Estimated Uncertainty in Segmented Gamma Scanner Assay Results due to the Variation in Drum Tare Weights - 9332

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ABSTRACT

General purpose gamma scanners are often used to assay unknown drums that differ from those used to create the default calibration. This introduces a potential source of bias into the matrix correction when the correction is based on the estimation of the mean density of the drum contents from a weigh scale measurement. In this paper we evaluate the magnitude of this bias that may be introduced by performing assay measurements with a system whose matrix correction algorithm was calibrated with a set of standard drums but applied to a population of drums whose tare weight may be different. The matrix correction factors are perturbed in such cases because the unknown difference in tare weight gets reflected as a bias in the derived matrix density. This would be the only impact if the difference in tare weight was due solely to the weight of the lid or base, say. But in reality the reason for the difference may be because the steel wall of the drum is of a different thickness. Thus, there is an opposing interplay at work which tends to compensate. The purpose of this work is to evaluate and bound the magnitude of the resulting assay uncertainty introduced by tare weight variation. We compare the results obtained using simple analytical models and the 3-D ray tracing with ISOCS software to illustrate and quantify the problem. The numerical results allow a contribution to the Total Measurement Uncertainty (TMU) to be propagated into the final assay result.

INTRODUCTION

The non destructive assay of drummed gamma-ray emitting radioactive waste is commonly performed using a spectroscopic drum scanner. Correction factors are needed to account for the attenuation of the characteristic gamma-ray lines by the contents of the drums. One way to estimate these corrections is to estimate the mean density of the contents and use it in a suitable mathematical algorithm. At each energy of interest the algorithm estimates the matrix correction factor from the mean density assuming a particular material composition. Generally the matrix is taken to be homogeneous and uniform with activity uniformly distributed throughout.

A common practice is to determine the parameters used in the algorithm from calibration measurements. These are typically performed using a set of standard drums and matrices chosen to simulate the waste forms. In application however it is possible to encounter a variety of drum types at a given facility. Where the differences are significant and can be recognized allowances can be made and an item specific calibration can be used. But, sometimes, especially in automated waste treatment plants, the drum type may not always be known to the assay system. In this case the assay will be based on the default settings. If the drum does not share the same characteristics as the calibration drum set, and in this study we are concerned principally with tare weight, then a bias can result.

The purpose of this work is to evaluate and bound the magnitude of the assay uncertainty introduced by tare weight variation. We use a combination of simple analytical models and 3-D ray-tracing to illustrate and quantify the problem. The numerical results allow a contribution to the Total Measurement Uncertainty (TMU) to be propagated into the final assay result.

PARKER FORMULA APPROACH

The matrix attenuation correction factor for each segment of a Segmented Gamma Scanner (SGS) [1] can be estimated using the Parker equivalent slab model [2]. In this case the efficiency correction factor for each layer is determined using the following formula:

$$CF = \frac{\left(\frac{\mu}{\rho}\right)_{tot-coh} \cdot \rho \cdot D \cdot \kappa}{1 - exp\left(-\left(\frac{\mu}{\rho}\right)_{tot-coh} \cdot \rho \cdot D \cdot \kappa\right)} \qquad \text{(Eq. 1)}$$

where $\left(\frac{\mu}{\rho}\right)_{tot-coh}$ = mass attenuation coefficient of the matrix, excluding coherent scattering [3] (cm^2/g),

ρ = matrix density (g/cm^3)

D = internal drum diameter (cm)

κ = geometric factor (≈ 0.82 for the cylindrical drum geometry) [4]

If the measured drum has a different tare weight then the calculated apparent matrix density will differ from the “true” value. The difference between the “true” and the “apparent” densities will result in that the measured activity will be either under or over reported. Two types of drums different from the standard “Q2 drum” set [5] (25.5 kg) used for calibration were considered in this study:

- light drum (23.8 kg)
- heavy drum (28.0 kg)

Variations in weight due to drum height variation were not considered explicitly in this study. The deviation of -1.7 kg (light drum) and +2.5 kg (heavy drum) in the measured activity for the net mass uncertainty is shown in Fig. 1 below. All graphs are given for a silica (sand) matrix, which is a medium atomic number matrix. The same type of data may be easily obtained for other materials included in the calibration set if necessary. For a given density matrix the reported to true activity would agree if the drum under study was of the same type as the drums used in calibration. The $A_{Reported}/A_{True}$ ratio would be 1 at all energies in this case. The two curves shown for each energy plotted represent the bias that would be present had the drum been lighter or heavier that the calibration type respectively.

