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Application Note – AN0301-1

Calibrating Gross Beta Counters with Cs-137

Subtitle: Why Do I Fail My Performance Tests?

Gas flow proportional counters (GFPC) and liquid scintillation counters (LSC) are used to determine the gross alpha and beta activity of various types of samples. It must be emphasized that these instruments are used to determine gross activity, not nuclide specific activity. Before these instruments may be used they must first be calibrated using reference standards of known activity. In the United States, these standards are prepared from material that is traceable to or certified by the National Institutes of Standards and Technology (NIST). The calibration procedure determines a beta efficiency conversion factor used to convert a raw count into a reliable activity concentration.

Two popular radionuclides used for beta calibrations are Cesium 137 and Strontium 90. Most often the calibration certificates that accompany the radionuclide standard solutions or sources only state the activity of the parent radionuclide. However, the total emissions from these sources include both the parent activity and the activity from any and all daughter radionuclides present in the decay chain. Sr-90 feeds its daughter radionuclide Yttrium-90 and Cs-137 feeds its daughter meta-stable Barium 137. Failure to include these daughter emissions in the total activity of the calibration standard will result in a higher that actual efficiency factor that leads to reporting lower than actual sample activities. In the case of Sr-90 the error is 100% while in the case Cs-137 the error is approximately 10%. With Sr-90 the error is blatantly obvious.

The error associated with Cs-137 is often overlooked until results are compared with those of other laboratories that “correctly” compensate for Ba-137-IT. This compensation is accomplished by multiplying the Cs-137 specific beta activity by a factor of 1.095. At Protean Instrument, we are frequently asked for references or justifications for using this factor.

The justification is fundamental physics; the whole is equal to the sum of the parts. It is the same justification that tells us to multiply the activity of a Sr-90 source by a factor of 2.00 to include the contributions of its Y-90 daughter. The total activity emitted from a sample is a summation of the activities from all of the radionuclides present on the sample. With this obvious proposition in mind, consider samples containing either Sr-90 or Cs-137.

Other than being primarily beta emitters, Sr-90 and Cs-137 have at least one other thing in common. The half-lives of their respective daughters are very short compared to that of the parent. In these cases the activity of the daughter relative to that of the parent approaches a value that is constant with time and reaches a

point referred to as transient equilibrium. The daughters reach transient equilibrium with their respective parents for times greater than 10 half-lives of the daughter (i.e. ~26 days for Sr-90 and ~26 minutes for Cs-137).

The activity ratio between daughter and parent is expressed as:

$$\frac{A_D}{A_P} = \frac{fT\frac{1}{2}_P}{T\frac{1}{2}_P - T\frac{1}{2}_D}$$

The factor f is the fractional number of the parent decays that feed the daughter. In these cases:

Sr-90	f = 1.00	T½ = 28.6 years	Parent
Y-90		T½ = 64.1 hours	Daughter
Cs-137	f = 0.946	T½ = 30.17 years	Parent
Ba-137-IT		T½ = 2.55 minutes	Daughter

The total beta activity from a calibration source produced from one of these parent radionuclides is thus:

$$\beta_T = \beta_P + \beta_D$$

and after 10 half lives of the daughter

$$\beta_D = \beta_P * f * I_{\beta_D}$$

where I is the total intensities of the daughter's beta decays

Combining these two equations:

$$\beta_T = \beta_P * \left(1 + (f * I_{\beta_D})\right)$$

The intensity of the beta decays for Y-90 is 100% and 100% of the Sr-90 decays feed Y-90 therefore:

$$\beta_T = \beta_P * \left(1 + (1.00 * 1.00)\right)$$
$$\beta_T = \beta_P * 2.00$$

