Calibration of ^{192}Ir high-dose-rate afterloading systems

Steven J. Goetsch,[a] F. H. Attix, D. W. Pearson, and B. R. Thomadsen
Departments of Medical Physics and Human Oncology, University of Wisconsin Medical School, Madison, Wisconsin 53706

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A method is described for calibration of ^{192}Ir high-dose-rate (HDR) brachytherapy afterloading systems. Since NIST does not offer calibration of ionization chambers with the gamma-ray spectrum of iridium-192, an interpolation procedure is employed, using calibrations above (^{137}Cs, 662 keV) and below (250 kVcp, 146-keV x rays) the exposure-weighted average ^{192}Ir energy of 397 keV. The same total wall + cap thickness must be used for both calibrations, and for the ^{192}Ir measurements. A wall + cap thickness of 0.3 g/cm^2 is recommended to assure charged particle equilibrium and to exclude secondary electrons emitted from the source encapsulation. Procedures are described for determining the corrections for source–chamber distance and room scatter during the source calibration in inverse-square-law geometry. A new well-type ionization chamber has been designed specifically for convenient routine use with the HDR afterloading system. It can be calibrated by means of a previously calibrated ^{192}Ir source, and offers a simple means for verifying the decay rate and for calibrating ^{192}Ir replacement sources.

Key words: ^{192}Ir, brachytherapy, source calibration, afterloading, well-type ionization chambers

I. INTRODUCTION

High-dose-rate (HDR) remote afterloading brachytherapy devices, such as the MicroSelectron manufactured by the Nucletron Corporation, are becoming more common in the United States. It is estimated that at least 100 such devices are presently installed with 50 more expected to be delivered in the next year.[1] The most common radionuclide used in these units is ^{192}Ir in the form of a small pellet (0.5-mm diam, 4-mm active length, with 0.3-mm stainless steel wall) connected to a wire that pushes and pulls it through a 2-mm o.d. plastic catheter to guide it to the desired location(s). The initial activity of these sources is in the neighborhood of 10 Ci, or 3.7×10^{11} Bq. The half-life of ^{192}Ir is 73.83 days,[2] requiring relatively frequent (usually quarterly) source replacement to maintain short treatment times. Thus approximately 600 such sources will require calibration during the next year. Currently the only supplier of these sources is Mallinckrodt Diagnostica in the Netherlands. The company's calibration certificate provided with each new source states an overall uncertainty in activity of $\pm$ 10%. An independent recalibration should be carried out after installation of a source in an afterloading unit.

Calibration of iridium-192 in the form of brachytherapy seeds of two types (both of nominal activity 5.6*10^7 Bq, or 1.5-m Ci) was first offered at the U.S. National Bureau of Standards (NBS) in 1979, following the publication of a calibration technique by Loftus.[3] That author utilized a 50-cm^3 spherical graphite ionization chamber to measure the ionization produced in air from plaques containing many such seeds (47 of one type, 53 of the other type). The exposure rates corrected to a distance of 1 m in vacuum were determined. These calibrated ^{192}Ir seeds were then used to calibrate the NBS standard re-entrant chamber. Calibrations of these two types of ^{192}Ir seeds are now offered for source strengths of 0.004 μR m^2/s to 1 μR m^2/s. Prior to 1979, calibration of ^{192}Ir seeds was traceable to NBS only by means of other radionuclide sources.[4]

The University of Wisconsin Accredited Dosimetry Calibration Laboratory (UWADCL) has had frequent requests in the last 18 months for gamma-ray exposure calibrations of ionization chambers for use with ^{192}Ir HDR brachytherapy afterloading devices. The National Institute of Standards and Technology (NIST, formerly NBS), does not currently offer calibrations of ionization chambers with the gamma radiation of iridium-192, hence the ADCLs cannot offer such a calibration with direct NIST traceability. An interpolation between two calibration energies that are offered by NIST can provide a satisfactory solution to this problem until a time when more explicit calibrations become available. Ezzell has described a method which interpolates between a calibration performed with cobalt-60 with a buildup cap sufficient for 1.25-MeV gamma radiation, and an orthovoltage x-ray calibration with no buildup cap in place.[5] Ezzell also describes interpolation techniques utilizing cesium-137 gamma radiation, superficial x radiation, and other orthovoltage beam qualities, as well as some calibrations at one single radiation energy.[6] Clearly, these calibrations depend on weaker NIST traceability linkage.

