Background correction and dependency on quench.

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Introduction

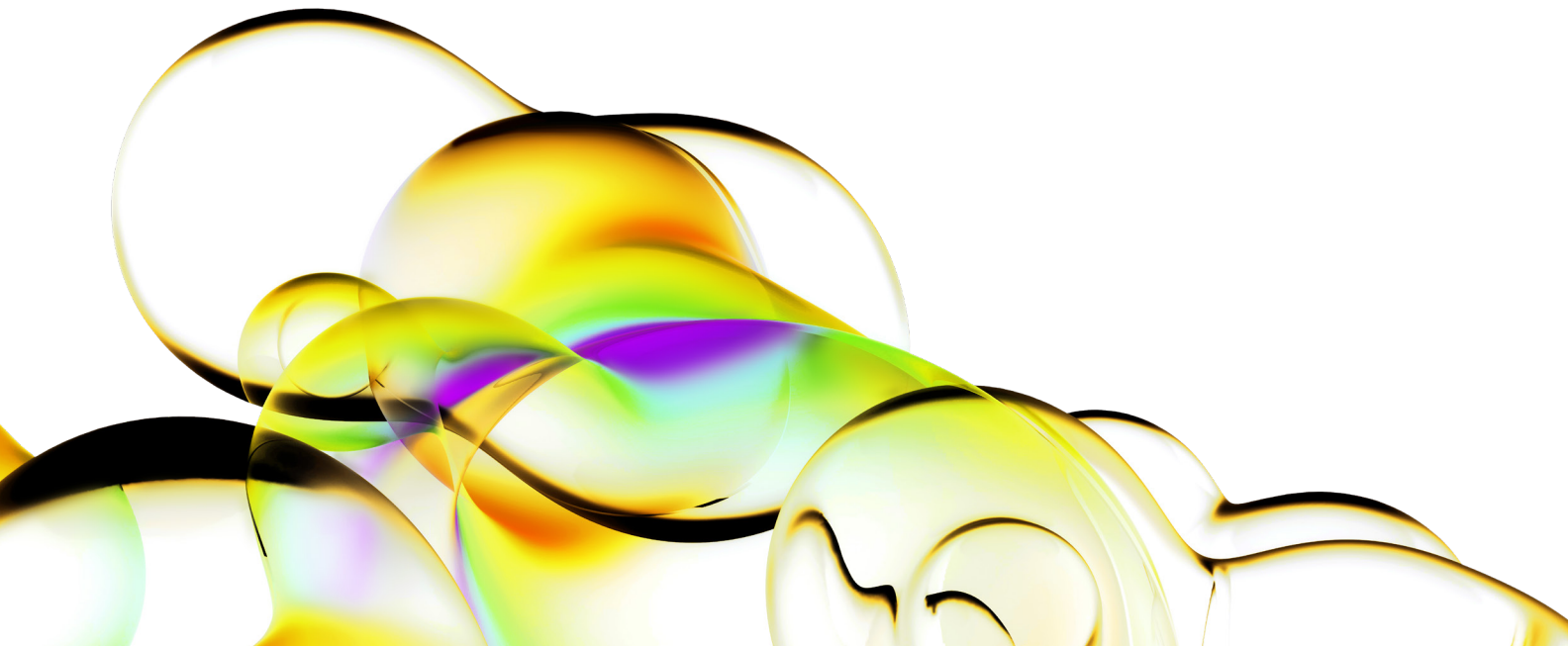
In case you do scintillation measurements with a significant contribution from the background you have to perform a background correction in order to get accurate results. Very often this has to be done for environmental samples or when measuring natural radioactivity.

Now the question arises how to prepare a suitable background sample. For the analysis of water samples very often so called “dead water“ is used. This is a water sample with very low background count rate. But independent on the project the background sample should show the same composition as the sample of interest only radioactivity should be missing. However, the preparation of such a sample can be a challenge in some cases.

A typical example is the measurement of biogenic samples. It is not always possible to get an identical fossil sample for a biogenic sample, especially, if the biogenic sample is a mixture of several substances.

In many cases it is necessary to find a fossil background sample which comes close to the biogenic sample. When preparing the background sample, the following topics have to be taken into account:

1. Volume of the sample
2. Volume of the cocktail
3. Sample vial material
4. Quench of the background sample



It is long known that the background is increasing with the sample volume.[1] A larger volume of the sample increases the probability of an interaction with external radiation. In addition, the cocktail to sample ratio is decisive. A larger amount of cocktail, increasing the amount of solvent, increases the probability for the first scintillation step which is the energy transfer from the ionizing particle to the solvent. Another important topic is the material of the vial in use. Glass vials contain significant amounts of ^{40}K and other radionuclides resulting in significantly higher background as displayed in Table 1.