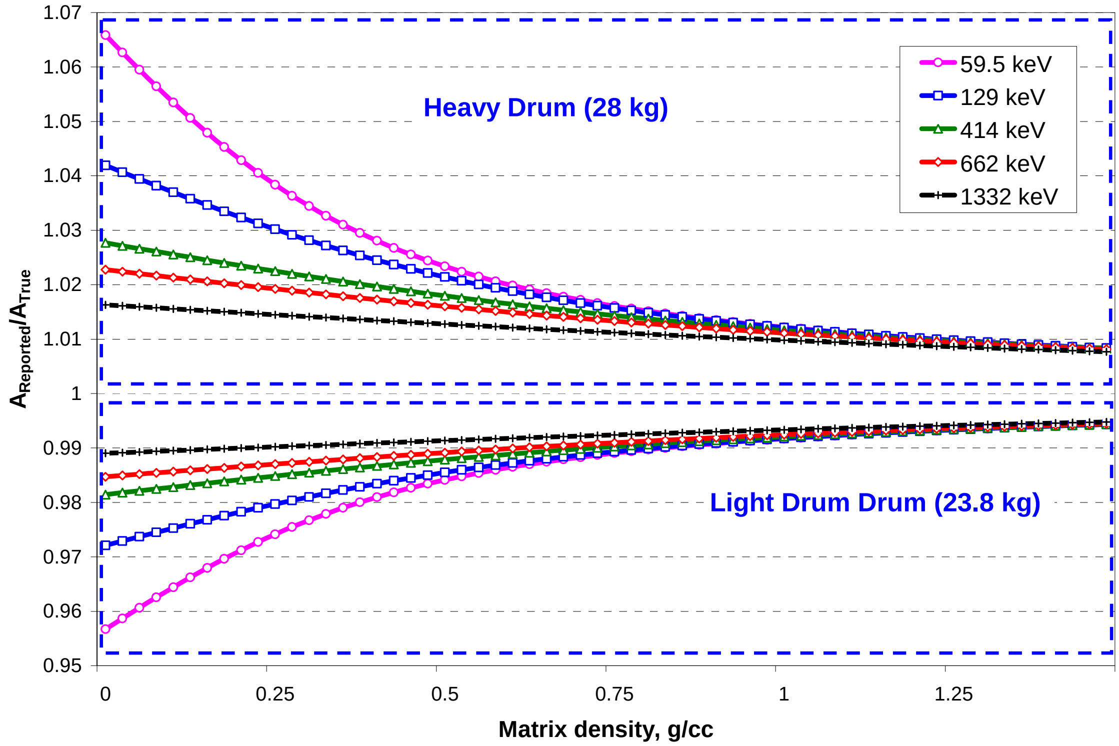

Fig. 1. Deviation of the measured activity from the "true" value estimated for different gamma energies.

Besides the matrix density, additional deviation in the reported activity may come from the difference in wall thicknesses for light and heavy drums compared to the calibration items. Table I shows a simple estimation of the magnitude of this effect using the exponential attenuation formula assuming that the reason for the difference in tare weight is the result of a difference in the gauge of the steel used to fabricate the drum. The same data are graphically presented in Fig. 2. The attenuation model assumes a distant photon detector and is described as follows:

$$f_w = exp\left(-\left(\frac{\mu}{\rho}\right)_{tot-coh} \cdot \rho \cdot \Delta t\right) \qquad \text{(Eq.2)}$$

where $\left(\frac{\mu}{\rho}\right)_{tot-coh}$ = mass attenuation coefficient of the steel drum wall, excluding coherent scattering [3] in units of (cm^2/g),

ρ = density of the steel (7.86 g/cm^3)

$\Delta t = t_{Q2} - t_{assay}$ = difference in drum wall thickness (cm) relative to the Q2 calibration set

Table I. Difference in the Measured Activity for Light (Wall Thickness 1.32 mm) and Heavy (Wall Thickness 1.56 mm) Drums Compared to the Q2 Drum (Wall Thickness 1.42 mm)

