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660-6
500-100
6000-100
660-7 & 660-8

CT Probes and Phantoms

Operators Manual

March 2005
Manual No. 660-6-1 Rev. 3

Fluke Biomedical
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Section 1
Introduction

1.1 Product Description

CT Probes, Models 660-6, 500-100, and 6000-100 are designed to be used with Phantoms, Models 660-7 and 660-8, to measure exposure produced by Computed Tomography (CT) Scanners.

The probes (Figure 1-1) consist of a pencil type ionization chamber with a sensitive length of 10.0 cm. The Model 660-6 probe chamber is connected, via 0.9 m (3 ft.) of low noise flexible cable, to a signal digitizing pre-amplifier. It is designed to be readout on a Model 660 Digital Exposure Meter. The Model 500-100 probe chamber is connected to 0.9 m (3 ft.) of low noise flexible cable terminated with a male BNC size triaxial connector. It is designed to be readout on a quality electrometer. Model 600-100 (not-shown) is similar to the Model 500-100, but designed for the NERO™

The phantoms (Figure 1-2) are designed in accordance with the definition in the FDA Center for Devices and Radiological Health, performance standard 1020.33 Computed Tomography (CT) equipment, “NCT Dosimetry Phantom”. Model 660-7 is a body phantom; Model 660-8 is a head phantom.

1.2 Specifications

1.2.1 CT Probes

Detector Type	Vented air ionization chamber
Volume	3.2 cc
Sensitive Length	10.0 cm
Chamber	**Material:** Clear Acrylic **Inside Diameter:** 6.4 mm **Wall Thickness:** 54 mg/cm^2
Electrode	**Material:** Aluminum **Diameter:** 0.64 mm
Sensitivity	10 R cm/nC (nominal)
Factory Calibration	100 KVCP, 5.5 mm Al hvl
Energy Response	+5%, 1 mm Al to 10 mm Al hvl (see Figure 1-3) **Uniformity (along axis):** + 3% over central 90% of active length (see Figure 1-4)
Beam Orientation	Normal to chamber axis
Phantom Adapter	**Outside Diameter:** 1.27 ± 0.04 cm (0.50 ± 0.015 in)
Model 66O-6 (with Model 660 Readout)	**Maximum Display:** 999 R cm/min, 99.9 R cm **Maximum Resolution:** 0.01 R cm/min, 0.001 R cm

