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Stem corrections for ionization chambers

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Ionization chambers often exhibit a stem effect, caused by interactions of radiation with air near the chamber end, or with dielectric in the chamber stem or cable. These interactions contribute to the apparent measured exposure. To determine the stem effect for several common ionization chamber systems, exposures were measured with TLD capsules placed at the center of ^{60}Co fields of various sizes. These exposure measurements then were repeated with various ionization chamber systems, including two Victoreen R meters (25- and 100-R chambers), a Capintec 192 dosimeter with a Farmer 0.6-cm^3 probe, a PTW transit dose probe, and an EG&G IC-18 probe with a Keithley 610-B electrometer. From a comparison of TLD and ionization chamber measurements of the variation in exposure rate with field size, stem corrections for the different systems were determined within 1%.

Ionization chambers often exhibit a stem effect caused by interactions of photons with air near the chamber end or with dielectric material in the stem or cable.[1,2] These interactions contribute to the apparent measured exposure. Ionization chamber calibrations from the National Bureau of Standards and Regional Calibration Laboratories are performed in a prescribed geometry where part or all of the stem is exposed to radiation. When the chamber is irradiated in a different geometry, with a different amount of stem exposed, a correction factor may be necessary to compensate for an altered stem contribution to the chamber response.

Two simple methods have been recommended for investigating the stem effect. One method is to position the sensitive volume of the ionization chamber somewhat off center in a rectangular field of radiation[3] (Fig. 1). With the chamber in position 1, the entire stem is exposed and the stem effect contribution to the measured exposure is maximum. With the chamber rotated 180° to position 2, about 90% of the stem is exposed, but the electrodes at the end of the chamber are outside the field. A third measurement is obtained for position 3, with the stem perpendicular to the long axis of the field and only about 10% of the stem exposed. This orientation provides the response from essentially only the sensitive volume of the chamber. Additional measurements are obtained with the chamber in intermediate positions.

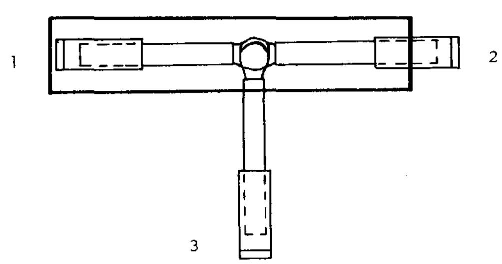

FIG. 1. Condenser ionization chamber in several orientations in a 25×5-cm radiation field for determination of stem ionization.

A second popular method for determining the stem effect involves positioning the chamber as before, with its sensitive volume off center in the radiation field.[1] In this approach, however, the different stem exposures are obtained by rotating the collimator rather than the chamber.

For both of these methods, stem effect correction factors are determined by dividing the response of the chamber exposed under conditions duplicating those of the calibration laboratory by the chamber response with different amounts of stem exposed. However, disadvantages are associated with the use of these methods. For example, the actual length of stem exposed can be measured accurately in no more than four collimator or chamber orientations, because the field edge intersects the chamber obliquely in other orientations. In the first method, the chamber must be repositioned precisely between exposures to ensure that the sensitive volume remains in the same location as the orientation of the chamber is changed. Also, the intensity and energy of the photons irradiating the chamber stem may

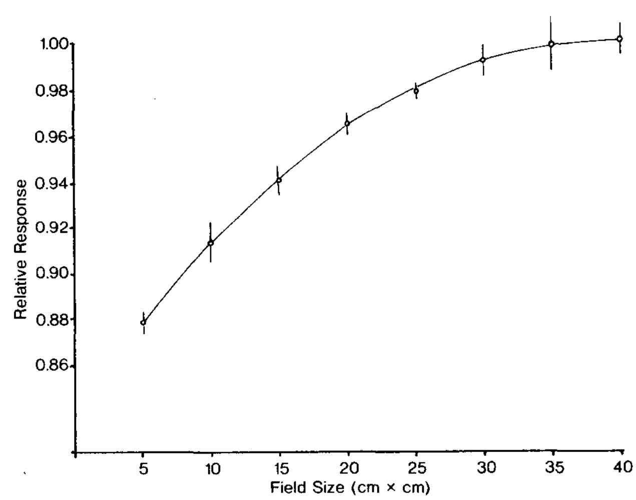

FIG. 2. Response of lithium fluoride powder irradiated on the central axis of square radiation fields of various sizes.

