MIRION TECHNOLOGIES

Application Note

Understanding Performance Specifications for Low Background Alpha Beta Counters

Comparisons between vendors' systems, often a tedious task, can lead to frustration and confusion. This application note will serve as a tool to guide you through the process of comparing low background, alpha beta systems. It will point out potential Figure of Merit (FOM) comparison errors by demonstrating fundamental, scientific principles as they apply to basic detector theory and functionality, and explain the importance of detector design. So, let's begin.

FOM – What Is It and Is It Useful?

Many people use the Figure of Merit (FOM) calculation to compare the performance of sample throughput between low background, alpha beta systems. While the FOM can be a useful tool, it can also lead to erroneous conclusions if not used properly. Simply stated, FOM is a measure of performance for a machine: a parameter or characteristic of a machine, component, or instrument that is used as a measure of its performance.

FOM is generally defined as e^2/b, where "e" is the efficiency and "b" is the background for a particular instrument. FOM can be used to deduce sample throughput for different systems. However, using the above definition fundamentally makes FOM a useless tool when comparing systems between vendors. Here's why.

Since the values used to calculate FOM are efficiency and background, all ***variables*** that affect them should be controlled and equal. Since vendors publish background and efficiency specifications based on their own unique testing, the variables that affect background and efficiency can produce very different results. This ultimately leads to erroneous assumptions regarding sample throughput. Since most of the variables are efficiency related, we'll begin there.

What are the ***variables*** that affect efficiency?

1) Geometry
2) Backscatter
3) Attenuation
4) Self-absorption

We will not discuss self-absorption or attenuation in this application note. We will address geometry and backscatter only.

1) Geometry

2π vs. 4π?

Since many vendors do not reveal if published efficiencies are 2π or 4π, assumptions about FOM values can be incorrect by orders of magnitude if this variable is unknown or not well defined when making comparisons.

First, let's discuss how 2π and 4π calibrations are derived. Imagine if a point source was suspended in mid-air. We assume that half of the particles will travel in the plane above the source and half will travel in the plane below the source. If you place a detector on top of the source, the most a detector could detect is one-half the disintegration rate of the source. If we adjust the calibration information for the detector to detect one half the given disintegration rate, the detector will in theory detect 100% of the particles hitting the probe – defined as a 2π calibration. For example: source certificates usually give a 2π emission rate. This simply means that the source has been calibrated based only on the particles emitted from one surface of the source. If we enter the 2π emission rate into our calibration setup for the instrument, we essentially obtain a 2π calibration for that detector. A 2π efficiency calibration of 74% for ^{90}Sr would be the same as a 4π efficiency calibration of 37% for ^{90}Sr. The FOM between two different systems does not have the same meaning if the type of calibration, 2π or 4π, is not well defined.

Solving for FOM as e^2/b and assuming a 0.7 cpm background in each case:

$$\text{FOM} = \frac{74^2}{0.7} = 7822$$

compared to:

$$\frac{37^2}{0.7} = 1955$$

In this example, there is a 400% difference between the calculated FOM values. In summary, knowing the type of efficiency calibration published from each vendor is critical when making your comparisons between different systems.

Another aspect related to geometry that is equally important when comparing efficiencies is planchet depth. The depth of the planchet defines the distance from the sample to the gas flow detector window. The sample to detector distance will affect the efficiency measured with a system in two ways:

1. Charged particles (alphas and betas) have different ranges. Range is defined as the average depth of penetration of a charged particle into an absorber (air, lead, P-10 gas, etc.) before it loses all of its energy and stops. For example, the range in air for a ^{210}Po alpha particle is only about 2.5 cm or one inch. Beta particles have a much greater range in air, or about four meters per MeV of beta energy.

2. If a 4 mm diameter source is placed in a position so that there is no space between the source and the window of a 2.25 in. diameter sample detector, the detector will view nearly 50% (nearly 2 π) of the disintegrations of the source. Particles that impact the detector at very low angles, almost parallel to the window, will not likely generate enough charge, ionization, in the detector to result in a countable pulse. As the source is moved away, the detector will no longer view 50% of the disintegrations, but some percentage less. The greater the spacing, the smaller a percentage of 2 π and the lower the efficiency of the detection system.

From the above we can conclude that the distance of the source from the active detector area will impact both our alpha and beta efficiency. The alpha efficiency will be impacted by both phenomenon described above while beta efficiency, since betas have a much longer range, will be mostly affected by angular considerations.