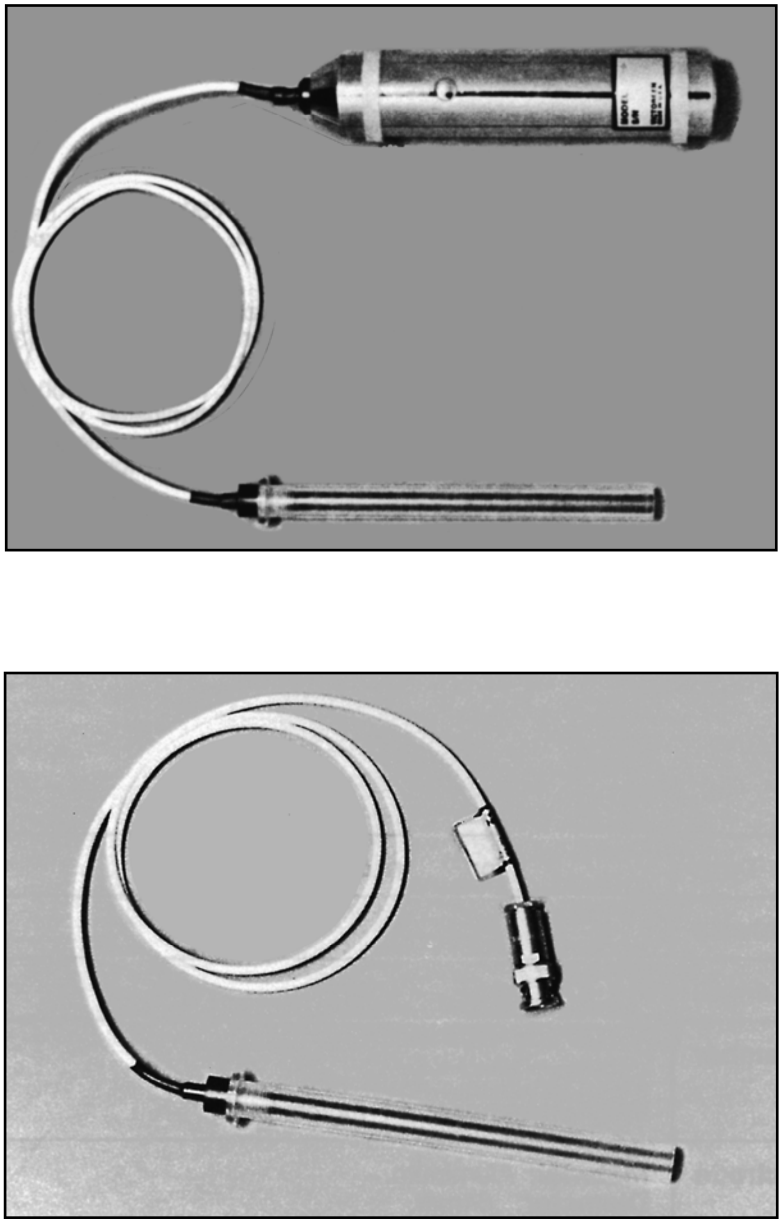

Figure 1-1. Model 660-6 and Model 500-100 CT Probes

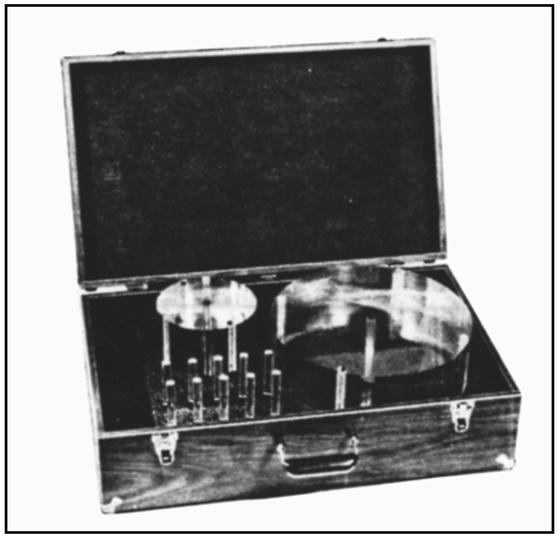

Figure 1-2. Model 660-7 and Model 660-8 Phantoms

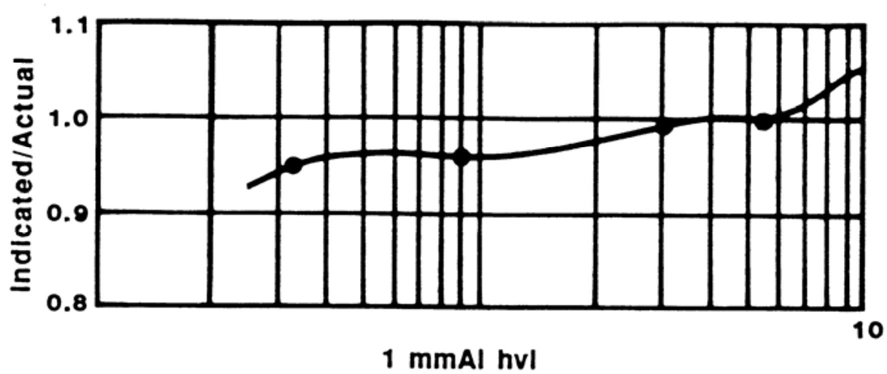

Figure 1-3. CT Probe Energy Response (Phantom Adapter Removed)