Isotope	Energy, keV	Over reporting, % (light drum)	Under reporting, % (heavy drum)
Am-241	59.5	9.4	-11.8
Pu-239	129.3	1.7	-2.4

Pu-239	413.7	0.7	-1.0
Cs-137	661.7	0.6	-0.8
Co-60	1332.5	0.4	-0.6

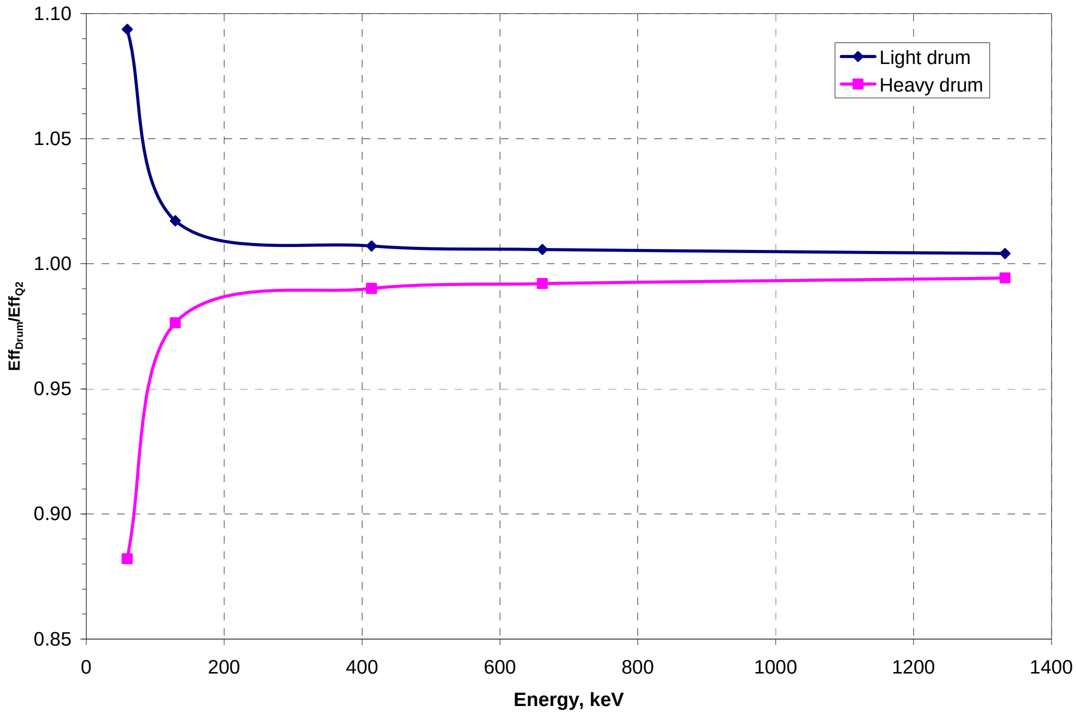

Fig. 2. Estimated efficiency variation due to the drum wall thickness variation.

The combined effect on the measured activity from the wall thickness variation between two drums and the difference between the "true" and the "apparent" densities is shown for a sand matrix in Fig. 3. The combined effects is simply the product of the two factors – density bias and difference in wall attenuation.