Using the graph below (Figure 1), counting a ^{90}Sr source positioned as close to the detector as possible will produce an efficiency of approximately 55% (backscatter included, see below). Compare that efficiency to one obtained from counting the same source in a 1/8 in. planchet resulting in an efficiency of 47% (backscatter included, see below).

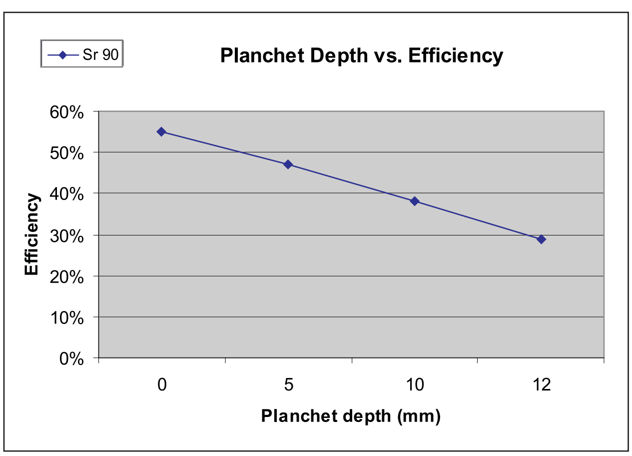

Figure 1

The resulting FOM values are 4321 and 3155 respectively based on a background of 0.7 cpm – a 137% difference simply due to planchet depth.

In a similar set of measurements, a 4 mm diameter ^{241}Am alpha source was placed consecutively in 1/8 in. and 5/16 in. deep inserts and the efficiency was measured. The efficiency in the 1/8 in. insert was determined to be 41.7% while the efficiency in the 5/16 in. insert was measured to be only 34.2%.

In summary, FOM is only a valid tool if the geometric factors that affect efficiency are known, well defined and equal for each efficiency value used in the FOM equation.

2) Backscatter

The next factor affecting efficiency that we will discuss is called backscatter. Backscattering is the phenomenon by which particles that travel away from the detector area are "scattered" back toward the detector area as shown in the illustration below.

In Figure 2, some of the charged particles on the bottom of the source are "scattered" against the planchet back toward the detector area where they are detected and registered as counts.

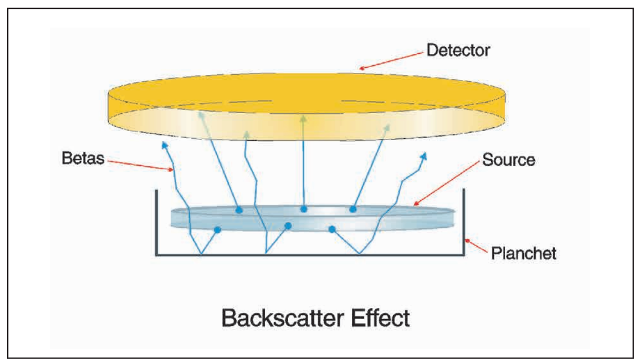

Figure 2

In Figure 3, the charged particles on the bottom of the source have nothing to "scatter" against and are subsequently not detected.

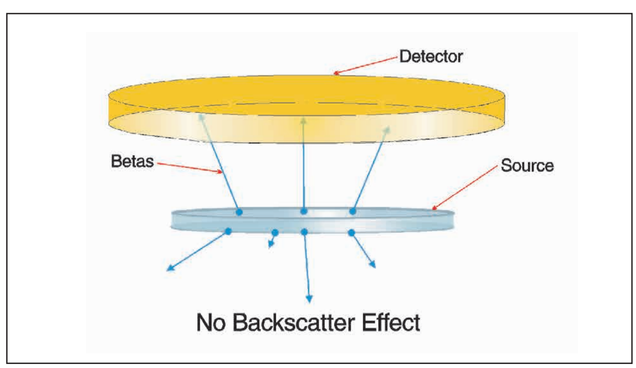

Figure 3

The amount of backscatter for charged particles is a function of the material used for source placement, such as stainless steel planchets. Since some type of planchet is always used to position and hold the source or sample in place while counting, some backscatter effect will always occur during the acquisition. Figure 4 below illustrates the backscatter effect as a function of the Z of the planchet material used. From this graph, we conclude that different planchet materials and isotopes will produce varying degrees of the backscatter effect.