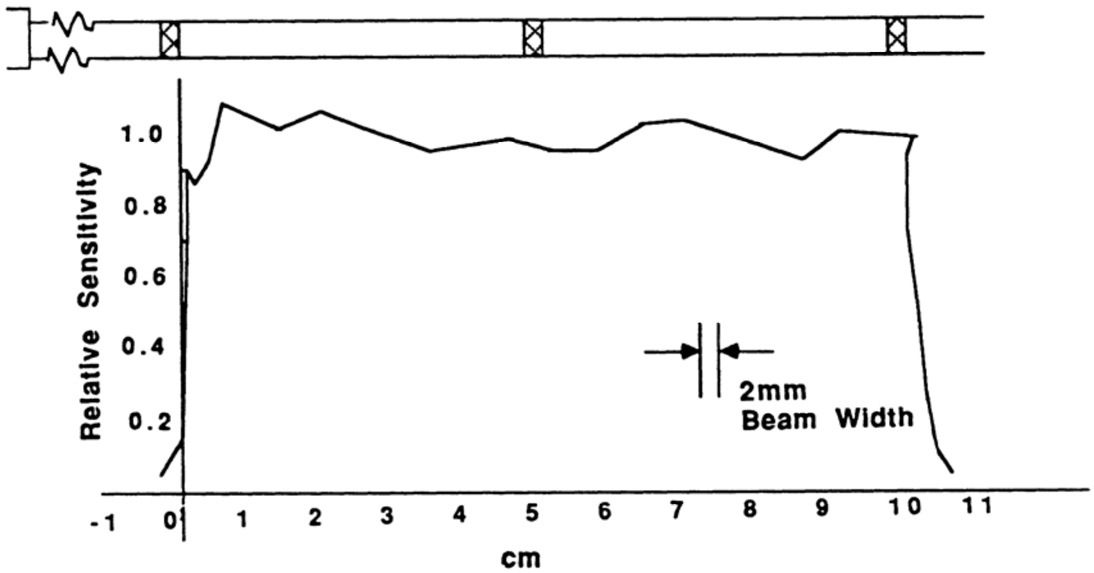

Figure 1-4.CT Probe Unit Length Response

Model 660-6 (Cont'd)	**Intensity Limits:** **Continuous Beam:** 985 R/min (1% recombination loss, ion chamber) 1080 R cm/min (electronic preamp limitation) **Pulsed Beam:** 1.6 mR/pulse (1% recombination loss) **Maximum Pulse Repetition Rate:** 700 Hz **Ion Transit Time:** 1.3 ms
Model 500-100 (with 300 Volt Collection Potential)	**Leakage Current:** **10 min polarization time:** $<10^{-13}$ A **2 hr polarization time:** $<10^{-14}$ A **Intensity Limits:** **Continuous Beam:** 4.86 kR/min (1% recombination loss) **Pulsed Beam:** 51.5 mR/pulse (1% recombination loss) **Maximum Pulse Repetition Rate:** 3.3 kHz **Ion Transit Time:** 0.3 ms **Connector:** BNC triaxial

1.2.2 Phantoms

Material	Acrylic Plastic
Thickness	15 cm
Diameter	**Model 660-7 Body Phantom:** 32 cm (12.60 in) **Model 660-6 Head Phantom:** 16 cm (6.30 in)
Probe Holes	**Arrangement:** One on center, four around periphery (90 degrees apart, 1 cm in from edge) **Inside Diameter:** 1.27 cm
Volume	3.2 cc

1.3 Receiving Inspection

Upon receipt of the unit:

1. Inspect the carton(s) and contents for damage. If damage is evident, file a claim with the carrier and notify Fluke Biomedical, Radiation Management Service at 440.248.9300.
2. Remove the contents from the packing material.
3. Verify that all items listed on the packing list have been received and are in good condition.

NOTE

If any of the listed items are missing or damaged, notify Fluke Biomedical.

1.4 Storage

If the unit is to be stored prior to use, pack it in the original container(s), if possible, and store in an environment free of corrosive materials, fluctuations in temperature and humidity, and vibration and shock.

CAUTION

The equipment described in this manual is intended to be used for the detection and measurement of ionizing radiation. It should be used only by persons who have been trained in the proper interpretation of its readings and the appropriate safety procedures to be followed in the presence of radiation.

Although the equipment described in this manual is designed and manufactured in compliance with all applicable safety standards, certain hazards are inherent in the use of electronic and radiometric equipment.

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Section 2
Theory of Operation

2.1 Theory of Operation

In a phantom, integration of the radiation exposure profile produced by a single scan from a CT scanner along a line normal to the slice, divided by the table increment, is equal to the average exposure produced by a series of scans to a central slice at that point. * The line of integration must be of sufficient length to intercept both the primary beam and the Compton scanner produced in the phantom. The integral is expressed as R cm.