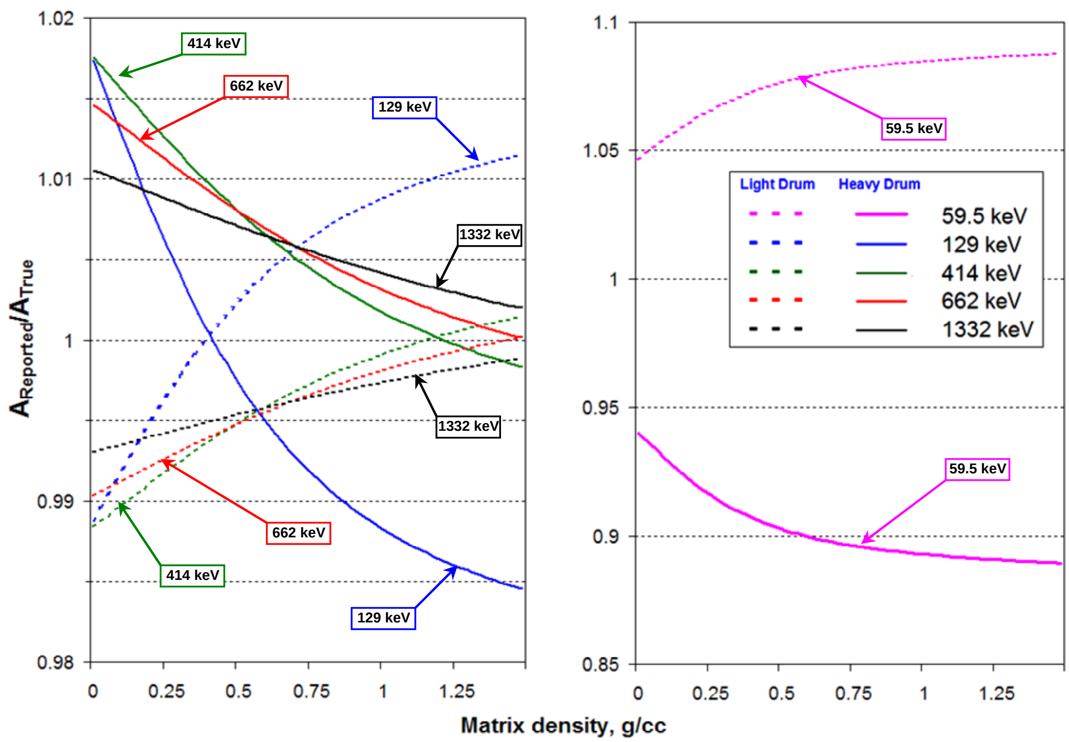

Fig. 3. Deviation of the measured activity from the "true" value estimated for different gamma energies with drum wall thickness variation effect taken into account.

ISOCS APPROACH

The analytical results are useful to get a feel for the magnitude and interplay of the effects but they are simplistic in that they do not represent the 3-D nature of the problem.

A more "thorough" evaluation of the uncertainty was undertaken using the ISOCS software [6]. A typical SGS counting geometry was simulated. The geometry shown in Fig. 4 included GC2018 coaxial detector pointed at the 208L drum. The lead collimator was used to limit the detector field of view. The collimator dimensions are 5cm vertical opening x 30cm horizontal width and 22cm deep. The drum-to-detector distance was 29cm.

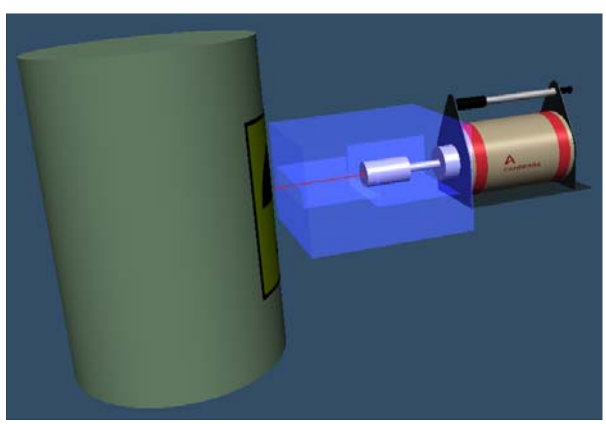

Fig. 4. A typical SGS geometry as simulated using ISOCS. ***Note: the collimator is set transparent for better visibility.***

As we discussed before, the impact of the unknown drum tare weight influences the apparent density of the fill matrix used when navigating the multi-curve surface (Efficiency vs Energy and Matrix Density). Table II demonstrates this effect for two different drums – one drum is heavier and the other is lighter than the standard Q2 drum used to calibrate the system. Typically the Q2 drums use low-Z materials for low density and for the highest density use only sand. In order to investigate an impact of the matrix type (low atomic number (low-Z) vs high-Z material) an additional iron matrix was also considered in this study.

Table II. Effect of the Drum Weight Variation on the Apparent Density of the Fill Matrix

Matrix	Matrix density, g/cc		
	Q2 Drum (25.5 kg)	Light Drum (23.8 kg)	Heavy Drum (28.0 kg)
Foam	0.0284	0.0202	0.0404
Softboard	0.490	0.482	0.502
Particle Board	0.681	0.673	0.693
Sand	1.580	1.572	1.592
Iron	1.580	1.572	1.592

As a result, a larger/smaller correction factor than needed will be applied and hence the measured activity will be over- or underestimated as shown on Fig. 5 below. Note that there was no significant difference observed between the low-Z and high-Z matrices.