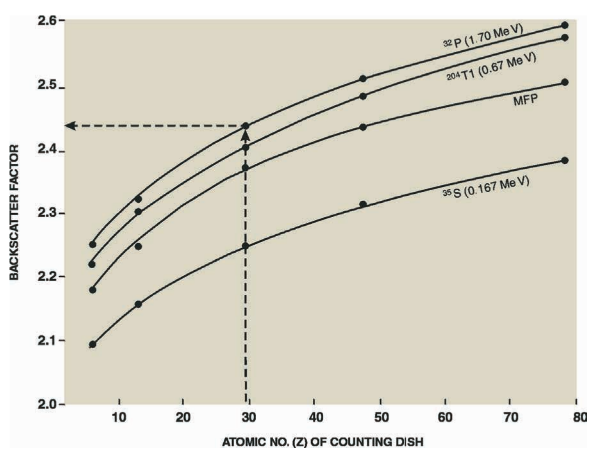

Figure 4
("Evaluating the Performance of the Internal Counter" by J. S. Nader, G. R. Hagee and L. R. Setter. Nucleonics, Vol 12, No. 6, June 1954)

Efficiency results published by vendors typically include some backscattering effect, especially for betas. Since some vendors do not disclose whether or not backscatter is included in published efficiency specifications, the FOM comparison becomes an invalid tool unless the *exact* backscatter factor is known (including the type of planchet material used for source placement as well as the source mounting material). Efficiencies can differ by as much as 17% due to backscatter alone.

The FOM values in Figure 5 were obtained using published warranty specifications from one vendor for beta efficiency and background using a single instrument. The FOM value in blue, 2382, is based on an efficiency that included no backscatter. The FOM in purple, 3958, is based on the same instrument but using an efficiency value that includes backscatter. So it is easy to see how the FOM becomes invalid if the data used to calculate it is not well defined.

"Warranty" vs. "Typical" Specifications

Another important observation is to note the difference between FOM values for a system using *warranty* specifications versus the FOM calculated based on *typical* specifications. Some vendors compare their typical specifications against the competitor's warranty specifications. Historically, a typical efficiency is a "best case" value that is not always reproducible but usually achievable. A warranty efficiency is used as a lower limit for testing purposes. In other words, vendors should not ship a detector that exhibits an efficiency value below the warranty spec. The warranty spec can be interpreted as a "worst case" value. Vendors that use a typical efficiency value versus a warranty efficiency value in the FOM equation cause confusion and lead customers to incorrect assumptions.

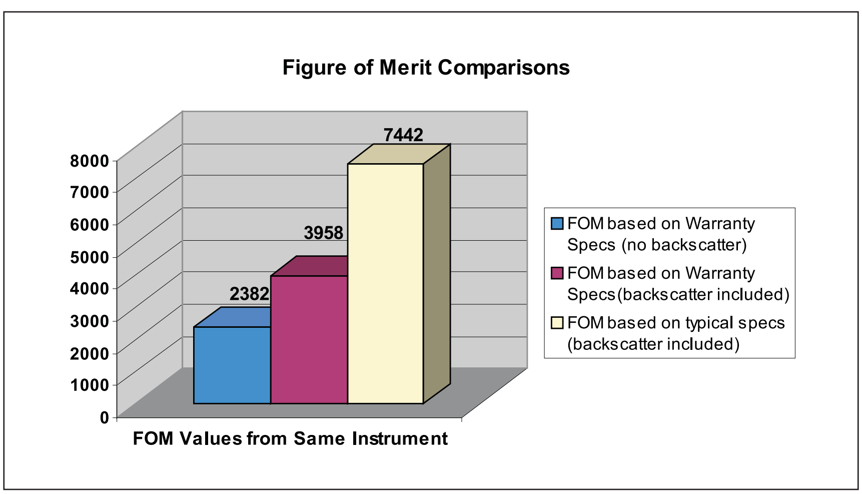

Figure 5

In summary, there are many variables that affect the FOM calculation making it a useful tool ***only if*** the conditions used to calculate it are known and well defined. If you still feel inclined to use the FOM as a comparison tool, do the homework, and request all the necessary data from each vendor to ensure you make the right decision. The list below provides some of the data needed to make a valid FOM comparison:

1) Is the efficiency value 2π or 4π?
2) What planchet depth was used to count the source?
3) What type of planchet material was used to hold the source?
4) Is backscatter included in the published efficiency value?
5) What source was used, i.e., ^{90}Sr, ^{99}Tc?
6) Are the efficiency values warranty specifications or typical specifications?

