

Dose Calibrator Assay of Iodine-123 and Indium-111 with a Copper Filter

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Objective: The accurate measurement of radionuclides in a dose calibrator can be affected by container geometry especially for low-energy photons. This study investigated the effectiveness of using copper filtration for selective absorption of low-energy x-rays during the measurement of ^{123}I and ^{111}In to minimize variations in measurement as a function of geometry.

Methods: Copper absorbers of varying thickness were used to define the absorption profile of low-energy x-rays in the 20- to 50-keV energy window with ^{125}I and a gamma scintillation spectrometer. Iodine-123 and ^{111}In standards were assayed in a dose calibrator, with and without a copper filter positioned in the ion chamber well, to determine new isotope calibration settings for these nuclides with the copper filter. Samples of ^{123}I and ^{111}In , of constant activity but various volumes, were assayed in 1-ml, 3-ml and 10-ml plastic syringes and a 10-ml glass vial with and without copper filtration to assess the influence of geometry on the accuracy of measurement.

Results: A copper thickness of 0.6 mm removed 99.5% of ^{125}I photons in the 20- to 50-keV window and significantly reduced the low-energy component of ^{123}I and ^{111}In . Activity measurements of ^{123}I and ^{111}In in the dose calibrator varied with container type and volume without copper filtration but were essentially unchanged when a copper filter was used.

Conclusion: A copper filter ≥ 0.6 mm thick eliminates the need for geometry correction factors for measuring ^{123}I and ^{111}In with the dose calibrator.

Key Words: iodine-123 measurement; indium-111 measurement; copper filtration; dose calibrator

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The radionuclide dose calibrator permits the rapid and accurate measurement of radiopharmaceuticals in nuclear medicine. The accuracy of measurement is generally unaffected by container configuration for photon energies above 100 keV, but may require correction for lower energies, particularly in

the 20- to 50-keV range as with ^{125}I (1). Certain radionuclides, such as ^{123}I , ^{111}In and ^{127}Xe , which have high-energy photopeaks also emit substantial amounts of low-energy characteristic x-rays that produce variations in measurement when different container configurations or materials are used (2,3). One method to deal with this problem uses a gamma camera to define the activity in an ^{123}I source which is then applied to assign correction factors for assay in a dose calibrator. While this technique has scientific merit it is cumbersome to apply in practice (3). Another suggestion is to use a copper filter that preferentially absorbs the x-rays with minimal effect on the high-energy photopeaks and, thereby, reduces the effect of varying source geometries (2). We have applied the principle of this technique in our laboratory for several years, yet a technical bulletin (4) describing the assay of ^{111}In in different container configurations using correction factors for each, suggests that the benefit of copper filtration in dose calibrator measurement may have escaped notice by the nuclear medicine community. This may, in part, be due to little interest in the technique because fewer radiopharmaceuticals labeled with ^{123}I and ^{111}In were available at the time these reports were written. Presently ^{123}I -sodium iodide for thyroid imaging, ^{123}I -m-iodobenzylguanidine (MIBG) for adrenal imaging and ^{111}In labeled to pentetate (DTPA), pentetate (OctreoScan®) and several antibodies (OncoScint CR/OV®, Myoscint® and ProstaScint®) have increased the number of times these nuclides are routinely assayed with the dose calibrator. With these considerations in mind, the purpose of this study was to demonstrate in better detail the value of copper filters in dose calibrator measurements of ^{123}I and ^{111}In and present a practical approach to encourage the use of the technique.

MATERIALS AND METHODS

The absorption of K x-rays of ^{125}I was assessed with a gamma scintillation spectrometer (Tracor Northern, Middleton, WI) to determine the thickness of copper required to filter out similar energy K x-rays of ^{123}I and ^{111}In . Before use, the spectrometer was calibrated with a ^{137}Cs source. A point source of ^{125}I (8.8 μCi) was counted at a constant source-to-detector distance with and without copper absorbers ranging in