TABLE I. Stem correction factors determined as varying lengths of stem were exposed to ^{60}Co radiation in a number of different ionization chambers.

Ionization chamber	Length of stem exposed (cm)	Stem factor
Victoreen Model 553, 25 R	20.0	1.000
	17.5	1.008
	15.0	1.009
	12.5	1.007
	10.0	1.014
	7.5	1.016
	5.0	1.023
	2.5	1.034
Victoreen Model 621, 100 R	20.0	1.000
	17.5	0.996
	15.0	0.992
	12.5	1.001
	10.0	1.005
	7.5	1.011
	5.0	1.024
	2.5	1.029
Farmer, 0.6 cm^3	20.0	1.000
	17.5	1.002
	15.0	1.002
	12.5	1.002
	10.0	0.999
	7.5	0.998
	5.0	0.999
	2.5	1.007
Nuclear Associates PTW 30-333	20.0	1.000
	17.5	1.003
	15.0	1.002
	12.5	1.008
	10.0	1.005
	7.5	1.003
	5.0	1.002
	2.5	1.014
EG&G IC-18	20.0	1.000
	17.5	0.998
	15.0	0.996
	12.5	0.997
	10.0	1.000
	7.5	1.001
	5.0	1.003
	2.5	1.007

vary from one orientation of the chamber to the next. This asymmetry may be an even greater disadvantage with the second approach to determination of stem correction factors.

Disadvantages of the more popular methods for determining stem corrections can be avoided with the following approach. Small dosimeters such as lithium fluoride capsules are placed on the central axes of radiation fields varying in size from an area which covers only the sensitive volume of an ionization chamber, to an area which encompasses the sensitive volume and entire stem. These small dosimeters provide data relating the exposure rate at the central axis to field size. Next, an ionization chamber for which stem corrections are desired is positioned in place of the small

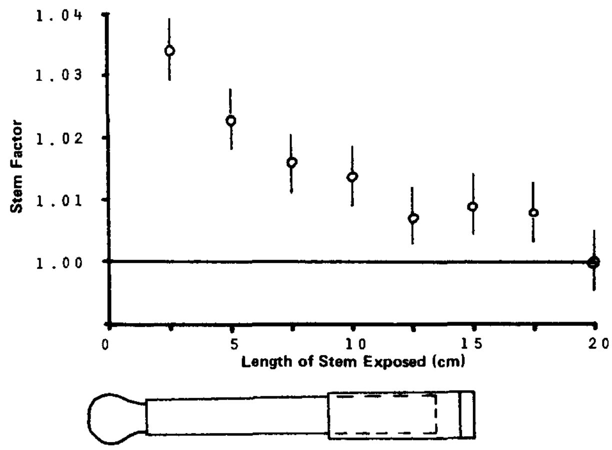

FIG. 3. Stem correction factor versus length of stem exposed to ^{60}Co radiation for a Victoreen Model 553 25-R condenser chamber. (Data given in Table I.)

dosimeters, and exposures are measured for fields of various sizes. With the data obtained with the small dosimeters, the ionization chamber measurements are normalized to the field size used for calibration of the chamber. For any amount of stem irradiation, the stem correction may be determined by dividing the normalized chamber response at that field size into the response for the field size used for chamber calibrations.