A long, thin radiation probe can be used for the measurement. The probe should be calibrated in a uniform field covering its entire sensitive length, with a correction factor determined in the conventional manner. Subsequent probe readings, multiplied by the correction factor and then by its sensitive length, will be in units of R cm.

The CT probes are designed especially for CT scanner applications. The correction factor due to their length (10.0 cm) is built into the probe calibration:

- The Model 660-6, when used with the Model 660, is read directly in R cm or R cm/min.
- The Model 550-100 correction factor is stated in R cm/coulomb

NOTE

In applications where the probes are used to measure uniform field exposure in terms of R, the Model 660 readings should be divided by 10 or the Model 500-100 correction should be divided by 10.

*R. A. Jucius, G. X. Kambic, "Measurements of Computed Tomography X-Ray Fields Utilizing the Partial Volume Effect"

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Section 3
Operation

3.1 Operation

The following considerations should be noted when using CT Probes and Phantoms:

- The phantom adaptor (built-up sleeve) is designed to provide mechanical protection for the ion chamber and to properly place the probe's sensitive volume in the phantom.
- The phantom adaptor should never be removed from the probe in the field; it should only be removed when necessary and in the calibration laboratory (e.g., to verify probe sensitivity).
- The hole plugs supplied with the phantoms have small 1.5 mm holes through their midpoint. When the phantom is properly centered in the CT beam, the holes will appear as small rectangles on the CT scan.
- The ion chamber electrode is not guarded; therefore, after a collection voltage is applied, allow five minutes for the insulators to polarize.
- If using the Model 660 readout, five minutes after the unit is turned on remove the plug button in the probe preamp and adjust the zero (while in the Rate Mode).

CAUTION

The Model 660 does not read below zero; therefore, adjust the zero from a positive reading down to just zero. Otherwise, appreciable error may be introduced due to negative leakage.

Use the above guidelines and following procedure to take data

1. Position the phantom, readout device, and cable.
2. Connect the probe to the readout device.
3. Turn on the readout device, applying a collection voltage.
4. Run a scan to check that the holes in the hole plugs are visible.
5. Place the probe in the phantom.
6. Place the probe readout in the integrate mode.
7. Wait one minute to be sure there is not excessive leakage.
8. Run scans and record data as required.

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Section 4
Probe Calibration

4.1 Probe Calibration

The Models 660-6 and 500-100 probes are factory calibrated with the correction factor built into the calibration. However, since the NERO™ electrometer is calibrated with the internal ion chamber, it is impossible to supply a CT probe correction factor that applies to all NEROs. Therefore, the user must calibrate the probe with the NERO it is to be used with. Use the following procedure:

NOTE

Calibration should be performed on a standard radiographic x-ray machine rather than a CT machine.

1. Set the x-ray machine to 100 kVp, 300 mA, and 0.5 sec.
2. Place the probe on the table:
   - The source to detector distance (SDD) should be 40 inches.
   - The equilibrium sleeve should be in place.
   - The probe should be perpendicular to the tube axis to minimize the heel effect.
3. Collimate the beam so that it uniformly irradiates the entire length of the probe.
4. Attach the probe to the NERO detector:
   a. Connect the BNC connector to the appropriate jack on the side of the NERO
   b. Plug the banana plug into its mating jack.
5. Position, and if necessary shield, the NERO detector so that radiation does not fall on the ion chamber.
6. Use the detector cable to plug the detector into the NERO unit, plug the unit into AC power, and turn it on.
7. Verify the mR correction factor by pressing the key sequence **F mR** on the NERO. The correction factor should be displayed on the LCD.

NOTE

If 1.000 is not displayed, enter **1** and press **ENT**.

8. Set the NERO up for an exposure by pressing the key sequence F 5. Observe the following:
   - The display will clear as NERO measures electrometer drift for twelve seconds.
   - The NERO will then beep and display 0.0 mR.
9. Make an exposure and record the results.
10. Press **NEXT** to clear the display.
11. Repeat Steps 9 and10 to obtain a total of five exposures.

NOTE

All five exposures should be within 3%.