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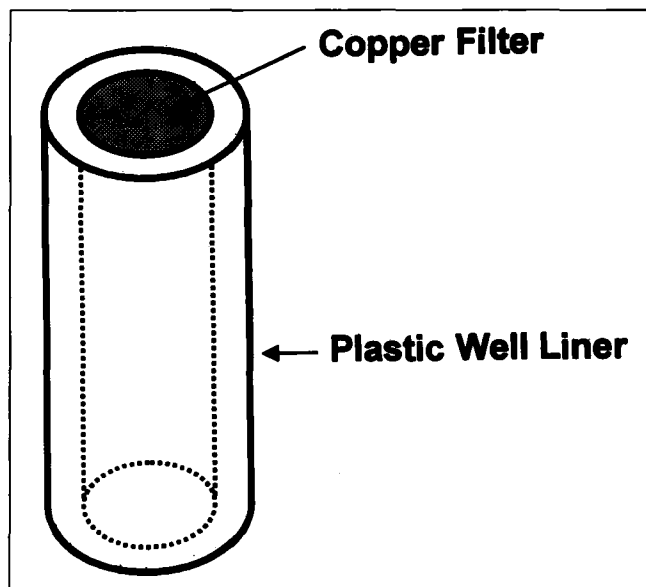


FIGURE 1. Cylindrical copper filter for dose calibrator measurement of ^{123}I and ^{111}In .

thickness from 0.15–0.76 mm. Iodine-125 counts were collected in a 20- to 50-keV window. All counts were corrected for background.

For dose calibrator measurements, cylindrical copper pipe (5.08 cm diameter \times 25.4 cm length) of 0.64 mm or 1.1 mm thick were used, sealed at the bottom with a similar thickness of copper. The copper pipe was secured inside a plastic sleeve similar to that supplied as the ion chamber well liner with Capintec (Capintec, Inc., Ramsey, NJ) dose calibrators (Fig. 1). This facilitated insertion of the copper filter into the ion chamber well during dose measurements. Sources were positioned in the well to read their maximum activity at approximately 4 inches from the bottom. Before any measurement, the dose calibrator was adjusted for background and checked for proper operation with a ^{137}Cs standard.

Accuracy assessments for ^{111}In were made with a 5-ml (382 μCi) standard solution in a thin-walled glass ampule obtained from the National Institute of Standards and Technology (NIST). Measurements were made in a Capintec dose calibrator (Model 127R, Capintec Inc., Ramsey, NJ) with and without a copper filter and the measured activity was compared to the calibrated activity after decay correction. Three independent measurements were made and an average was obtained. The instrument's isotope calibration setting was adjusted to read the calibrated activity of the ^{111}In standard with the copper filter in place thereby adjusting for the absorption of K x-rays. This gave a copper filter calibration setting for ^{111}In . Similar measurements were made with ^{123}I . Since no ^{123}I standard source is available, a commercial NIST-traceable source of ^{123}I -sodium iodide was used. For this experiment a 10- μl aliquot of the ^{123}I solution was obtained with a calibrated micro-liter pipette, transferred quantitatively to 5 ml of saline in a 5-ml thin-walled glass ampule and assayed in the dose calibrator with and without a copper filter. The activity in this aliquot, determined from the radionuclide concentration and the man-

ufacturer's calibrated activity, was compared to the measured activity. This procedure was done in triplicate and a copper filter calibration setting for ^{123}I was determined for each measurement and the result averaged.

The effect of geometry and container type on the assay of ^{123}I and ^{111}In was assessed with syringes and vials typically used in nuclear medicine to assay radiopharmaceuticals. An accurate volume (250 μl) of known activity of ^{123}I -sodium iodide or ^{111}In -indium chloride was added to 1-ml, 3-ml and 10-ml plastic syringes (Becton-Dickinson, Franklin Lakes, NJ) and a 10-ml molded glass vial (generator elution vial, Mallinckrodt, Inc., St. Louis, MO) and assayed in the dose calibrator. Incremental amounts of nonradioactive saline (for ^{123}I) or 0.1 M HCl (for ^{111}In) were added to each container followed by reassay until each container was filled to capacity. Measurements were made with and without the copper filter with the calibration setting adjusted accordingly. For each container, the percent difference in incremental readings from its starting volume to its final volume was calculated to determine any effect of volume on measurement. In addition, for each container the activities measured at different volumes were averaged to give a mean container activity. The mean activity in each container measured with the copper filter using the filter-corrected calibration setting was compared to the mean activity measured without the copper filter using the original manufacturer's calibration setting to assess the magnitude of error that might occur if the manufacturer's calibration setting was used without appropriate correction for the container.

