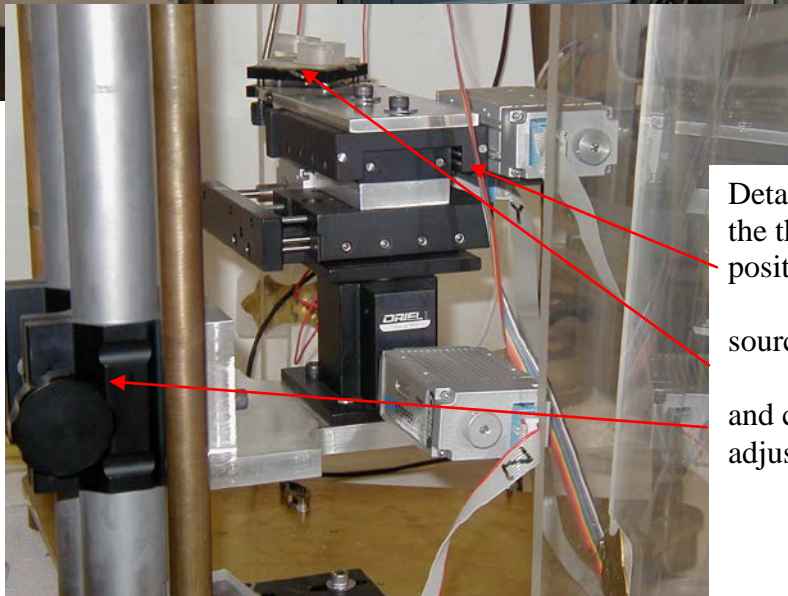
Figure 5. Photographs of NIST extrapolation chamber

View looking up at the high-voltage electrode/entrance window

Detail view from the front showing depth gauge carrying high voltage to the window mounting ring



NIST medical extrapolation chamber in plastic shielding box with measurement equipment



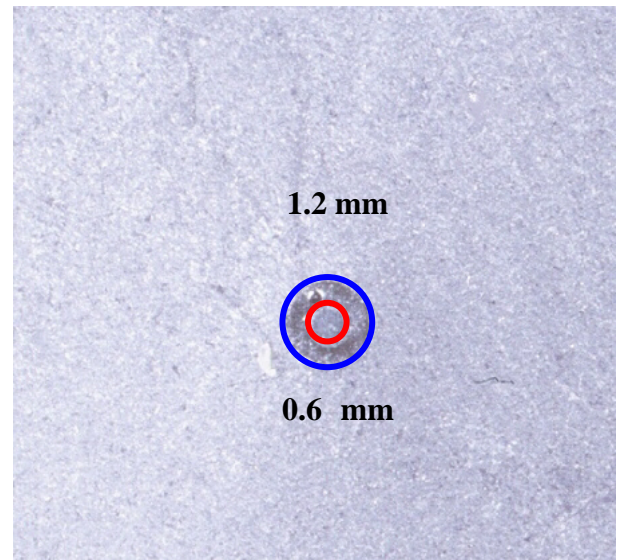
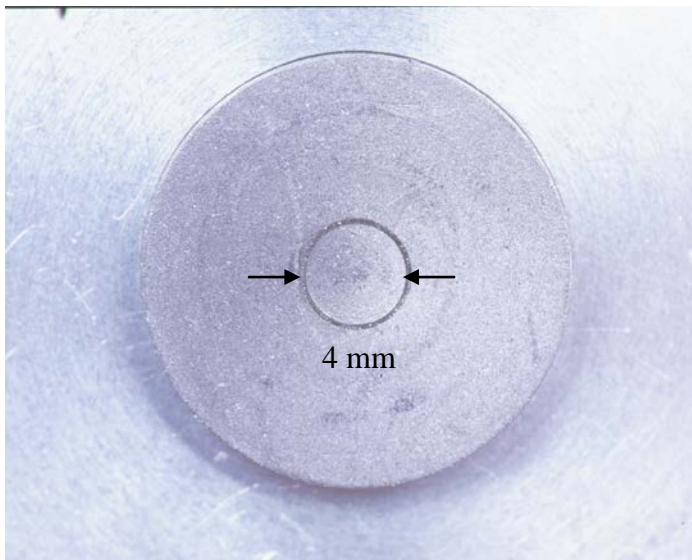
Detail view from side of the three dimensional positioning platform, source leveling platform and coarse height adjustment