12. Compute an average of the five exposures. Record the average as the Measured Value.
13. Press **EXIT** to return the NERO to the Ready condition.
14. Remove and disconnect the CT probe.
15. Place the NERO detector in the center of the beam.
16. Raise the tube 2.25 inches to compensate for the height of the detector box.
17. Make an exposure and record the results.
18. Press **NEXT** to clear the display.
19. Repeat Steps 17 and 18 to obtain a total of five exposures.

NOTE

All five exposures should be within 3%.

20. Compute an average of the five exposures. Record the average as the *True Value.*
21. Compute the correction factor for the probe as follows:
    cf = 1 x True Value/Measured Value where 1 = the probe length (10 cm).
22. Record the correction factor.

Use the computed correction factor when making CT dose measurements. Enter it into the NERO as the mR correction factor (by pressing **F mR**, entering the factor, and pressing **ENT**). The display will then read directly in mR cm.

Appendix A
Radiation Dosimetry in Computed Tomography

A.1 Radiation Dosimetry in Computed Tomography

This Appendix contains the following Technical Notes article, as published in Volume 7 No. 4 of “Medical Physics” in Jul / Aug 1980.

Measurements of Computed Tomography X-Ray Fields

Utilizing the Partial Volume Effect[a]

Robert A. Jucius and George X. Kambic

Measurements of Computed Tomography X-Ray Fields Utilizing the Partial Volume Effect[a]

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(Received 22 June 1979; accepted for publication 4 February 1980)

Due to the x-ray field geometry, exposure measurements on computed tomographic (CT) scanners require modification of widely used measurement techniques. Ionization chambers have geometries which do not allow measurement of narrow rotating x-ray fields. However, by utilizing the partial volume effect, an ion chamber can be calibrated to measure narrow x-ray fields with a spatial resolution of down to 1 mm. The number of scans required to reconstruct a complete profile depends on the resolution required, and is typically on the order of 10 to 20 scans. This is accomplished using a series of attenuating sleeves over the ionization chamber. The chamber and sleeves are calibrated against a standard chamber using large field geometries. Comparisons with TLD measurements are shown to verify the accuracy of the technique.

Key words: computerized tomography, dosimetry, ionization chambers

I. INTRODUCTION

Due to the x-ray field geometry, exposure measurements of CT scanners require modification of widely used measurement techniques. Ionization chambers have geometries which do not allow measurement of narrow rotating x-ray fields. This paper shows a method of using an ion chamber that is specifically designed for CT systems to measure narrow x-ray fields with experiments showing a spatial resolution down to I mm. However, this method should be applicable to other small volume ion chambers.

II. EXPOSURE MEASUREMENT TECHNIQUES

A generalized CT scanner geometry is shown in Fig. I with a typical exposure profile along the axis of rotation as compared to a single TLD or a series of TLD's. Previously we have reported a method of replacing a series of TLD's with an ion chamber.[1] Similar results have been reported by Suzuki and Suzuki.[2,3] In this paper the single TLD is replaced by an ion chamber system.

The ion chamber used in these measurements is a Capintec Inc. PC-4P pencil type ion chamber with a 10 cm active length. Figure 2 shows the response of the chamber to a narrow (1 mm) x-ray field and Fig. 3 compares a typical CT exposure profile to a 10cm chamber, a 5 cm chamber, and a series of TLD's. The nomenclature that is used throughout this paper for measuring exposure using the PC-4P chamber and a series of calibrated attenuating sleeves is as follows:

X = exposure at any point on exposure profile;
X_1 = exposure on PC-4P chamber with sleeve;
X_0 = exposure on PC-4P chamber with no sleeve;
X_A = excess exposure in gap A;
$\overline{X}(t)$ = average exposure for increment t;
$D(Z)$ = exposure distribution;
$D1(Z)$ = exposure distribution with sleeve;
A = length of aperture in sleeve (cm);
L = length of chamber (cm);
B = transmission of sleeve X_1 (with A = 0)/X_0;
t = scan table increment;
$D_2(Z)$ = exposure in aperture A.

The chambers and sleeves utilized are shown in Fig. 4.