It is the initial purpose of this paper to describe how an interpolative calibration can best be accomplished. We will then describe a rigorous method for calibrating the ^{192}Ir source in an afterloading unit, including determination of corrections for positioning and room-scatter errors. Finally, a well-type ionization chamber designed specifically for routine calibration of these afterloading systems will be described.

II. INTERPOLATIVE CALIBRATION OF CAVITY ION CHAMBERS

The photon (gamma + x ray) spectrum of ^{192}Ir is complex, including approximately 24 lines occurring in the ener-

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gy range from 9–885 keV.[3] Approximately 88% of the exposure is delivered by 12 gamma lines at and above 296 keV. The exposure-weighted average of all lines is 356 keV. This is raised to 397 keV by removal of two strong L x-ray lines at 9.00 and 9.44 keV, which are almost completely attenuated by the source capsule, and hence do not influence measurements. The average of 397 keV falls approximately halfway between the ^{137}Cs gamma-ray energy of 662 keV and the average energy (146 keV) of a 250 kVcp, medium-filtration x-ray beam (HVL = 3.2-mm Cu), the nearest beams available for ionization chamber calibrations at both NIST and the UWADCL. Thus a simple averaging of the exposure calibration factors (N_x) or air kerma calibration factors (N_k) obtained for an ionization chamber at these two energies (in other words, linear interpolation) suggests itself as a rational basis for deriving a calibration factor appropriate for ^{192}Ir. However, the chamber wall must be thick enough to provide charged particle equilibrium, and the broad-beam attenuation of radiation passing through it must be correctly accounted for, as discussed in the following paragraphs.

A proper interpolation between ^{137}Cs and x rays requires that the same chamber-wall thickness be used in both measurements. If the wall thickness is changed between sources, the continuity of the instrument's characteristics across the energy range of the interpolation is lost, and the ^{192}Ir calibration becomes indeterminate. Photon dosimetry requires that an ionization chamber's wall thickness (including buildup cap, if any) must be sufficient to provide charged particle equilibrium (CPE) for the highest energy of secondary electrons present. In the absence of higher-energy photoelectrons, the minimum chamber wall thickness required for CPE is that just sufficient to stop maximum-energy Compton recoil electrons. Strict application of this criterion in the present case calls for a wall thick enough to stop 687-keV electrons generated by 885-keV gamma rays, the most energetic photons emitted by any of the three sources. The range of these electrons is 0.28 g/cm^2 of plastic (e.g., Lucite), or 0.31 g/cm^2 of graphite, which are both equivalent to 9.3×10^{22} electrons/cm^2. Although this seems to be an overly conservative choice for the minimum required wall thickness, in view of the relative weakness of the 885-keV line in ^{192}Ir, this wall is also thick enough to filter out any secondary electrons (either photo- or Compton) that may be generated in the source encapsulation. Figure 1 strongly suggests the presence of such electron contamination, to be discussed below.

Conventional exposure (or air kerma) calibrations do not require explicit chamber-wall attenuation corrections, as such calibrations refer to the radiation quantity in free space at the chamber center location. However, in the present case, where an interpolation of calibration factors is necessary, the attenuation must be explicitly accounted for.

The equation for deriving the ^{192}Ir exposure calibration factor $(N_x)_{\mathrm{Ir}}$ as an average of those for x rays and ^{137}Cs can be written as

$$(A_w N_x)_{\mathrm{Ir}} = (\tfrac{1}{2})\left[(A_w N_x)_{\mathrm{x\,ray}} + (A_w N_x)_{\mathrm{Cs}}\right] \qquad (1a)$$

or

$$(N_x)_{\mathrm{Ir}} = \left[(A_w N_x)_{\mathrm{x\,ray}} + (A_w N_x)_{\mathrm{Cs}}\right]/2(A_w)_{\mathrm{Ir}},$$