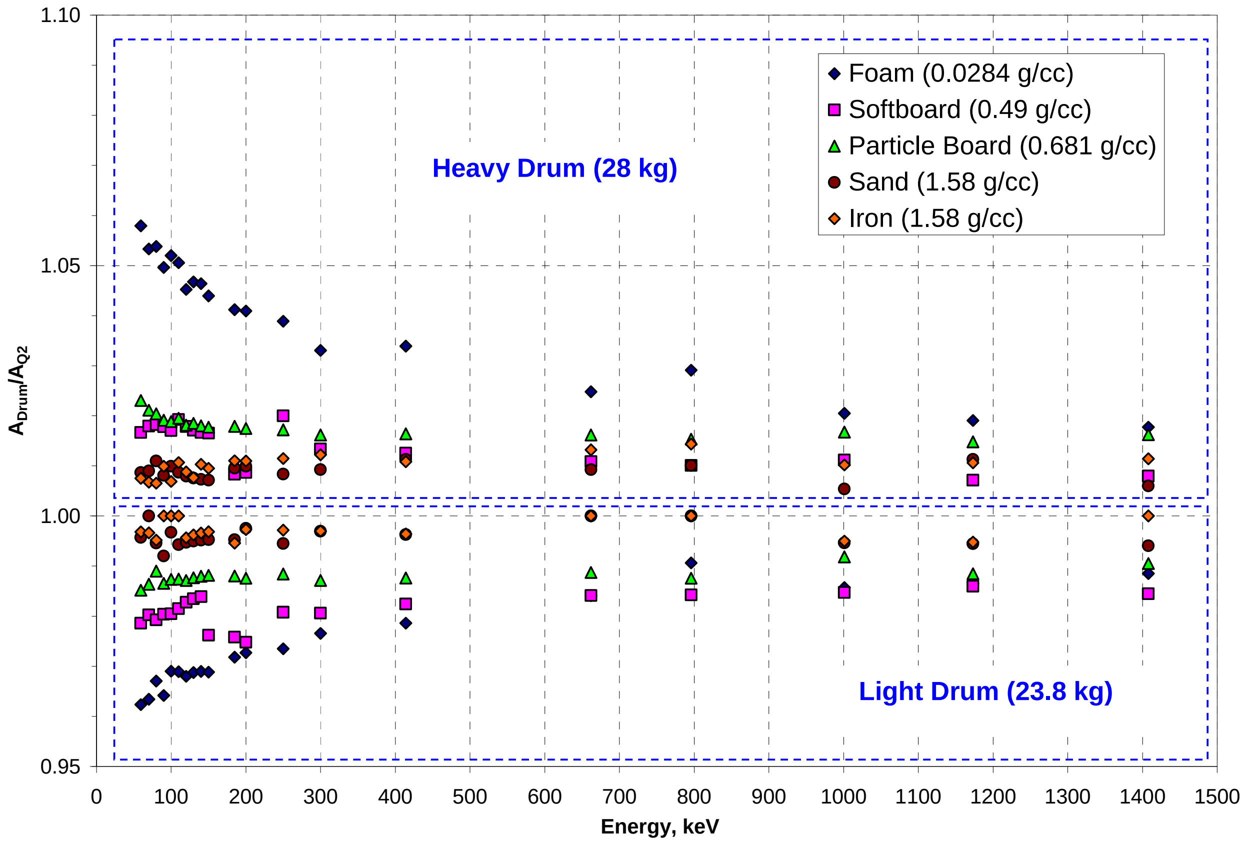

Fig. 5. Deviation in the measured activity due to the variation in matrix density caused by the increased/decreased (Heavy Drum/Light Drum) empty drum weight. ***Note: drum wall thickness is the same for all containers.***

In this case we assumed that drum wall thickness is constant for all containers and the weight difference is only due (conceptually) to a "heavy/light plate in the bottom of the drum". These results are comparable to those shown in Fig. 1 using the simple Parker model.

Another possible reason for the weight difference is that the container wall thickness can vary from drum to drum. Table III shows approximate wall thicknesses that were estimated for different drum types based on their weight. These are the same as were used in the analytical calculations.