The approach described here for determination of stem corrections is preferable to other methods for several reasons. Any number of measurements with varying amounts of stem irradiation may be obtained simply by varying the field size in appropriate increments. The field edge always intersects the chamber at right angles, permitting unambiguous determination of the amount of stem exposed. The chamber orientation is not altered between exposures, which reduces or eliminates errors caused by imprecise repositioning. Finally, the chamber is exposed in the same geometry and with the same photon beam characteristics as those encountered during use of the chamber for dosimetric measurements.

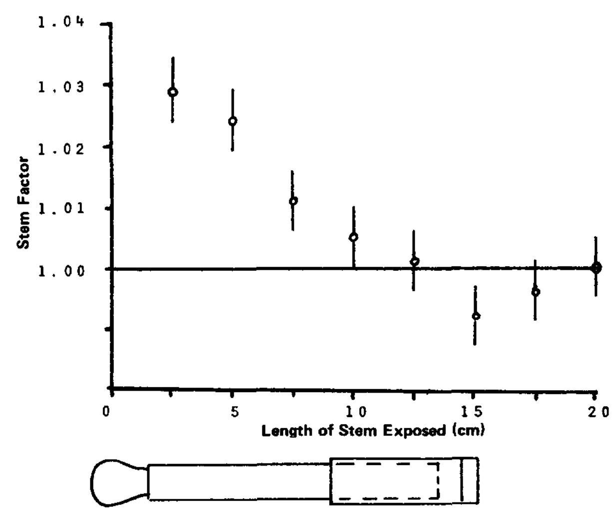

FIG. 4. Stem correction factor versus length of stem exposed to ^{60}Co radiation for a Victoreen Model 621 100-R condenser chamber. (Data given in Table I.)

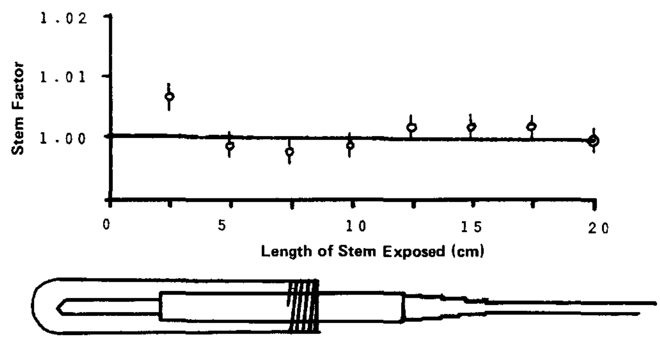

FIG. 5. Stem correction factor versus length of stem exposed to ⁶⁰Co radiation for a Farmer 0.6-cm³ ionization chamber. (Data given in Table I.)

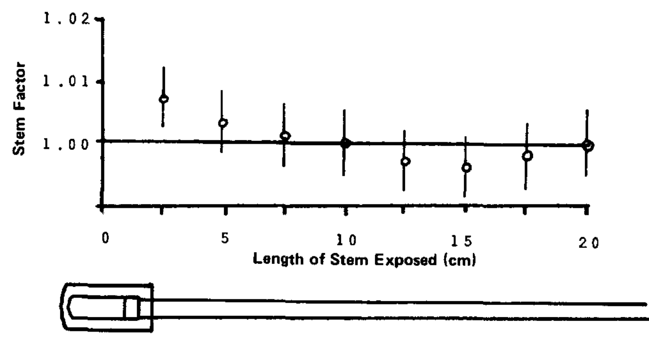

FIG. 7. Stem correction factor versus length of stem exposed to ⁶⁰Co radiation for an EG&G IC-18 cavity ionization chamber. (Data given in Table I.)

For verification of the approach described here for determination of stem effect correction factors, capsules of TLD-100 lithium fluoride powder enclosed in Lucite equilibrium sleeves were exposed on the central axes of eight square fields of ⁶⁰Co radiation. The capsules were exposed individually to avoid errors caused by off-axis positioning and by scatter from one capsule to another. Data obtained with the TLD capsules are plotted in Fig. 2, with error bars averaging ±0.7% representing the standard deviation of the mean for each group of measurements. The TLD measurements were compared to readings obtained with a Farmer probe positioned vertically along the central axis of ⁶⁰Co fields of various sizes. These Farmer probe readings correlate within 0.6% with the TLD measurements.