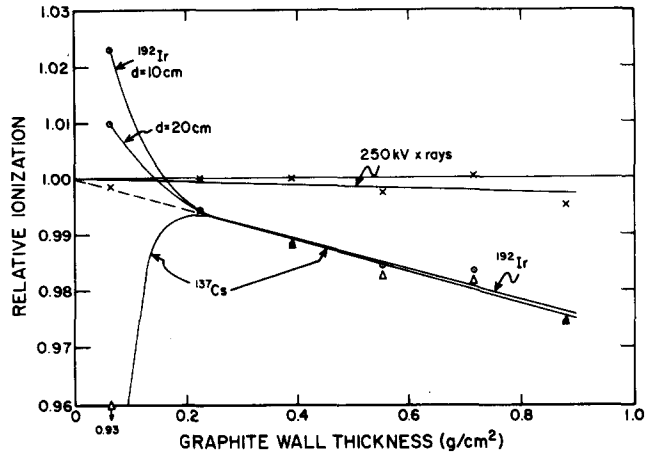

FIG. 1. Attenuation of 250-kVcp (146-keV) x rays, ^{192}Ir gamma rays, and ^{137}Cs gamma rays in graphite caps covering a Farmer-type ionization chamber. Indicated slopes are least-squares fits to measured data with various thicknesses of caps added. Note that the chamber wall of 0.065 g/cm^2 is insufficient to exclude incident electron contamination, which evidently produces excessive ionization at 10- and 20-cm distance from the source.

where $(N_x)_{\mathrm{Ir}}$, $(N_x)_{\mathrm{x\,ray}}$, and $(N_x)_{\mathrm{Cs}}$ are the exposure calibration factors for ^{192}Ir, 250-kVcp x rays, and ^{137}Cs, respectively, and $(A_w)_{\mathrm{Ir}}$, $(A_w)_{\mathrm{x\,ray}}$, and $(A_w)_{\mathrm{Cs}}$ are the corresponding ratios of the exposure inside the chamber to that at the same location in free space. (The quantity kerma in air may be substituted for exposure throughout).

Values of A_w were obtained from measurements made with a Farmer-type chamber exposed to each of the three photon sources, yielding the results shown in Fig. 1. Graphite caps 1, 2, 3, 4, and 5 mm in thickness and 9 cm in length, with a density of 1.63 g/cm^3, were added to the 0.065 g/cm^2 graphite wall chamber. The least-squares average slopes obtained from the ionization measurements with the caps were: 2.7% (Ref. 7), 0.3%, and 2.8% per g/cm^2 for the ^{192}Ir, x rays, and ^{137}Cs, respectively. The two gamma-ray values closely approximate the mass energy-absorption coefficient of 2.9% per g/cm^2 at both 397 and 662 keV, indicative of so-called "straight-ahead" photon scattering in broad-beam geometry. The relatively small attenuation observed for the x-rays results from larger-angle Compton photon scattering at the lower energies.

Based on these measured slopes, the attenuation factors A_w for the ^{192}Ir, x rays, and ^{137}Cs qualities, respectively, were found to be 0.9916, 0.9991, and 0.9914 for a 0.31 g/cm^2 graphite wall. Inserting these values into Eq. (1a) gives the following formula for $(N_x)_{\mathrm{Ir}}$.

$$(N_x)_{\mathrm{Ir}} = 0.5038\,(N_x)_{\mathrm{x\,ray}} + 0.4999(N_x)_{\mathrm{Cs}}. \qquad (1b)$$

Assuming that $(N_x)_{\mathrm{x\,ray}}$ and $(N_x)_{\mathrm{Cs}}$ do not differ by more than about 10%, as is usually the case, Eq. (1b) can be approximated by

$$(N_x)_{\mathrm{Ir}} = (1+x)\left[(N_x)_{\mathrm{x\,ray}} + (N_x)_{\mathrm{Cs}}\right]/2, \qquad (1c)$$

where $x = 0.0037\ (t/9.3\times10^{22})$ for a wall thickness of t electrons/cm^2.