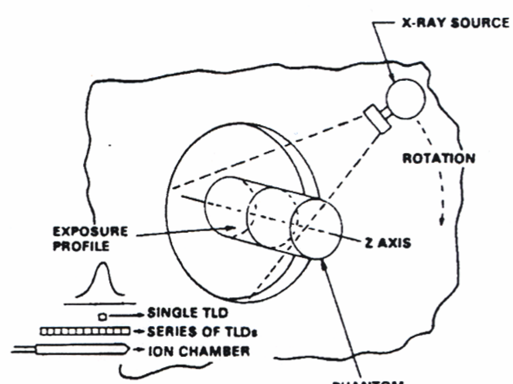

Fig. 1. Schematic of typical CT scanner operation. The axis of rotation of the x-ray tube, the exposure profile, the TLD's , and the ion chamber are all directed along the Z direction.

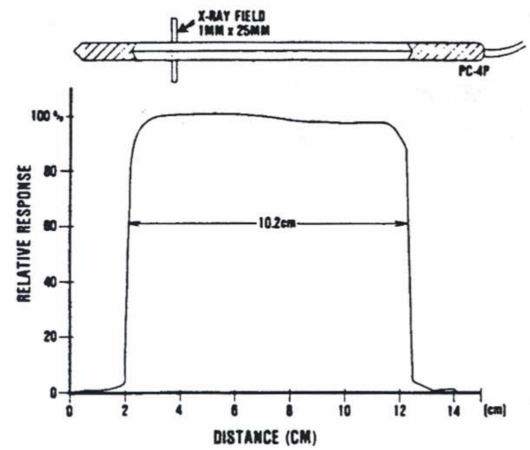

Fig 2. Chamber response to narrow x-ray.

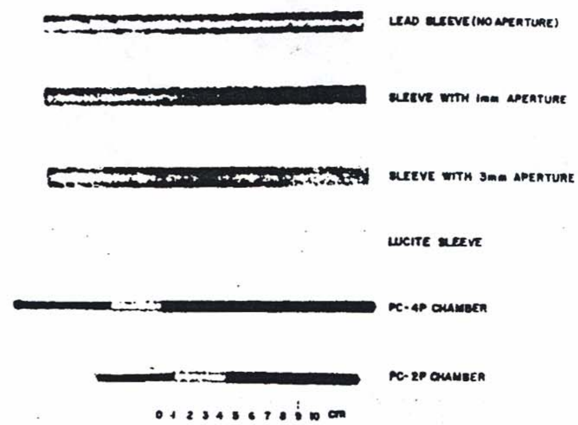

Fig 4. Chambers and lead sleeves utilized in measurements. The lead thickness is 1 mm.

Figure 5 is a plot of the exposure profile for a typical scan where any point of the profile is the exposure X obtained from TLD readings. All exposure profiles are along the axis of rotation of the CT system. The ion chamber reads X_0 or the average exposure under the curve over the length (L) of the chamber. When X_0 is multiplied by chamber length and divided by the table increment it gives X(t) or the average exposure to a central scan of a series of scans as described in Jucius and Kambic.[1]

When a lead sleeve with an aperture A is placed over the chamber the exposure profile is as shown in Fig. 5 (dashed line) where X_1 is the average chamber reading in the aperture including the transmitted radiation through the lead sleeve over the length of the chamber. The curve of the attenuated beam is not to scale because the percent transmission of x-rays at typical CT operating techniques through the lead sleeve is less than 1 %. With the aperture A equal to O, the exposure profile is the exposure transmitted through the lead sleeve. The transmission B is determined by dividing X_1 by X_0 when A is set to 0.

By combining the three profiles the exposure X in the aperture A can be calculated. Graphically, the exposure can be calculated by taking the area under the curves and obtaining:

$$AX = LX_1 - LBX_0 + ABX\,. \qquad (1)$$

The solution of this equation for X is:

$$X = L(X_1 - BX_0)/A(1 - B)\,. \qquad (2)$$

The three terms in Eq. (1) may require some clarification. LX_1 is the integral of the curve $D_1(Z)$.

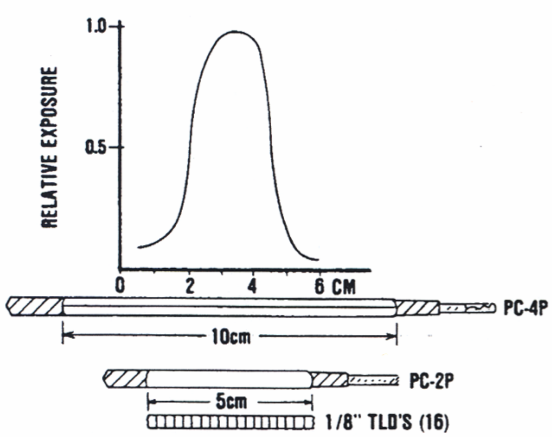

Fig 3. Comparison of single exposure profile to active length of detector systems.

