TECHNICAL NOTES

Some phantom designs for radiation dosimetry and CT applications[a)]

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Solid phantoms designed with nesting, rotatable cylinders, allow increased flexibility in the positioning of dosimeters or test objects, permitting continuous movement as in a water phantom, but with increased ease of handling. Using such phantoms, measurements can be made at almost any point in the cross section of a phantom, an ability not achievable with currently existing solid or water phantoms. A separate phantom design allows easy measurement at points along circles or radii in a phantom.

Key words: phantoms, dosimetry, calibration

I. INTRODUCTION

Many physicists prefer to work with solid phantoms, rather than water phantoms, due to the convenience of handling. The fluidity of water eliminates its use in situations such as electron arc-therapy measurement, which use a cylindrical phantom lying on its round surface, with a dosimeter entering the flat surface. Solid phantoms, however, traditionally both have not been water equivalent and have forced fixed geometry on the user. The use of water-equivalent materials as developed by White[1–3] and Constantinou,[4] which are now commercially available, eliminate the first of the two disadvantages. Using phantoms as described below, partially overcomes many of the geometrical constraints of solid phantoms.

II. DESCRIPTION OF PHANTOM DESIGNS

A. Variable position block phantom

Figure 1 shows a cross section of a block-type phantom composed of three parts: (1) the flat-surfaced, $30\times 30\times 15$ cm^3 frame, (2) an inscribed and centered, large cylinder, 15 cm in height, and (3) a smaller, dosimeter-carrying cylinder, eccentrically positioned at the edge of the large cylinder. The smaller cylinder contains a hole for placement of a dosimeter or test object. By making the diameter of the small cylinder, d_s, equal to the radius of the large cylinder, r_l, plus the radius of the hole, ϵ, the axis of the hole can assume any position within the circular cross section of the large cylinder, except for the peripheral $\delta + \epsilon$ thick strip, where δ is the thickness of the thinnest portion of the wall. Conceivably, since both cylinders are completely inscribed, δ could go to zero, although in practice, values of 1 mm could be expected.

Placing a solid block of the same dimensions on the bases of the cylinders results in a standard size calibration phantom. The edges of the cylinders could be marked indicating the rotational angles, as indicated in Fig. 1, to position the center of the hole at given depths in the center of the phantom, using the relations

$$\theta = \cos^{-1}\left[\frac{d - r_l - \delta}{-2(r_s - \epsilon)}\right],$$

$$\phi = 2\theta.$$

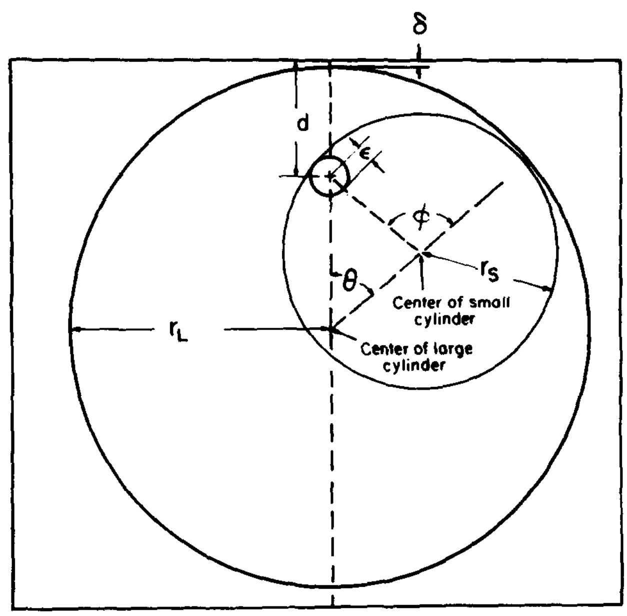

FIG. 1. Variable position block phantom, shown in cross section.