As noted above, Fig. 1 also reveals the presence of electron

contamination in the ^{192}Ir gamma-ray field, adding about 2.5% to the ionization at 10 cm from the source, or 1.2% at 20 cm, when the wall thickness is 0.065 g/cm^2. The conclusion of Ezzell that a chamber wall of 0.053 g/cm^2 is sufficient to produce CPE for ^{192}Ir gamma rays is not consistent with the ranges of the secondary electrons, nor is it supported by present data, which imply that the excess ionization would exceed 2.5% for that wall thickness at 10 cm distance from the source. Corresponding measurements with the same chamber in a ^{137}Cs gamma-ray beam show the expected ionization buildup, indicating the relative absence of electron contamination due to greater source–chamber distance (1 m) and a narrow beam (10 cm). Figure 1 verifies that the recommended wall thickness is sufficient to remove electrons from the ^{192}Ir field, and to provide equilibrium buildup for ^{137}Cs.

III. CALIBRATION OF THE IRIDIUM-192 SOURCE

The short half-life of this radionuclide, with the consequent necessity for frequent source replacement, requires some local method of accurate and convenient source calibration to verify the activity reported by the manufacturer. The problem is complicated by the activity level of these sources, typically 3.7×10^{11} Bq (10 Ci), which produces an ionization current of only about 1×10^{-11} A in a 1.0-cm^3 ionization chamber at a distance of 20 cm. Going to larger separations to improve the measurement accuracy of the distance between centers of the chamber and source reduces the current accordingly, leading to larger percentage contributions by leakage current and gamma-ray scattering from the room surroundings, and poorer reproducibility. Getting closer of course worsens the distance error and requires a larger geometric correction[8] for the size and shape of the ionization chamber.

The following method is recommended as a way to maximize accuracy in such a calibration, of course using a cavity chamber with thick enough walls to provide CPE, as discussed above. A precise mechanical scanning apparatus is required, such as that used for field mapping in water phantoms. The catheter that guides the source is stretched tautly in a fixed C-clamp arrangement such as that shown by Ezzell,[5] while the ionization chamber is moved to various nominal distances d (10, 15, 20, 25, 30, 35, 40 cm) from the source. To avoid variable photon scatter from nearby objects, it is advisable to provide fittings to elevate the chamber and source above the empty phantom box and scattering hardware. Lead cladding of low-Z parts can be used to further reduce Compton scattering.

A charge-integration method is necessitated by the low ionization current, to obtain acceptable precision. If the timing mechanism in the afterloading device is used to time the exposures, a correction must be made for ionization produced in the chamber while the source is in transit between its shield and the irradiation location, unless the exposure times are very long relative to the transit time of a few seconds. This correction can be treated as a shutter-timing error, bearing in mind that the size of the correction depends on the source–chamber distance, as well as on the proximity of the catheter to the chamber along its route. Hence, it is preferable to use a separate timer in connection with the electrometer, in a method that allows repeated exposures to be made while the source remains fixed in position.[9]

For the present measurements one of us (DWP) constructed a timer that supplies trigger pulses to a Fluke Model 8840A digital voltmeter, connected to the unity-gain output of a Keithley Model 602 electrometer. Pressing the START button freezes the initial voltage reading and starts the timer. At the end of a preset time interval, the final voltage is displayed. The charge accumulated during the time interval is obtained by subtracting the initial from the final voltage reading, and multiplying the result by the calibrated electrometer capacitance. Caution should be exercised when using external timers with digital voltmeters equipped to be controlled in this manner. If the digital voltmeter is used in the autoranging mode, significant errors may be introduced. These voltmeters should be used on a fixed range to avoid errors caused by the autoranging time.

Leakage current (if significant) and atmospheric corrections must of course be accounted for. If the chamber is of the Farmer type, a multiplicative Kondo–Randolph geometrical correction of 1.006, 1.003, and 1.001 should be applied to the readings obtained at $d = 10$, 15, and 20 cm, respectively.[8] A spherical Shonka–Wyckoff (Exradin)[10] chamber with a volume of 3.6 cm^3 requires a corresponding correction factor of 0.997 at 10 cm, and 0.999 at 15 and 20 cm.