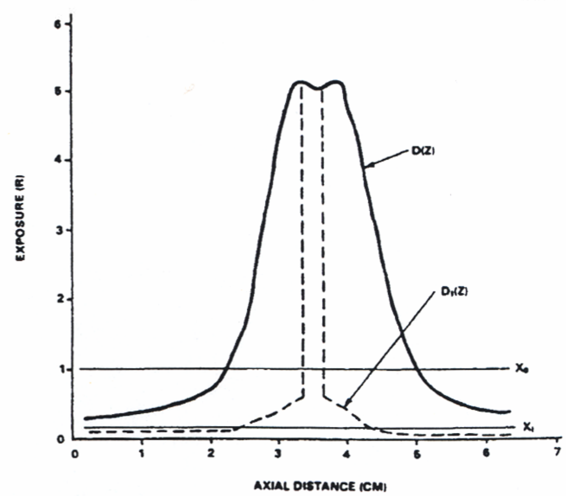

Fig 5. Exposure profiles for scans using no sleeve, [D(Z)], and a sleeve with A>0, [D_1(Z)].

The term LBX_0 subtracts out all the components of the exposure due to the attenuating sleeve, including the part of the probe in aperture A. Hence the term ABX is required which adds back in the exposure only due to the interval A, with a sleeve over that length. This term is actually the integral of $D_1(Z)$ again, but only over the length A when A is shielded with lead.

III. THEORY

In this section, a simple expression for the peak exposure in a small increment is developed. The general application for the ion chamber in measuring the average exposure in the central scan of a series of scans was developed in Jucius and Kambic,1 and is given in Eq. (3),

$$X(t) = (X_0 L)/t. \qquad (3)$$

The transmission through the attenuation sleeve is determined as the ratio of the exposure to the ion chamber with the attenuation sleeve (A = 0) to the exposure to the chamber with no attenuation sleeve (A = L).

$$B = \left[\int_{-L/2}^{L/2} D_1(Z)dZ\right]\left[\int_{-L/2}^{L/2} D_1(Z)dZ\right]^{-1} = X_1/X_0. \qquad (4)$$

For 0 < A < L, S is defined as the sum of two contributions, $D_1(A)$ plus $D_2(A)$, with $D_2(A)$ nonzero only in A (the excess exposure in the region A). S is the integral exposure and is equal to X_1L. X_1 is obtained from X(t) by setting t = L.

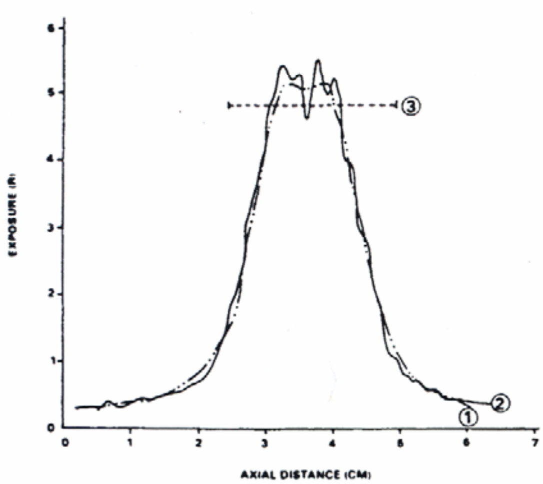

Fig 6. Exposure profiles for 3 cases; 1) TLD's spaced as intervals of 0.9 mm, 2) TLD's spaced at 3.2 mm intervals, and 3) with $X(t) = X_0Lt^{-1} = X_0(10.2\ cm)(2.6)^{-1}$