Ionization chambers for which stem correction factors were desired were exposed in square ⁶⁰Co fields of various sizes with the chamber perpendicular to the central axis of the beam. The exposure measurements at each field size were normalized with the TLD data to a large (40×40-cm) field. Stem correction factors then were determined by dividing the normalized exposure at each field size into the exposure measured for the large field. These data are tabulated in Table I and plotted in Figs. 3–7. In these figures, the error bars represent the estimated precision with which each chamber can be read.

From the data in Table I, it is apparent that the stem effect is rather small, although not necessarily negligible, for most of the chambers tested. Victoreen condenser chambers are an exception to this conclusion. At very small field sizes the slight difference in size between TLD capsule and chamber may be significant, possibly causing an apparent increase in the stem factor.

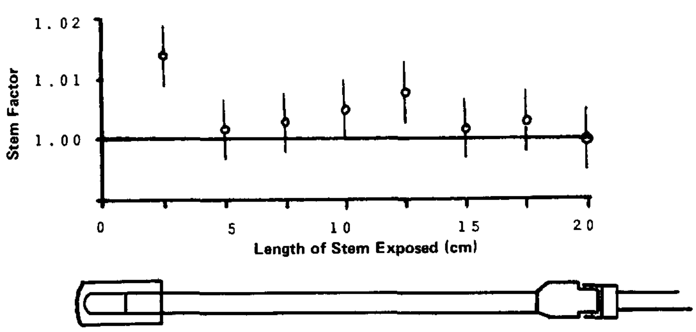

FIG. 6. Stem correction factor versus length of stem exposed to ⁶⁰Co radiation for a Nuclear Associates PTW 30-333 transit dose chamber. (Data given in Table I.)

Other investigators[3] have reported significant nonlinearity in the response of some Victoreen chambers exposed with the stem fully in the beam, where nonlinearity is described as a nonmonotonic relationship between chamber reading and exposure. To eliminate any influence of chamber nonlinearity upon results reported here, all Victoreen chamber measurements were obtained for exposures producing a chamber response from one-half to two-thirds full scale. In addition, the response of a Victoreen Model 553 25-R high-energy chamber was determined for various exposure times in a ⁶⁰Co beam. No nonlinearity greater than 0.6% was observed over the range 16–88% full scale. Hence, relaxation of the one-half to two-thirds full-scale constraint would not have influenced the estimated stem corrections, at least for this particular chamber.

The field size used for chamber calibration varies from one calibration laboratory to the next. At the National Bureau of Standards, calibrations are performed in a field which varies in size with the photon energy and with the chamber range. Recent reports from NBS explicitly state the field size which was used. Regional calibration laboratories in New York City and Houston calibrate all chambers in a 10×10-cm field.[4,5] At Victoreen Instrument Division, ⁶⁰Co calibrations are performed in a field which varies in size with the exposure range of the chamber.[6] For example, a 2.5-R chamber may be calibrated in a 14.5-cm-diam field. To keep exposure times reasonable, a 100-R chamber is positioned closer to the ⁶⁰Co source during calibration. This procedure reduces the field size to 4.8-cm diameter. The actual field size used for calibration of a particular chamber is available from the company upon request.

Standardization of calibration field size among standardization laboratories would appear to be a prudent suggestion.

[1]G. D. Adams, Radiology **78**, 77 (1962).
[2]J. F. Fowler and F. T. Farmer, Br. J. Radiol. **29**, 118 (1956).
[3]C. G. Orton and J. B. Seibert, Radiology **110**, 732 (1974).
[4]R. Sell (personal communication).
[5]R. Shalek (personal communication).
[6]B. Ulman (personal communication).