To avoid any position backlash error, readings are to be taken by scanning continuously in one direction through the sequential distances. It is essential in this method that the changes in distance be correct, in order to derive the correction c that yields the true center-to-center source–chamber distances, d':

$$d' = d + c. \tag{2}$$

The charge readings after application of the corrections discussed above are denoted here as M_d (M_{10}, M_{20}, etc.) referring to the nominal distances d (cm) at which they were obtained. Assuming that the same amount of room-scattered gamma radiation arrives at the chamber regardless of distance d, a constant reading M_s due to scattering is included in each reading:

$$M_d = M'_d + M_s, \tag{3}$$

where M'_d is the reading from primary photons only.

For each nominal distance d and charge reading M_d an equation of the following form can be written:

$$f = M'_d(d')^2 = (M_d - M_s)(d + c)^2, \tag{4}$$

in which f is a constant independent of d, assuming that the corrected readings produced by primary radiation obey the inverse-square law as a function of the true distance between source and chamber centers. Any group of three such equations, for three distances, can be solved for the three unknowns M_s, c, and f. Making measurements at more than three distances overdetermines the result, and allows averaging of several solutions to minimize the error.

An example of the results obtainable from such measurements and calculations is shown in Table I, which refers to an Exradin A3 spherical chamber of 3.6 cm^3, with 2.50-mm

TABLE I. Exradin A3 chamber (C552 air equivalent plastic) data with HDR ^{192}Ir source. Average value of f for all distances: 895.18 nC cm^2 or 8.9518×10^{-11} C m^2. f values at individual distances have a standard deviation of $\pm$ 0.08% relative to the average. Columns defined in the text.

d (cm)	c (cm)	d' (cm)	M_d (nC)	M_s (nC)	M_s%	M'_d (nC)	f (nC cm^2)
10.00	−0.296	9.704	9.5242	0.0146	0.15	9.5096	895.5
15.00	"	14.704	4.1532	"	0.35	4.1386	894.8
20.00	"	19.704	2.3228	"	0.63	2.3082	896.2
25.00	"	24.704	1.4816	"	0.99	1.4670	895.3
30.00	"	29.704	1.0293	"	1.42	1.0147	895.3
35.00	"	34.704	0.7580	"	1.93	0.7434	895.3
39.64	"	39.344	0.5921	"	2.47	0.5775	893.9

air-equivalent plastic walls (including cap), at nominal distances from 10–39.64 cm from the HDR ^{192}Ir source in the MicroSelectron unit at the U.W. Hospital. The first and fourth columns, respectively, list the nominal source–chamber distances and the corrected charge collected during 2-min exposures measured by means of the external timer already described. Column 2 gives the distance correction that resulted from averaging the solutions from five combinations of three equations of the form shown in Eq. (4). Notice that in this case, the chamber was actually almost 3 mm closer to the source than the nominal measurements (d) indicated. Obviously one can position the chamber more accurately than that, but this gross example illustrates the power of the method to correct positioning errors.

Column 3 shows the corrected distances d'. Column 5 gives the average value of the room scatter contributing to the observed ionization and column 6 restates that value in terms of percentages of M'_d. Column 7 then gives the ionization readings obtained by subtracting column 5 from column 4, thus removing the scatter effect. The final column lists the values of f obtained by multiplying column 7 by the square of column 3 values. The average value of f is 8.9518×10^{-11} Cm^2, about which the individual values vary with a standard deviation of $\pm$ 0.08%.

Figure 2, based on the same data as Table I, compares plotted values of $f = (d')^2 M'_d$ from the last column with the products d^2M_d, $d^2M'_d$, and $(d')^2M_d$. The shape of the d^2M_d curve results from the combined effects of the distance error and the room scatter contribution. The $d^2M'_d$ curve has been corrected for room scatter but not for the distance error, while the $(d')^2M_d$ curve is corrected for distance but not for the scatter. Here, f is seen to be almost completely independent of distance, indicating that it satisfies inverse-square behavior as required for valid source calibration.

The exposure calibration factors (N_x) for the Exradin A3 chamber were determined by NIST to be 9.871×10^8 R/C for the 250-kVcp x-ray beam with medium filtration, and 9.948×10^8 R/C for ^{137}Cs gamma rays. The average of these two factors is 9.910×10^8 R/C. The C552 air-equivalent plastic comprising the wall and cap has a density of 1.76 g/cm^3, and an electron density of 3.009×10^{23} electrons/g which is practically the same as that of graphite (3.008×10^{23}). Thus the 2.5-mm (or 0.44-g/cm^2) wall + cap is thicker than the recommended minimum of 0.31 g/cm^2. The quantity x in Eq. (1c) thus should be 0.0053 when applied to this chamber, and the resulting value of $(N_x)_{Ir}$ is 9.96×10^8 R/C.