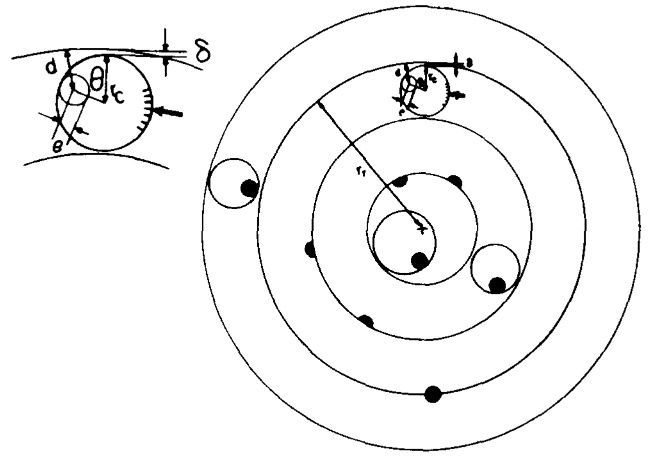

FIG. 2. Variable depth cylindrical phantom, shown in cross section. Dark circles indicate holes for dosimeters.

B. Variable depth cylindrical phantom

Figure 2 shows a set of concentric cylindrical rings of phantom material. Each ring contains a cylindrical dosimeter carrier into which an appropriate dosimeter can be placed. Rotating the rings and carriers allows for positioning a dosimeter at any point in the phantom except those points within $\pm(e+\delta)$ of the interface of two rings. Cutting a hemicylindrical notch in each surface of each ring permits measurements at the radii of ring interfaces by matching notches to form a cylindrical hole. Unused holes can be rotated out of the way of the beams so as not to perturb measurements.

Measurements in cylindrical phantoms usually use the radial depth to the chamber (i.e., the depth perpendicular to the surface of the ring). The angle θ, to set a given depth below the surface of the ring containing the carrier, as shown in the insert of Fig. 2, is given by

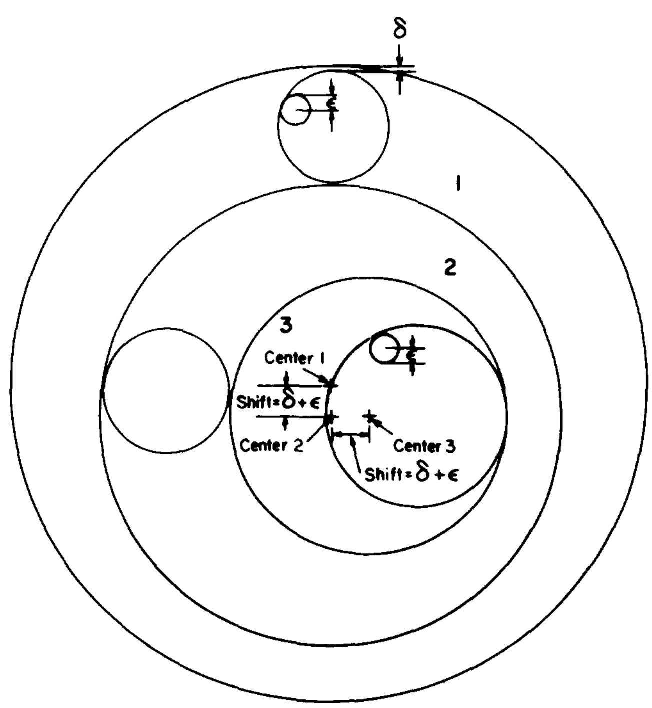

FIG. 3. Cylindrical phantom shown with eccentrically cut rings.

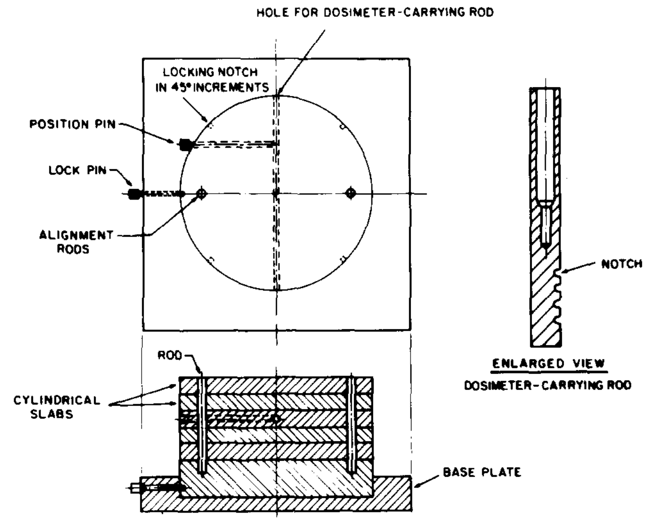

FIG. 4. Variable angle and position phantom.