RESULTS

The attenuation of low-energy photons from ^{125}I in the 20- to 50-keV energy window by varying thicknesses of copper is shown in Figure 2. Attenuation over the range from 0–0.76-mm copper shows photon transmittance decreasing exponentially from 100% to less than 1% due to the large mass attenuation coefficient of copper for low-energy characteristic x-rays. A copper thickness of 0.6 mm and greater provides almost complete absorption of K x-rays in the 20- to 50-keV range.

Table 1 shows the measurement of ^{123}I and ^{111}In standard sources in the dose calibrator with and without the use of a copper filter in the ion chamber well. Note that the calibration setting experimentally determined for each nuclide with a copper filter is substantially lower than without the filter. This reflects the increased sensitivity needed due to removal of the highly abundant low-energy photons by the copper filter. The small difference in calibration settings between the 0.64-mm and 1.1-mm thick filters reflects the low attenuation of high-energy photons by copper. By removing most of the characteristic x-rays, with little effect on the principal photopeak gamma rays, a copper filter should permit assay of these radionuclides with greater accuracy in containers with varying geometries. Table 2 demonstrates this fact. It shows the measurement of ^{123}I and ^{111}In in different size plastic syringes or a glass vial, each containing a constant amount of activity but with varying volumes. Depending on the container used, measurements

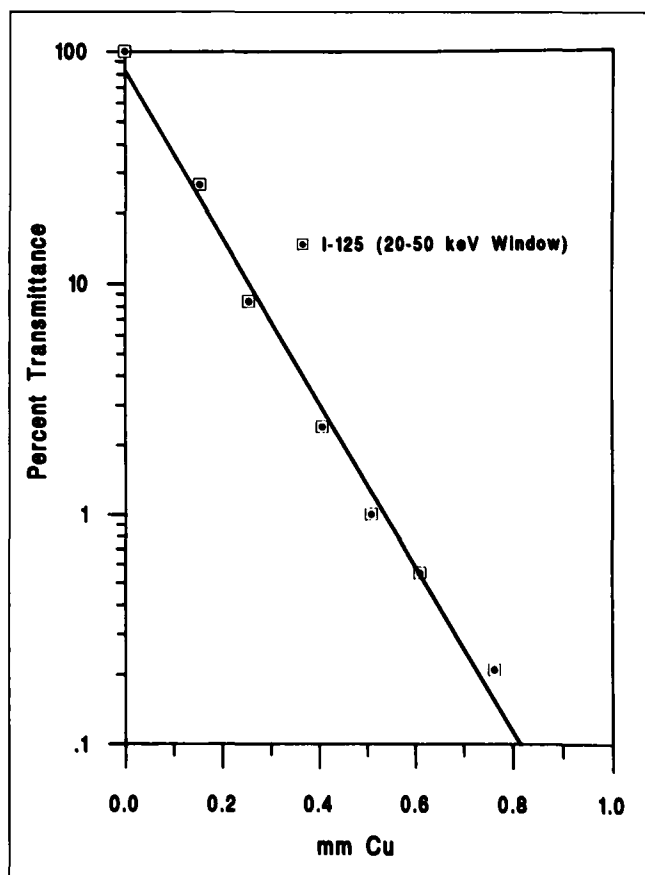


FIGURE 2. Attenuation of ^{125}I photons in copper.

made without a copper filter demonstrated a variability of 1%–7% for ^{123}I and 1%–4% for ^{111}In from the smallest to the largest volume in a container. Measurements of the same containers made with a copper filter gave the true calibrated activity of the nuclide solution placed in the containers and demonstrated insignificant change in the reading with change in volume. Most significant was the difference between the mean activity measured in plastic syringes with and without the copper filter. For example, the 1-ml syringe measured without the copper filter using the manufacturer's calibration setting, gave a reading that was 43.9% higher for ^{123}I and 31.4% higher for ^{111}In than the true activities of these nuclides in the syringes measured with the copper filter and its respective cali-

TABLE 2
Effect of Container Type and Volume on Dose Calibrator Measurement of Iodine-123 and Indium-111 With and Without Copper Filtration