The constant f divided by the exposure time interval dt (s) can be related to the exposure rate dX/dt and the air kerma rate dK_a/dt by the following equations:

$$(d')^2\frac{dX}{dt} = \frac{(N_x)f}{dt} \tag{5}$$

and

$$\frac{dX}{dt} = \frac{dK_a}{dt}(0.9992)\{[(33.97)(2.58\times10^{-4})]\}^{-1} = 114.0\frac{dK_a}{dt}. \tag{6}$$

Hence,

$$(d')^2\frac{dK_a}{dt} = 8.77\times10^{-3}\frac{N_x f}{dt}, \tag{7}$$

where N_x is the exposure calibration factor (R/C), dt is the exposure time interval (s), 0.9992 is the value of $(1-g)$, the fraction of the secondary electron energy for ^{192}Ir that does

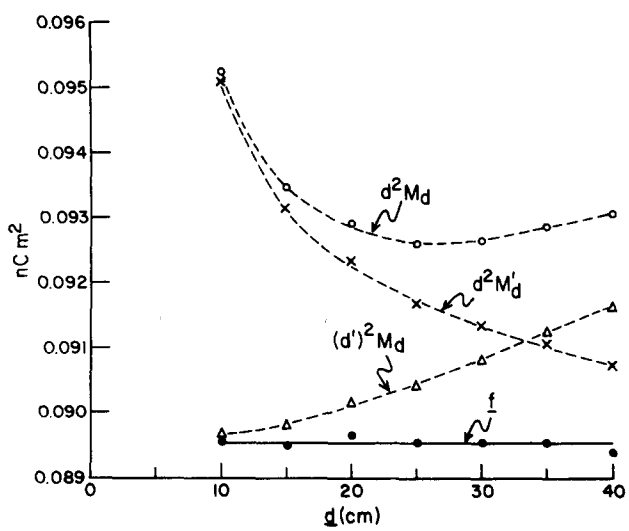

FIG. 2. Dependence of f, $(d')^2M_d$, $d^2M'_d$, and d^2M_d upon nominal source–chamber distance d.

not escape as bremsstrahlung, 33.97 J/C is the value of W/e for air, 2.58×10^{-4} converts the exposure X from C/kg to R, and d' is expressed in meters.

Applying the average value of $f=8.9518\times10^{-11}$ C m^2 from Table I, $(N_x)_{Ir}=9.96\times10^8$ R/C, and $dt=120$ s, Eq. (5) gives 7.43×10^{-4} R m^2/s, equivalent to 2.675 R m^2/h.

The ^{192}Ir data of Loftus,[3] corrected for the change in W/e value from 33.7 to 33.97 J/C, and eliminating the effect of the 9.00 and 9.44 keV L x-ray lines, give a value of 0.459 R m^2/Ci h for the exposure-rate constant. The corresponding effective activity of the ^{192}Ir source used in the above measurements was 2.675/0.459 = 5.83 Ci, or 2.16×10^{11} Bq, on 24 Feb. 1990. The manufacturer's calibration certificate for this source gives the activity as 3.7×10^{11} Bq (10 Ci) on 24 Dec. 1989. Using the 73.83 day half-life for ^{192}Ir, this corresponds to 5.59 Ci at the time of these measurements. This is 4.1% less than our measurements indicate, but within the manufacturer's quoted $\pm$ 10% accuracy.

IV. WELL-TYPE CHAMBER FOR ROUTINE CALIBRATIONS

The foregoing method for rigorous calibration of ^{192}Ir high-dose-rate afterloading sources is clearly too time-consuming and complicated for routine recalibrations, and a simpler method would also be desirable for calibrating ^{192}Ir replacement sources. Virtually all of the difficulties disappear when one shifts from small ionization chambers in inverse-square law geometry to a well-type chamber designed for this application.[11] A simplified drawing of such a chamber is shown in Fig. 3. The chamber is filled with air and open to the atmosphere through a vent hole. The source catheter is to be inserted into the closely fitting thin-walled aluminum tube on the axis, until the end of it touches the bottom. The source is then moved to the location of maximum reading. The thickness of aluminum between the source and the ion-collecting volume of the ionization chamber exceeds 0.31 g/cm^2, as required for CPE with Ir-192 gamma rays.