$$\cos\theta = \frac{(r_r-d)^2-(r_r-r_c-\delta)^2-(r_c-e)^2}{2(r_r-r_c-\delta)(r_c-e)},$$

where r_r ≡ outer radius of the ring, r_c ≡ radius of the carrier cylinder, d ≡ depth of center of the dosimeter, e ≡ radius of the dosimeter, and δ ≡ thickness of material overlying the carrier cylinder. The thickness of any additional outside rings must be added to d to give the actual depth of measurement.

Cutting the internal holes in the rings eccentrically (as in the block phantom) instead of concentrically, with the same radii, but the centers moved $(e+\delta)$ away from the ring's dosimeter carrier, and expanding the diameter of each dosimeter carrier by this same amount, eliminates any "forbidden depths" at which measurements could not be made. Figure 3 illustrates such a phantom.

Unfortunately, with eccentric-ring phantoms the radial depths to any point in the inner rings is no longer given by an unique angle on the dosimeter carrier, since the thickness of the more outer rings varies with the rotational angle between the two rings.

C. Variable angle phantom

A third phantom design, shown in Fig. 4, carries the dosimeter mounted in a rod which slides through a cylindrical

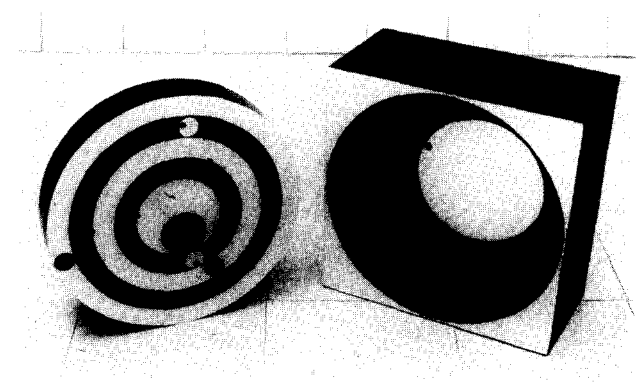

FIG. 5. Photograph of the variable position block phantom and the variable depth cylindrical phantom with its backing phantom material.

slab phantom. The phantom, which is made up of slabs of various thicknesses, is held in position by two rods on opposite sides of the dosimeter track. The phantom can be rotated, and set to predetermined angular increments (such as 45°) by a pin in the base plate which falls into notches on the side of the phantom. With the beam incident normally to the flat surface of the cylinder, such a phantom facilitates the measurement of beam symmetry, or with the chamber centered, of stem effect factors. Holes cut in a section of the dosimeter-carrying rod, distant from the measuring volume, allow easy setting of fixed increments along the chamber axis. Measurement of off-axis ratios in such a phantom requires ionization chambers of small axial length so as to avoid a large gradient along the chamber's sensitive length. Various depths would be set by rearranging the various thicknesses of cylindrical phantom material in the standard manner.

III. DISCUSSION

Figure 5 shows a photograph of the half of the variable position phantom which contains the cylinders, and the variable depth arc phantom, with similar backing material rings. The phantoms are constructed of the water-equivalent material, which machines easily and precisely. The cylinders move freely when turned, yet there is sufficient friction to hold them in place when no force is applied. These particular phantoms have been constructed to accept intracavitary dosimeters and diode probes, but any size or shape cavity could have been used. The arc phantom pictured has more, and smaller rings than that described earlier, in order to study the relationship between radius of curvature and dose in trans electron arc therapy. In general, fewer, larger rings would probably facilitate most clinical work.

Cylindrical phantoms can make significant impact in the calibration and dosimetry of arc therapy, both with photons and electrons, and in measurements related to tangential treatments. They also could prove useful in computerized tomography dose measurements, and, by replacing the dosimeters with test objects, evaluating imaging capability as a function of position in the field.

IV. CONCLUSION

Using the phantoms described above, dosimetric measurements can be performed with some of the same flexibility and accuracy of a water phantom, but with the convenience of a solid phantom.

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