MASTER

SPECTRAL DIFFERENCE IN COMMERCIAL ^{125}I PHOTON SOURCES

by

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INTRODUCTION

Several factors may alter the attenuation properties and the apparent spectral composition of the I-125 photon sources used in the absorptiometric determination of bone mineral content (BMC). Some of the more important attenuation and spectral altering factors are the presence of a radionuclide contaminant, induced fluorescence radiation, instrumentation shifts, and variations in the beam filtration.

The presence of the radionuclide contaminant I-126 has been previously observed in I-125 (1). It appears in reactor produced I-125 when a neutron is captured by the I-125. The amount of I-126 present is greatest for batch produced I-125 unless it is "aged", and is small ($< 0.1\%$) for continuously produced I-125 used in the current commercial sources. This amount of I-126 appears to have no effect on the BMC determinations.

Fluorescence radiation can be induced by I-125 if high atomic number (Z) material such as silver is part of the source or its container. Previous commercial sources (those provided before April, 1969) had the I-125 electroplated on a silver wire. The I-125 decay photons excited the 22 keV silver K x-ray and gave a low energy contribution to the spectrum. However, when the I-125 is electroplated on low Z materials such as charcoal as in the current sources the fluorescence is completely eliminated. Our earlier ion exchange resin bead sources made with polystyrene beads also had no induced fluorescence radiation.

Since the NaI-PMT detector signal passes through a single channel analyzer (SCA), the detection instrumentation is sensitive to gain variations. These gain variations can be caused by changes in the high voltage supply to the photomultiplier tube and/or by changes in the gain of the pulse amplifier. Either or both gain changes shifts the photopeak relative to the fixed SCA lower level-window settings making the detected spectrum appear to have either a higher or lower effective energy. Previous experiments, in which the BMC was measured as a function of the lower level position with a fixed window determined that the BMC will vary with shifts in the gain (2).

The I-125 decay spectrum is not monoenergetic but contains five different energy photons ranging from 27.5 to 35 keV. At these low energies the photoelectric effect is the dominant attenuation process and the attenuation coefficients are rapidly changing with energy.

* Atomic Energy of Canada Limited, Ottawa, I-125 source type C-236.

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Placing any material over the emission aperture of the I-125 will alter the energy composition of the emitted beam because for the same thickness of material the different photon energies present will be attenuated by different amounts. In general the lower energy photons are attenuated more than the higher energy photons.

The I-125 sources, used for bone mineral content measurements, are selectively filtered with tin which improves the monochromaticity and decreases the effective energy of the emission spectrum (3). Since we first began assembling our resin bead sources, the source output aperture has been covered with a 0.06 mm thick electrolytically pure tin foil. The tin has its K absorption edge at 29.2 keV and therefore, preferentially absorbs the two Te K_{β} x-rays and the 35 keV gamma present in the I-125 spectrum.

From the equation for bone mineral content, one can see that for the same calibration constants or attenuation coefficients increasing the effective photon energy decreases the ratio of I_0^*/I , thereby decreasing the integrated bone mineral content. Decreasing the effective photon energy would increase the ratio of I_0^*/I ,

$$B.M.C. = K \log(I_0^*/I_1)$$

thereby increasing the bone mineral content. Since our bone mineral content measurements have been made with a 0.06 mm tin filtered source, any decrease in the filter thickness will result in a decreased bone mineral content. Since the measured bone mineral content depends upon the energy composition of the photon spectrum to obtain long term precision in the mineral content measurements, the tin thickness, hence the effective filtration, must remain constant. Recently we have observed variations in the tin filter thickness of commercial I-125 photon sources by observing a reduction of the bone mineral content of our K_2HPO_4 polymethacrylate block standards (4).

METHODS AND RESULTS

These first observations of lower bone mineral content could also have been due to incorrect equipment settings or a constant source of background counts, possibly due to a radionuclide contaminant. Additional intercomparison scans with older sources at constant equipment settings eliminated the possibility of errors in the equipment settings. The lack of any unusually high background count plus the observation that the effect did not change with time eliminated the possibility that the sources contained a radionuclide contaminant. Therefore the decrease in bone mineral content was apparently due to a decrease in the source filtration.

This decrease in effective filtration could have been due to either or both of the following: a "change" in the effective filtration of the aluminum source capsule and/or a decrease in the tin foil thickness. To test possible differences in source capsules a suspected

deviant source capsule was placed in a brass holder from an old source and filtered with the filter from the old source holder. Scans of the K_2HPO_4 standard with this source capsule-holder-filter combination gave results comparable with results obtained with correctly filtered sources (Table 1). The effective capsule filtrations were apparently the same. Next we placed the deviant source capsule in its original brass holder, but replaced its original filter with a filter cut from our tin stock (this is the same tin stock used to filter all our home-built sources). Now the scans of the K_2HPO_4 standard agreed with the long term average values for the standard (Table 1).

To further demonstrate that the problem was due to insufficient tin filtration, the standard was scanned with another underfiltered source where additional amounts of .001-inch tin attenuators were placed between the source and the standard. The bone mineral content of the standard was plotted as a function of the tin thickness (Figure 1).

This source had two company supplied tin filters. The total initial thickness of tin on the source was estimated to be .0012-inch, which was twice the thickness of a single filter. The thickness of a single filter was estimated by assuming the filter was a disc with a cross sectional area, A , thickness, t , mass, m , and density, ρ . By measuring the mass and cross sectional area, and assuming the density is constant, one can calculate the thickness of the disc.

Adding the extra tin caused the bone mineral content to quickly reach the expected average value. Again when the tin filter was replaced with tin from our stock, the values for the standard agreed with the long term average values.