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Figure 6. Photographs of collecting electrode surfaces; left: 4-mm diameter; right: 0.6-mm diameter (outer circle: outer edge of the insulator with diameter 1.2 mm; inner circle: outer diameter of the collecting electrode with diameter 0.6 mm)



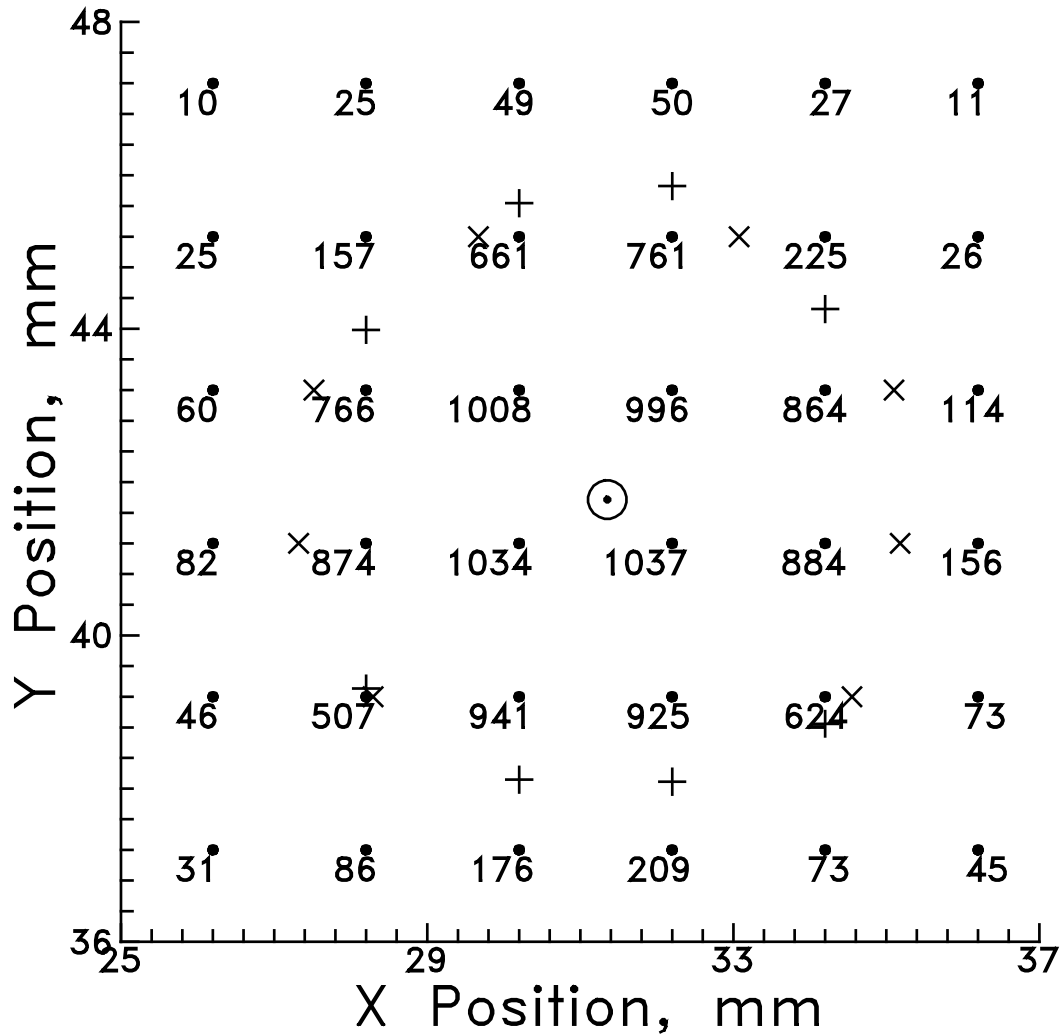
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Figure 7. Sample data set for illustrating the concept of source center. The plus signs indicate the locations of  $x_{50i+,-}$  while the crosses indicate the locations of  $y_{50j+,-}$ . The accompanying table shows the actual data. Results of measurements not shown indicated the maximum signal was 1053 and this was used for the basis of the 50 % value for the calculation.





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Figure 8. Two dimensional MQA model applied to the calibration of ophthalmic applicators.

	National Standard: Extrapolation chamber with 4 mm electrode	Additional Device: Calibrated Radiochromic Film
Unknown Source	Calibration	Quality Control on Calibration
Reference Eye Plaque	Quality Control on Standard	Calibration of Radiochromic Film

CALIBRATION OF OPHTHALMIC APPLICATORS

Figure 9. Collecting electrode fabrication