Table III. Drum Wall Thickness Necessary to Reflect Changes in a Drum Weight[a]

	Q2 (25.5 kg)	Light Drum (23.8 kg)	Heavy Drum (28.0 kg)
Wall thickness, mm	1.42	1.32	1.56

[a] These are estimated wall thicknesses. The actual drum thickness may vary from these values.

Increased wall thickness will affect the counting efficiency as shown in Fig. 6. These data obtained using ISOCS calculations are consistent with the estimated results given in Table I and Fig. 2 above, which are based on a simple 1-D attenuation calculation.

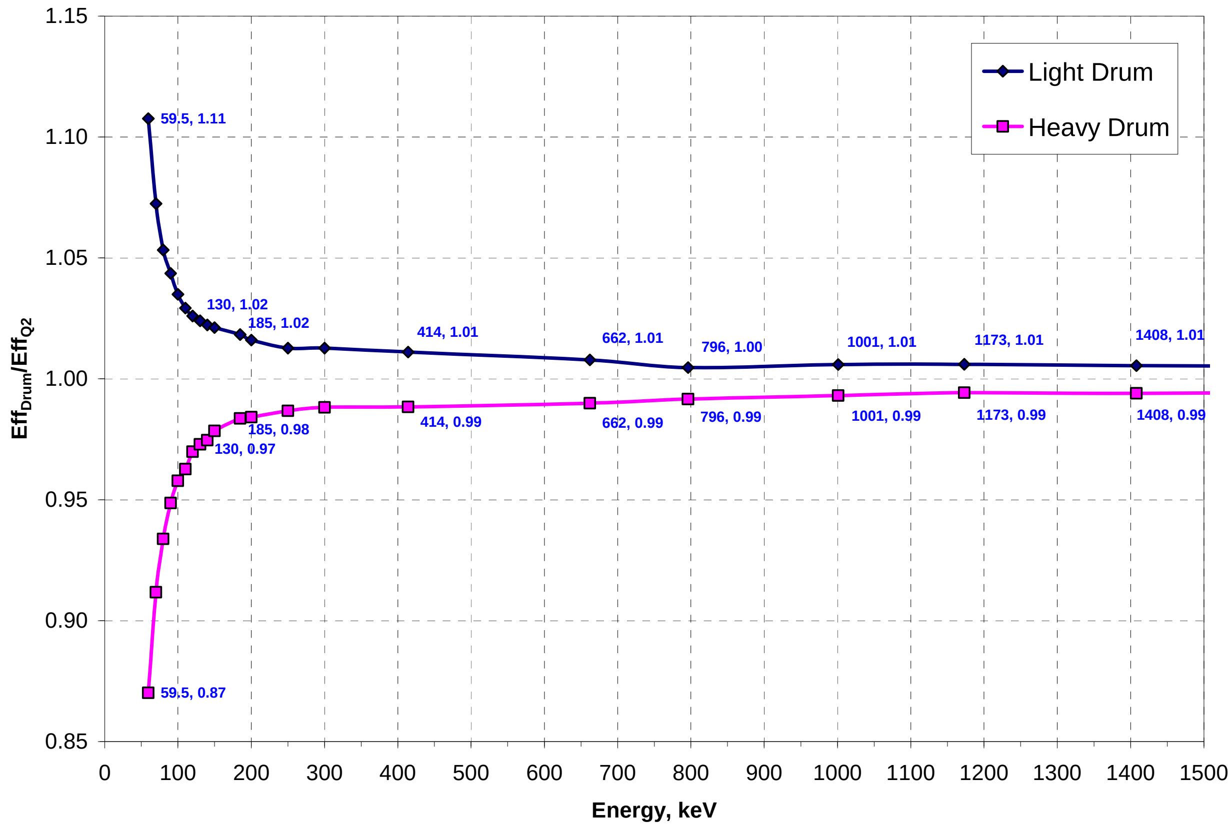

Fig. 6. Efficiency deviation due to the empty drum wall thickness variation as a function of gamma energy as determined using ISCOS.

It is important to know where the tare variation comes from. The change in the counting efficiency due to the wall thickness variation may partially compensate the effect of the activity over- and underestimation due to the incorrect determination of the apparent matrix density, see Fig. 7. Although, for low energy gamma-ray (< 100keV) the wall thickness effect may worsen the final results.