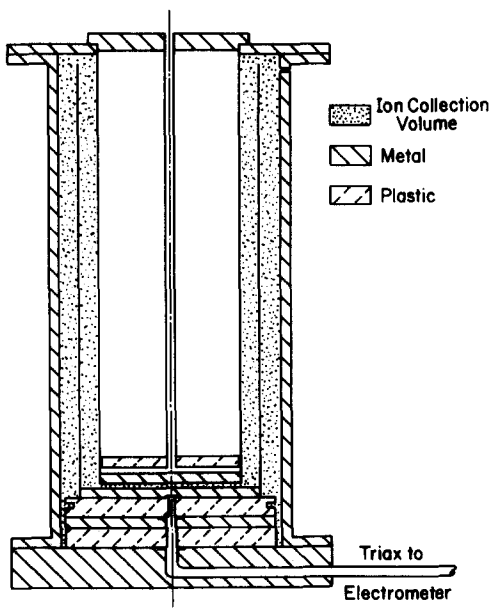

FIG. 3. Simplified cross-sectional drawing of the fully guarded well-type ionization chamber[11] designed for calibration of HDR ^{192}Ir sources. The overall height is 17.5 cm. Other dimensions are approximately to scale. The source catheter fits snugly within the central thin-walled aluminum tube. That tube assembly is removable, leaving a well 3.6 cm in diameter and 12.1 cm deep. The ion-collection volume (245 cm^3) is vented to the atmosphere. The voltage is applied through triax cable to the collecting electrode, which is a thin-walled aluminum tube that approximately bisects the collecting volume.

Figure 4 is a plot of ion current versus source midpoint distance from the bottom of the well. The maximum is at 51 mm, with a decrease of 0.1% in moving the source up or down by 4 mm. Thus the source calibration position is not critical and is readily reproducible. Ten consecutive readings of current, separated by returning the source to its shield, gave a standard deviation of only 0.01%. Placing the chamber on the floor versus on a table had no effect, demonstrating insensitivity to scattered photons from outside the chamber. Observed leakage current is less than 10^{-13} A.

Ionic recombination was measured with a 6.5 Ci ^{192}Ir source by using bias voltage of + 150 and + 300 V. Ionization current of 4.512×10^{-8} and 4.517×10^{-8} A, respectively, were observed. Using the two-voltage technique,[9] this measurement indicates an ionic collection efficiency of 99.96% with 300 V applied. The magnitude of the ionization current collected was found to be independent of the sign of the polarizing voltage within 0.1% and to have a value of about 7 nA/Ci.

Such a chamber can be calibrated by means of an HDR ^{192}Ir source which itself can be calibrated by the inverse-square method described above. Periodic (e.g., yearly) recalibration of the well-type chamber is recommended, although it is designed for maximum stability. Constancy of its radiation sensitivity can be verified by means of a ^{90}Sr – ^{90}Y ophthalmic applicator (half-life = 28.1 years) reproducibly

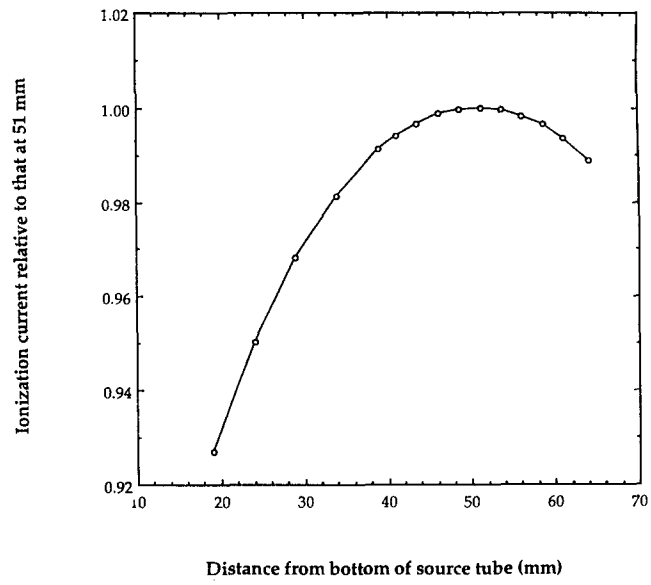

FIG. 4. Relative ionization versus distance of the source from the bottom of the well. The maximum occurs at 51 mm.