The answers to these questions should be exactly the same for each vendor to ensure a valid FOM comparison is made.

As an alternative, the best measure to compare two like systems is to test them simultaneously in a real laboratory environment. This is the only valid, scientific comparison since published specifications are often generated from atypical situations in order to produce the "best" values possible. Although specifications are necessary to offer some baseline performance of the instrument, comparing those specifications without knowledge of a valid comparison can lead to incorrect observations or assumptions.

Part II – Detector Design – Not All Detectors Are Created Equal

Single Anode vs. Dual Anode – Is It Important?

Detector design, erroneously omitted during comparisons between vendors' alpha/beta systems, is the single most important aspect when comparing two like systems. The second part of this application note will show why detector design is critical for accurate measurements of prepared, unknown samples.

Published efficiency specifications are based on uniformly distributed point sources centrally located and counted as close to the detector area as possible. This will deliver the absolute best possible efficiency for any system but is unrealistic when applied to the efficiency performance from unknown samples.

Unknown samples are inherently not distributed uniformly due to sample preparation methods. Unknown samples are either evaporated liquids or filter samples prepared by individuals using technique dependent methods. This usually results in sample activity that is not randomly or equally distributed across the planchet or filter. Figures 6 and 7 illustrate an evaporated liquid sample and a typical smear sample. Notice the non-uniform distribution of potential activity around the outer edges of both samples.

Detector design is critical for accurate measurements of these non-uniformly distributed samples. A comparison of the efficiency response of a single anode detector versus a dual anode detector will demonstrate the importance of detector design for unknown samples.

First, let's discuss some basic, gas proportional counter theory. All gas proportional counters operate on the principle of ionization. The process of ionization occurs when charged alpha and beta particles interact with neutral gas atoms and form ion pairs. Ion pairs consist of a free electron and a positive ion. When a sufficient electric potential is applied to the system, the Coulomb force increases causing the free electrons to migrate toward the positive charged anode wire(s) and the positive ions to migrate to the negatively charged cathode instead of recombining. The electric potential or voltage applied must be sufficiently strong enough to allow gas multiplication. Gas multiplication requires large values of electric field and is the basis for true proportionality.

Because gas multiplication is dependent upon electric field strength, weak areas of electric field within a detector will result in a dramatic efficiency loss.

Figure 6
Evaporated Liquid

Figure 7
Smear Sample

Consider the equation below:

The electric field at a radius *r* is:

$$E(r) = \frac{V}{r \ln(b/a)}$$

where:

V = Voltage applied between anode and cathode

a = Anode wire radius

b = Cathode inner radius

From this equation we can extrapolate that a *single* anode detector will experience decreased electric potential along the outer edges of the detector because as b increases, E, electric field, decreases. When electric field decreases, gas multiplication does not occur and hence the efficiency response of the detector decreases.

A study of a single anode detector versus a dual anode detector was conducted at a Canberra™ Tennelec™ facility. The results of this study prove that single anode detectors experience drastic efficiency loss around the outer edges.

A single anode detector was tested against Tennelec's dual anode detector. Figures 8 illustrates a 2.25 in. single anode detector, similar to ones provided by some vendors.

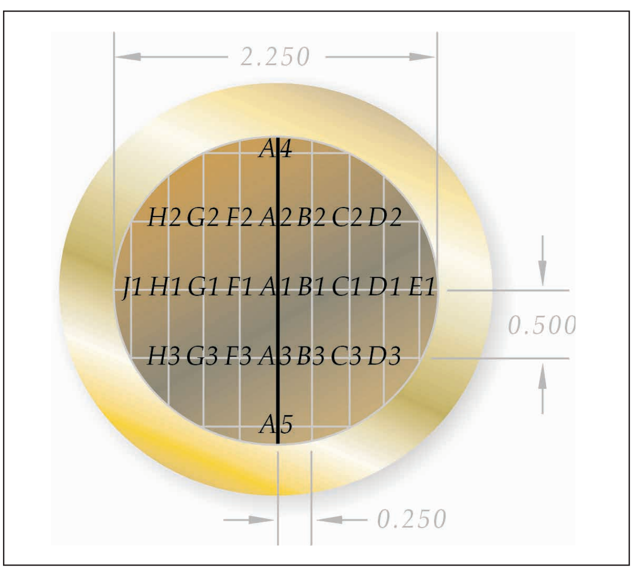

Figure 8
Single Anode Wire

The tests were performed using a collimated point source mounted to a 1 in. diameter disk. Measurements were taken with the collimated source positioned at different locations, denoted on the grid placement above.