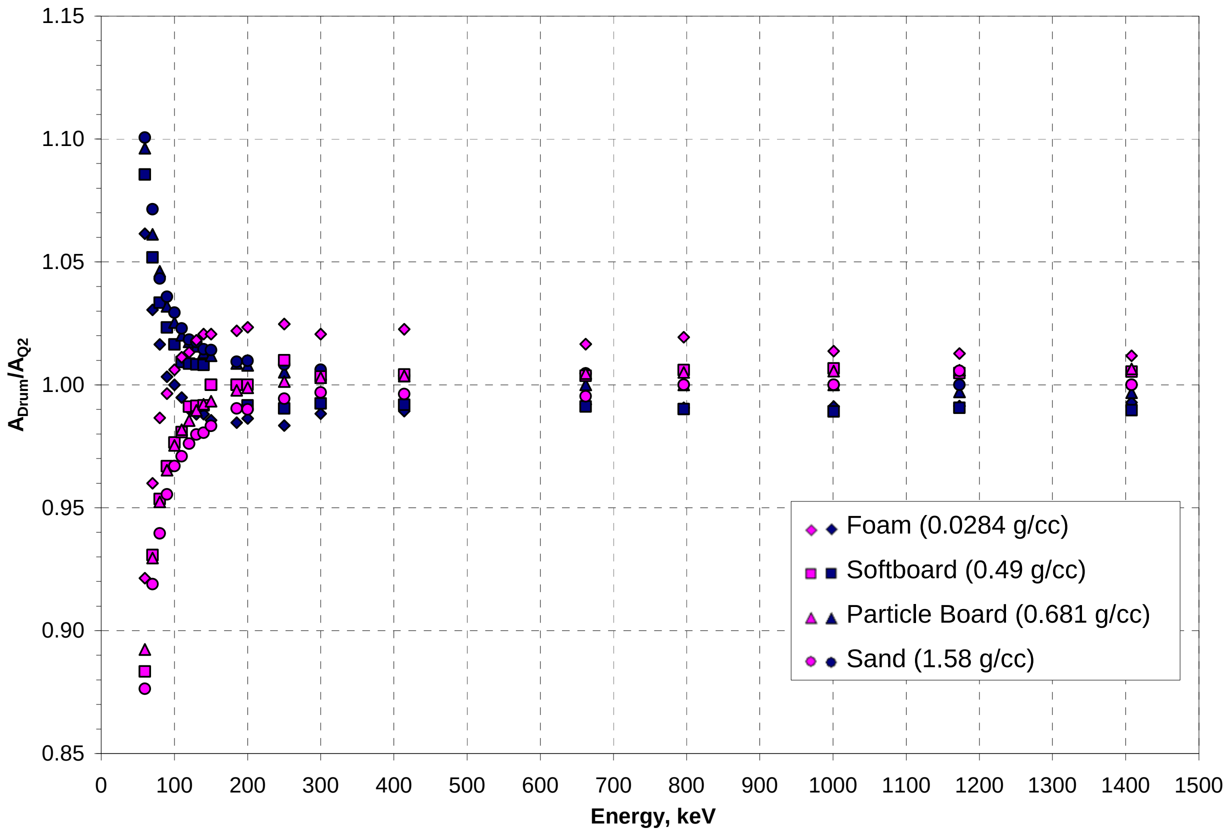

Fig. 7. Deviation in the measured activity caused by the variation in the empty drum weight when the drum weight difference is reflected solely as a drum wall variation. Data shown for Light Drum (blue dots) and Heavy Drum (pink dots) with respect to the standard Q2 drum. ***Note: effect for the iron (1.58 g/cc) matrix will be approximately the same as for the sand matrix as it was shown in Fig. 5 above.***

CONCLUSION

Overall, in the case of a heavier drum the deviation in the measured activity should be expected to be less than 3-5% for moderate to heavy density drums and gamma-ray energies above 100 keV. The effect may be more significant at low energies and becomes sensitive to details (e.g. atomic number of matrix). For the light drum, which does not differ as much in mass from the Q2 drum used during the calibration, the deviation of the measured activity will be mostly due to the difference in wall thickness. The wall effect will be more significant at low energies, below 100 keV, where the influence of photoelectric absorption becomes prevalent.

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