Volume in container	^{123}I activity (mCi)*		^{111}In activity (mCi)†	
	With copper	Without copper	With copper	Without copper
1-ml syringe				
0.25 ml	1.23	1.74	1.18	1.54
0.50 ml	1.23	1.76	1.18	1.55
0.75 ml	1.23	1.77	1.18	1.56
1.00 ml	1.23	1.79	1.18	1.55
Mean	1.23	1.77 (+43.9%)	1.18	1.55 (+31.4%)
3-ml syringe				
0.25 ml	1.23	1.62	1.18	1.49
0.50 ml	1.23	1.64	1.18	1.51
1.00 ml	1.23	1.68	1.18	1.51
2.00 ml	1.23	1.71	1.18	1.51
3.00 ml	1.23	1.73	1.18	1.51
Mean	1.23	1.68 (+36.6%)	1.18	1.51 (+28.0%)
10-ml syringe				
1.00 ml	1.23	1.57	1.18	1.44
2.00 ml	1.23	1.59	1.18	1.44
4.00 ml	1.23	1.63	1.18	1.45
8.00 ml	1.23	1.66	1.18	1.45
10.00 ml	1.23	1.67	1.18	1.45
Mean	1.23	1.62 (+31.7%)	1.18	1.45 (+22.9%)
10-ml vial				
1.00 ml	1.20	1.30	1.18	1.28
2.00 ml	1.20	1.28	1.18	1.27
4.00 ml	1.20	1.25	1.18	1.26
8.00 ml	1.19	1.22	1.18	1.24
10.00 ml	1.19	1.21	1.17	1.23
Mean	1.20	1.25 (+4.2%)	1.18	1.26 (+6.8%)

* ^{123}I calibration factor: 052 with 0.64-mm copper; 277 without copper.

† ^{111}In calibration factor: 193 with 0.64-mm copper; 303 without copper.

bration setting. Similar discrepancies were seen with the 3-ml and 10-ml syringes. There was less of a difference between the 10-ml glass vial measured with and without a copper filter reflecting a greater absorption of x-rays by the glass compared to plastic. Figure 3 supports this point showing the decrease in height of the x-ray peak of an ^{123}I source when counted in plastic versus glass. Note also the substantial reduction in the

TABLE 1
Copper Filter Calibration Settings for Iodine-123 and Indium-111

Source*	Calibrated activity (μCi)	Measured activity (μCi) without copper filter†	Calibration setting required to read calibrated activity	
			0.64 mm copper filter	1.1 mm copper filter
Indium-111	382	381	193	181
Iodine-123	370	428	52	48

* ^{123}I and ^{111}In each as a 5-ml solution in thin-wall glass ampule.

†Isotope calibration factors: ^{111}In = 303; ^{123}I = 277.

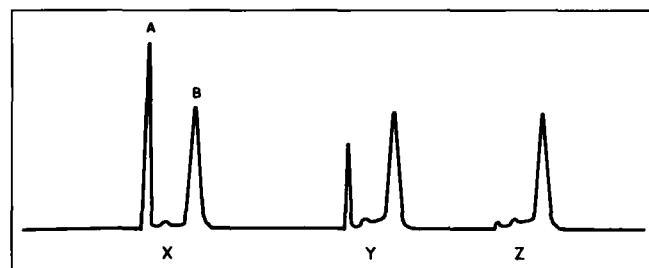


FIGURE 3. The gamma energy spectrum of ^{123}I in different materials with and without a copper filter. A = 27-keV x-ray peak; B = 159-keV gamma-ray photopeak; X = in a plastic tube; Y = in a glass vial; Z = in a glass vial plus 0.25-mm copper filter.

x-ray peak with the copper filter with minimal change in the photopeak.

DISCUSSION

Metallic filters of aluminum, copper, tin or lead have been used routinely in diagnostic or therapy x-ray machines to remove low-energy photons and increase the penetrating power of an x-ray beam. Linear attenuation coefficients of absorbers vary with the energy of x-ray or gamma-ray photons, the atomic number of the absorber and its density. For a given absorber attenuation varies only with photon energy and the pathlength of the photon within the absorber. Variation in sample volume, for example geometry, introduces a varying pathlength for the photons through the sample to the detector. Since the absorption of low-energy photons is highly dependent on the total pathlength through the absorber, small variations in geometry will cause large variations in the number of low-energy photons recorded. Table 3 demonstrates the change in linear attenuation coefficient as a function of absorber type and photon energy. Note the significant difference in attenuation coefficients between the low-energy photons and the high-energy photons. It is precisely for this reason that metallic absorbers are effective in filtering out low-energy photons from a mixed-energy beam while sparing high-energy photons.