Figure 9 illustrates the relative efficiency results for positions A1 through J1 measured with a single anode detector, Figure 8.

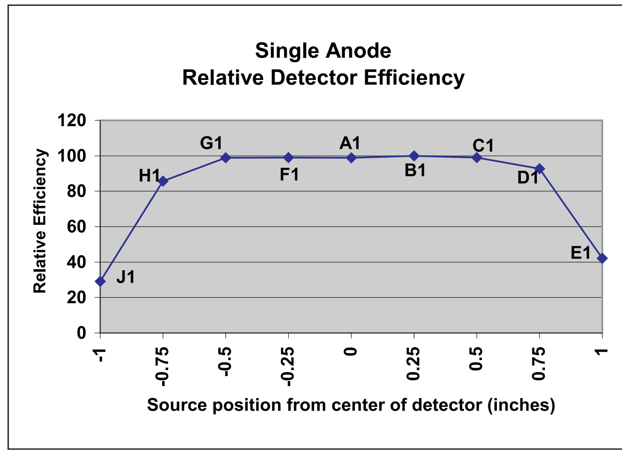

Figure 9

The data in Figure 9 shows that for positions J1 and E1 the detector experiences a 70% drop in efficiency. J1 and E1 represent positions that are approximately 1 in. from the central anode wire position, A1. For example, a sample that has activity deposited between locations H1 and J1, we can expect an efficiency response decrease of 20% to 70%.

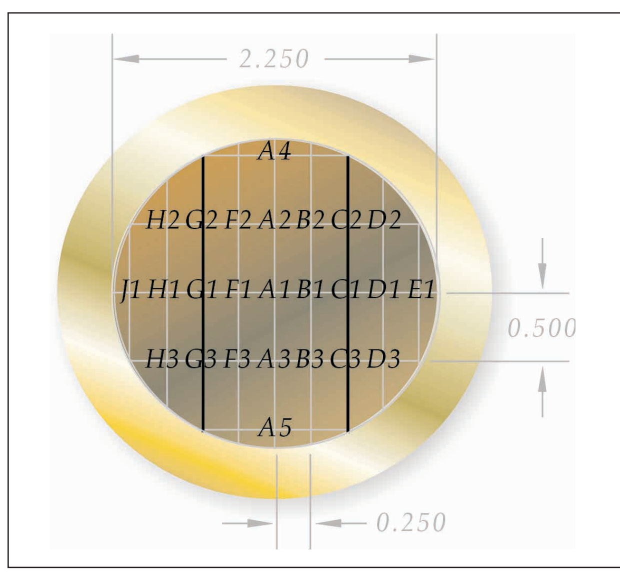

Figure 10
Dual Anode Wire

The exact same collimated source test described earlier was performed on a standard Canberra / Tennelec 2.25 in. diameter, dual anode detector, shown in Figure 10. The results of these tests, as well as the previously illustrated single anode results, are shown in Figure 11.

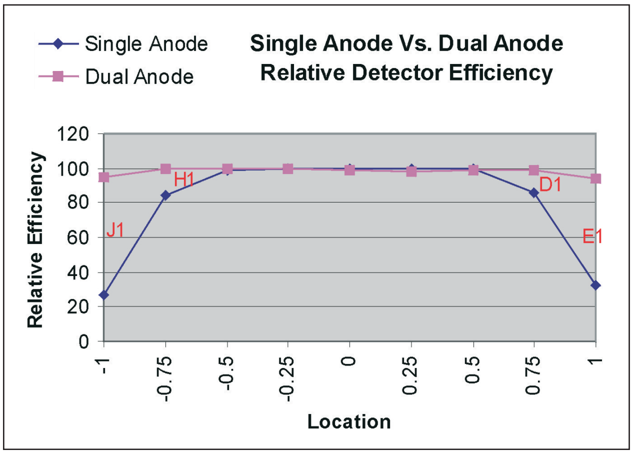

Figure 11

This figure clearly illustrates the superior performance achieved with a dual anode sample detector. While the dual anode detector is not perfect, the efficiency loss at the J1 and E1 positions is about 5% compared to the 70% loss a single anode detector exhibits.

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