positioned at the top of the 3.6-cm-diam well remaining when the central tube assembly is removed. Ionization currents of the order of 10^{-9} A are generated by the beta rays from such a source.

The UWADCL has requested accreditation by the AAPM in extending its services to include ^{192}Ir calibrations of suitable well-type chambers. Appropriate avenues are also being explored by which the U.W.-model chamber, already precalibrated, could be purchased by centers for use with these brachytherapy afterloading systems.

V. CONCLUSIONS

(1) Ionization chambers must have walls (including cap) thick enough for charged-particle equilibrium when measuring photon fields. For ^{192}Ir, this requires about 0.3 g/cm^2 to provide dose buildup as well as exclude any energetic electron contamination. Thin-walled ionization chambers may overrespond by 2%–3% close to the source as a result of these electrons.

(2) The same wall should be used for calibrations of the chamber with ^{137}Cs gamma rays and 250-kVcp (medium filter) x rays. The average of these calibrations, with a correction to adjust the wall attenuation, gives the calibration factor for ^{192}Ir.

(3) Such a chamber should be precisely positioned, preferably using a motorized scanner, at a sequence of at least three distances from the source, to allow proper corrections to be determined for the distance error and room scatter. An electrometer-linked timer is preferable to using the afterloader's timer, to avoid the necessity for measuring the transit time error at each distance.

(4) Routine ^{192}Ir source calibrations should be done with a suitable well-type chamber such as that shown here. This chamber can be calibrated using the ^{192}Ir source after it has been calibrated by the foregoing method, and its constancy checked (if desired) with a ^{90}Sr – ^{90}Y beta-particle source.

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[a] Present address: UCLA Medical Center, Depart of Radiation Oncology, 200 Medical Plaza, Suite B265, Los Angeles, CA 90024-1714.

[1] S. Teague, Nucletron Corporation, 9160 Red Branch Road, Columbia, MD, 21045, personal communication, August, 1990.
[2] National Commission on Radiation Protection, NCRP Rep. Number 58, *A Handbook of Radioactivity Measurements Procedures*, (NCRP, Bethesda, MD, 1985, 2nd ed.).
[3] T. P. Loftus, "Standardization of iridium-192 gamma-ray sources in terms of exposure," J. Res. NBS **85**, 19–25 (1980).
[4] P. D. Cobb and B. E. Bjarngard, "Calibration of brachytherapy iridium-192 sources," Am. J. Roentgenol. **120**(1), 120–121 (1974).
[5] G. Ezzell, "Evaluation of calibration techniques for the Microselectron HDR," in *Brachytherapy* 2: *Proceedings of the 5th International Selectron Users' Meeting*, edited by R. F. Mould (Nucletron, Leersum, Netherlands 1989), pp. 61–69.
[6] G. Ezzell, "Calibration intercomparison of an ^{192}Ir source used for high dose rate remote afterloading," Activity, The Selectron Users' Newsletter **3**, (1989).
[7] This slope supersedes the data published in the following reference: S. J. Goetsch and F. H. Attix, "^{192}Ir remote afterloading source calibration," AAPM Newsletter **15**(1), 3 (1990).
[8] S. Kondo and M. L. Randolph, "Effect of finite size of ionization chambers on measurements of small photon sources," Radiat. Res. **13**, 37–60 (1960).
[9] F. H. Attix, *Introduction to Radiological Physics and Radiation Dosimetry* (Wiley, New York, 1986), p. 321.
[10] Exradin, Inc., P.O. Box Q, Warrenville, IL 60555.
[11] F. H. Attix, U.S. Patent applied for, 1990.