Since tin changes the spectral composition of the I-125 energy spectrum, sources with less tin filtration should have a different spectral composition which is characterized by a higher effective energy or a lower effective attenuation coefficient.

One way to determine the spectral composition of a radiation source is to precisely measure its attenuation or absorption in some pure material. To test for spectral composition differences between correctly and incorrectly filtered I-125 sources, transmission measurements were made through copper foils .002-inch thick and lead foils .038-mm thick. These measurements were made with our clinical scanning system during the past year for each new source. The source-detector geometry of this system which had a source aperture of 2.3 mm, a detector aperture of 3.2 mm, and a source-to-detector distance of 173 mm could be considered representative for all the measurements. Count rates were either corrected for count loss or else kept below 10,000 per second to minimize count loss errors. The data was not corrected for background which was typically 0.5 counts per second for the 3-mm thick x 0.5-in. diameter NaI(Tl) detector.

The natural logarithms of the ratio of the attenuated and the unattenuated count rates were plotted as a function of the foil

thickness for six different commercial I-125 sources; two sources were attenuated with copper and four were attenuated with lead. The slope of each plot was estimated from a straight-line regression analysis. These estimated slopes which are the effective attenuation coefficients for the different sources are listed in Table 2. For each material and source the slopes were tested by a parallel straight line test to determine if the slopes for the underfiltered sources were significantly different than the slopes for the correctly filtered sources. With copper as the attenuating material, the slopes were not significantly different (Table 3). In fact, further statistical testing demonstrated that the regression lines were identical. However, with lead as the attenuating material, the slopes for the two correctly filtered sources were significantly different from the slopes for each of the two underfiltered sources (Table 3). The two sources which had insufficient tin filtration had a lower effective attenuation coefficient, implying that the beam had a higher effective energy.

DISCUSSION

The observations of low bone mineral content of the standard and the significantly lower effective attenuation coefficient for lead both agree with the hypothesis that these sources had insufficient tin filtration. This hypothesis was further confirmed when the B.M.C. of the standard approached its expected value after placing additional tin over the source aperture of an underfiltered source.

Provided that the change in B.M.C. is due only to spectral changes in the photon sources, careful comparison measurements of the K_2HPO_4 standard can detect these differences between sources. Although the observed changes in B.M.C. of the standard can be large ($\sim 6\%$), making judgements about spectral changes from scan measurements alone is still achieved by the process of elimination. One would prefer a more direct determination of the spectrum by spectrometry techniques. Most laboratories (including ours) lack the high resolution detectors (e.g., Si(Li)) necessary to observe these small spectral changes.

An alternative method to determine the energy spectrum of the I-125 sources is the attenuation technique. In general, the data are not precise enough to resolve the attenuation curve into a sum of exponential lines, one for each of the energies present in the beam. However, one can fit the data to a straight line and obtain an effective attenuation coefficient. Even though there are only small spectral differences between a correctly and incorrectly filtered source, small and significant differences in effective attenuation coefficients could be demonstrated for material with a high atomic number, Z , such as lead ($Z = 82$), while attenuation of the same sources by copper ($Z = 29$) showed no significant differences between the effective attenuation coefficients.

CONCLUSION

We have observed variations in the thickness of the tin filters in commercially available I-125 photon sources. Discussions with the manufacturer have revealed that the problem appeared due to a misunderstanding about the need for a constant tin filtration of the I-125 beam and inadequate quality control governing the thickness of the tin filter. In order to allow intercomparison of the data from all laboratories performing bone absorptiometric measurements with I-125 photon sources, all sources must have the same spectral characteristics and these spectral characteristics are controlled primarily by the thickness of the tin filter. The company intends to solve the problem by providing all users with a tin filter window which would be placed over the source holder. The separate tin window would be retained by the user and placed on each subsequent new source (5).

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Table 1. A comparison of the bone mineral content of the K_2HPO_4 standards determined with sources having different capsule-holder-filter source combinations and with the same source filtered with UW tin.

<u>Source-capsule</u>	<u>Source holder</u>	<u>Filter</u>	Ratio <u>B.M.C. Test Sources</u> <u>B.M.C. Control (UW filter)</u>
D	D	D	.938
D	F	F	.994
D	D	UW	1.000
C	C	UW	1.009
C	C	UW	1.006

Table 2. The slopes of the attenuation curves estimated from a straight-line regression analysis.

<u>Source</u> <u>Source</u>	<u>Attenuating</u> <u>Material</u>	<u>Slopes (Effective Attenuation Coefficients)</u>		
		layer ⁻¹	cm ⁻¹	cm ² /g
A	Pb	1.28	336.2	29.6
B	Pb	1.28	336.1	29.6
C	Pb	1.13	297.6	26.2
D	Pb	1.13	295.4	26.0
E	Cu	0.578	113.7	12.7
F	Cu	0.575	113.2	12.7

Table 3. A comparison of regression lines of the natural logarithm of the fractional transmission verses the number of copper or lead attenuators. Sources A, B, and F correctly filtered. Sources C, D, and E underfiltered.

<u>Sources Compared</u>	<u>Attenuating Material</u>	<u>t value</u>	<u>Significance Level</u>
A, C	Pb	3.99	.002
A, D	Pb	2.47	.05
B, C	Pb	5.83	.002
B, D	Pb	3.12	.01
E, F	Cu	0.273	----

Figure 1. The bone mineral content of the large chamber of the 3-chamber K_2HPO_4 standard as a function of the thickness of the tin filtration on a commercial I-125 photon source. The dashed line indicates the expected value of the bone mineral content for this chamber measured with a correctly filtered source.