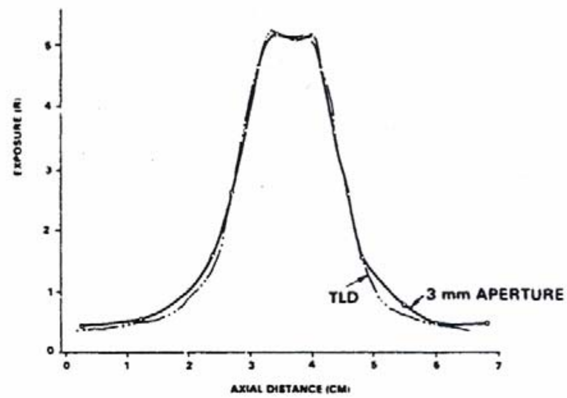

Fig 7. Exposure profile for TLD's and for a sleeved probe for A=3 mm calculated using Eq. (12). The parameters are A = 0.3 cm, B = 0.013, L = 10.2 cm and X_0 = 1.24 R.

Let

$$S = \int_{-L/2}^{L/2}\left[D_1(Z) + D_2(ZdZ)\right] D_2(Z) > 0 \text{ only in } A. \qquad (5)$$

$D_1(Z)$ and $D_2(Z)$ can be separated:

$$S = \int_{-L/2}^{L/2} D_1(Z)dZ + \int_{-A/2}^{A/2} D_2(Z)dZ. \qquad (6)$$

The exposure in A defined by $D_2(Z)$ can be rewritten:

$$\int_{-A/2}^{A/2} D_2(Z)dZ = X_A A. \qquad (7)$$

Using Eq. (4), S is also written as:

$$S = B\,X_0 L + X_A A. \qquad (8)$$

The exposure in A can be written

$$X = X_A + \int_{-A/2}^{A/2} \frac{D_1(Z)dZ}{A}. \qquad (9)$$

where

$$\int_{-A/2}^{A/2} \frac{D_1(Z)dZ}{A} = BX. \qquad (10)$$

and

$$X_A = X(l - B). \quad (11)$$

Solving Eqs. (8) and (11) simultaneously, and noting that $S = X_1L$, Eq. (12) for X is obtained:

$$X = L(1 - BX_0) / A(1 - B). \quad (12)$$

This agrees with Eq. 2 where X is calculated geometrically from Fig. 5.

IV. RESULTS

Figure 6 shows a typical exposure profile measured using TLD's (1) on edge, with 1 mm resolution, (2) flat, with 3 mm resolution, and (3) the PC-4P chamber reading (X_0Lt^{-1}). The chamber reading, line (3) on Fig. 6, is the exposure length product measured from an actual scan exposure profile (X_0L), and is graphed as a constant exposure to each point over the scan table increment (t).

Figure 7 is obtained using a 3 mm aperture in the lead sleeve. The circles are the values of X from Eq. (12), the broken line is the TLD measurements. Figure 8 is the same data using a lead sleeve with a 1.3 mm aperture. The overall agreement of the measurements is better than 10% above X = 1 R. The measurements below 1 R are not in as good agreement. This is because the component of the attenuated signal exceeds the signal in the aperture and the measurement inaccuracies increase. This can be seen by the larger variations in the 1.3 mm aperture data compared to the 3 mm aperture data. This system can be calibrated by the use of a large uniform radiation field. This is done be first exposing an unshielded chamber to a uniform field, secondly by exposing the chamber with a continuous lead sleeve, and finally by exposing the chamber with lead sleeve with aperture A. With these data, reading 1 = X = X_0, reading 2/X = B, reading in Aperture = X, and reading 3 = X_1. The aperture length is simply obtained by solving Eq. (12),

$$A = L/X(X_1 - BX_0) / (1 - B). \quad (13)$$

V. SUMMARY

By properly correcting for partial shielding of an ion chamber a segment of the chamber with aperture A can be used to measure narrow x-ray field exposures. This procedure is time consuming and cannot be used to make a large number of readings where TLD's or a segmented chamber would be needed, but it is a useful tool for measuring peak exposures for a single scan and comparing it to multiple scan exposures.

[a] Presented at the 1979 Annual Meeting of AAPM.

[1] R. A. Jucius. G. X. Kambic, SPIE Proc., Application of Optical Instrumentation in Medicine VI 127, 286-295 (1977).

[2] A. Suzuki and M. V. Suzuki, Med. Phys. 5, 536 (1978).

[3] G. X. Kambic and R. A. Jucius, Med. Phys. 6, 459 (1979)

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