While there are no betas *per se* from Ba-137-IT, there are three conversion electrons. Proportional counters and liquid scintillation counters detect electrons. A beta particle is an electron released during sub-nuclear transitions. A conversion electron is an electron released through sub-atomic transitions. In this case, both are of sufficient energy to be detected and the detector cannot discriminate between the origins. The total of the intensities for these three conversion electrons is 10.02% therefore:

$$\beta_T = \beta_P * (1 + 0.946 * 0.1002)$$
$$\beta_T = \beta_P * 1.095$$

As stated earlier, the consequences of failing to correct for the activity of the daughter is somewhat subtle with Cs-137 and may only be exposed during inter-laboratory comparisons. Cs-137 is a popular radionuclide choice for spiking the laboratory performance test samples. It is common practice for the standard solution to be certified by its Cs-137 beta activity per gram or milliliter, and/or by the Ba-137-IT 662 keV gamma activity per gram or milliliter. The latter is determined using gamma spectroscopy.

During inter-laboratory comparisons, the tester holds the "right" answer for the gross beta activity. It is the task of the participating laboratory to match the "right" answer. If the tester follows procedures such as those described in section 703 (*Gross Alpha and Gross Beta Radioactivity)* of the ***Standard Methods For the Examination of Water and Wastewater***, he might convert the Ba-137-IT gamma rate to equivalent beta disintegration rate by multiplying the gamma emission rate by 1.29. This conversion correctly provides the total beta (electron) emission, not just the Cs-137 emissions. If a participating laboratory calibrated their beta counter using only the Cs-137 emissions and compared their results with the "right" answer, they would be low by 9.5% if all else remained the same.

Other Sources of Error

Obviously errors are not limited to instrument calibrations. Consistent sample preparation techniques are also essential. These techniques are beyond the scope of this application note but a simple reminder should be adequate to send the interested reader on a reference search. We hesitate to remind a radiochemist that Cesium salts are volatile when heated therefore sample flaming should be avoided. We hesitate yet the source of most errors are fundamentally simple once exposed.

The performance test sample may also contain a mixture of alpha and beta emitting radionuclides. There is little interference with the alpha measurement due to the presence of a beta emitter but the opposite is not true. Since all alpha emitters contain some percentage of beta or beta-like emissions, the "alpha-to-beta crosstalk" or "alpha amplification" factor becomes significant. This is especially true since the spiked alpha activity is generally higher than that normally encountered in environmental samples. Crosstalk correction reduces the total beta count by a percentage of the alpha count detected. If the calibrated crosstalk value is too high, it will erroneously reduce the reported beta activity and vice versa.

Crosstalk values are determined empirically and may vary greatly with radionuclide, mass attenuation, sample media and counting geometry (i.e., sample to detector spacing). Alpha calibration standards should match the unknown sample's parameters in all of these aspects. Electroplated standards are not good choices for the radiochemistry laboratory as they will likely have higher alpha efficiency and crosstalk than encountered with self-prepared standards. At least part of this is due to the low mass attenuation and high beta backscatter associated with electroplated sources.

After Thoughts

Considering laboratory performance tests, it is reasonable to expect uniform results when instruments are calibrated in a uniform fashion. It would help if those who conducted laboratory comparison tests revealed their method of instrument calibration or at least the way they went about determining the "right" answer.

Arguably, there is a right way and a wrong way to calibrate gross alpha/beta counters. Sometimes good science takes a back seat to misguided conformity. When calibrating a gross alpha/beta counter, good science dictates that you account for all activity in the calibration source as is the aim of this application note. Good performance in an inter-laboratory comparison dictates that you make or avoid the same mistakes as the one holding the "right" answers. Hopefully the two are not incompatible.

References:

1. David C. Kocher, *Radioactive Decay Data Tables - A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments*, US Department of Energy, 1981, NTIS.
2. 703 Gross Alpha and Gross Beta Radioactivity, *Standard Methods For the Examination of Water and Wastewater*, APHA-AWWA-WPCF, 16th Edition 1985, American Public Health Association.
3. Cesium – Counting, *Users' Guides for Radioactivity Standards*, National Academy of Sciences – National Research Council, February 1974, NTIS