Iodine-123, ^{111}In and ^{127}Xe are three primary radionuclides used in nuclear medicine that might benefit from a copper filter in dose calibrator measurement. Their principal gamma-ray and x-ray emissions are summarized in Table 4 (5). Each of these nuclides has significant abundance of x-rays that can

TABLE 3
Linear Attenuation Coefficients for Low- and High-Energy Photons in Different Absorbers

Photon energy (keV)	Linear attenuation coefficient, cm^{-1}		
	Copper (d = 8.94)	Glass (d = 2.23)	Water (d = 1.00)
20	302.08	5.12	0.81
30	97.62	1.78	0.38
150	1.98	0.31	0.15
200	1.39	0.28	0.14
400	0.84	0.21	0.11

TABLE 4
Principal Radiation Emissions of Iodine-123, Indium-111 and Xenon-127 (4)

Nuclide	K-Shell x-rays		Principal gamma rays	
	Energy (keV)	Percent abundance	Energy (keV)	Percent abundance
^{123}I	27.5	45.9	159.0	83.3
	27.2	24.7	—	—
	31.0	8.7	—	—
	31.7	2.7	—	—
	30.9	4.5	—	—
^{111}In	23.2	44.4	171.3	90.2
	23.0	23.6	245.3	94.0
	26.1	12.2	—	—
	26.6	2.4	—	—
^{127}Xe	28.6	46.4	172.1	25.5
	28.3	25.0	202.9	68.3
	32.3	8.8	375.0	17.2
	32.2	4.6	—	—
	33.1	2.8	—	—

contribute to interferences in dose calibrator measurement of radiopharmaceuticals. Although ^{127}Xe is no longer routinely available for use, the frequency of measuring ^{123}I and ^{111}In radiopharmaceuticals in nuclear medicine practice necessitates instituting a simple and accurate method for the dose calibrator. The use of a copper filter in the dose calibrator well to selectively absorb low-energy x-rays with minimal effect on principal high-energy photopeaks has been shown in this study to be an effective method for reducing variations in measurement due to geometry and container attenuation. Without use of a low-energy x-ray filter, significant variations in dose calibrator readings can occur depending on container type and volume, necessitating the use of different correction factors for each situation. In the current study, container correction factors for ^{111}In were as follows: 0.76 (1-ml syringe), 0.78 (3-ml syringe), 0.81 (10-ml syringe), and 0.94 (10-ml glass vial). For example, a dose measured in a 1-ml syringe without a copper filter using the manufacturer's isotope calibration setting (303) for ^{111}In , would require multiplying the measured activity (1.55 mCi) by 0.76 to obtain the true activity (1.18 mCi) in the syringe. These calibration factors are similar to those determined by Mallinckrodt, Inc. in their technical bulletin (4) for assaying ^{111}In being 0.797, 0.812 and 0.821, respectively, for the syringes listed above. A major difference occurs, however, with the correction factor for the 10-ml glass vial where their factor is 1.136 and the one in this study is 0.94. This is likely due to the difference in the glass thickness of the vials. A repeat of the container geometry study using a different 10-ml molded glass vial (Wheaton Scientific, Millville, NJ) produced a greater absorption of x-rays by the vial and a correction factor of 1.074. This compares better to 1.136 in the Mallinckrodt study and, while not the same, points out the strong influence of container material on the assay of ^{111}In .

The use of correction factors is a cumbersome solution to the problem of correcting for absorption of characteristic x-rays as a function of volume and container type. This dependence can be eliminated by using a copper filter ≥ 0.6 mm thick. Such a filter is easily constructed from standard 5.08-cm (2-inch) diameter copper water pipe of 1.1 mm thick obtained from local plumbing supply houses. A vial holder to fit inside the copper pipe can be constructed from a plastic prescription vial to which a nylon tie-connector is cemented with glue to serve as a handle. Dose calibrator manufacturers could easily produce and supply such an after-market device to retrofit their dose calibrators currently in use in nuclear pharmacies and nuclear medicine laboratories.

CONCLUSION

A copper filter ≥ 0.6 mm thick facilitates accurate measurement of ^{123}I and ^{111}In with the dose calibrator. However, use of a copper filter requires establishment of new calibration settings different from those provided by the dose calibrator manufacturer. This is accomplished by assaying an ^{123}I or ^{111}In source of known activity and adjusting the isotope calibration dial so the dose calibrator reads out the known activity. For

subsequent measurement of ^{123}I - or ^{111}In -labeled radiopharmaceuticals, the copper filter is inserted into the dose calibrator well, the new calibration setting is dialed in, and the correct activity in the syringe or vial is read directly without need of a container or volume correction factor.

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