Table 1: Background in HDPE and glass vials

LLCM	Vial	% Efficiency (0-18.6keV)	Background (0-18.6keV)	% Efficiency (Opt. region)	Background (Opt. region)
Off	Glass	25.9	19.5cpm	18.9	4.1cpm
On	Glass	22.6	6.8cpm	19.3	2.5cpm
Off	Plastic	26.9	12.4cpm	21.8	2.5cpm
On	Plastic	23.0	6.0cpm	19.3	1.8cpm

For an accurate background correction, it is interesting to have a close look to the background. First, the background was determined in a completely empty glass vial followed by a measurement using the same vial filled with cocktail. The resulting background spectra are displayed in figure 1.

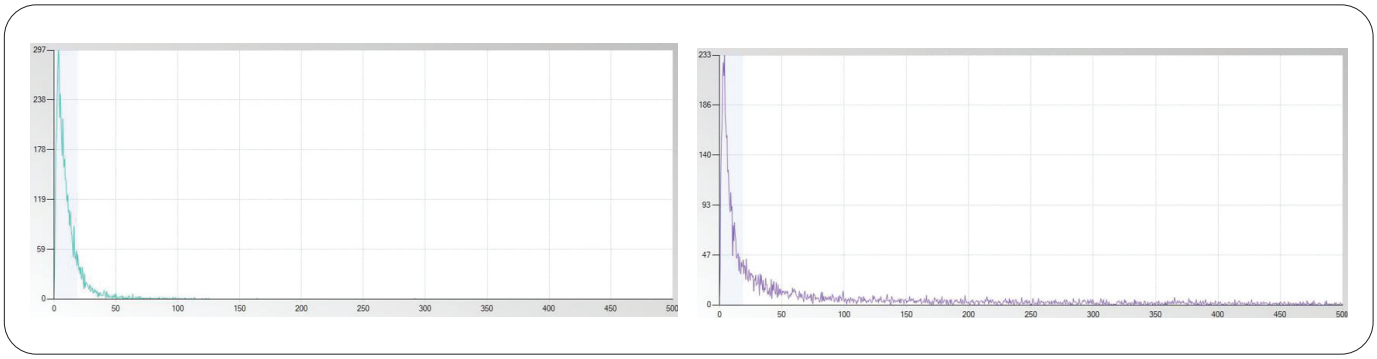


Figure 1: Spectrum of an empty vial (left) and spectrum with cocktail (right)

In the left energy distribution background is mainly visible in the low energy range between 0-50 KeV. The measured number of total counts with a Tri-Carb™ 4910 was 6079 in a measurement time of 300 minutes using glass vials in the open window from 0-2000 KeV.

These background signals are produced by electronic noise and Cerenkov events detected by the photomultiplier tubes (PMT´s) due to crosstalk between both PMT´s. This background originating from sources outside the cocktail is also called non-quenchable background.

In addition, we can see background due to higher energy interactions with the cocktail, such as cosmic radiation. This results in real scintillation events in the cocktail. This background is also called quenchable background and overlays the non-quenchable background.

The total background consisting of both, quenchable and non-quenchable background is displayed in the right energy distribution. It is obvious that the quenchable background is also visible in the higher energy range of the counting window. The number of total counts in the right energy distribution increased to 9723 under otherwise constant conditions. From this follows that approximately 1/3 of the total background is so-called quenchable background.

Knowing this it becomes obvious that the quench of the used background sample should be identical or at least as close as possible to the quench of the sample to be measured.

It is difficult to estimate the influence of quench on the background because this is very dependent on the used energy windows as shown in Table 2.

Table 2: Distribution of background in different energy windows[2]

Energy window (KeV)			Quench (tSIE)
Total counts 0-18.6	Total counts 0-156	Total counts 0-2000	
3676	6221	9723	714
4708	7429	9610	78

The upper measurement displayed in Table 2 was done in a glass scintillation vial with 20 ml of cocktail. The second sample was identical but 200µl of nitromethane were added. Therefore, the quench in the latter sample is much stronger. As can be seen from Table 2, this reduces the background in the completely open window from 0-2000 KeV but increases the background in the window for the Tritium and ^{14}C measurement. For a more detailed investigation of the effect, some background samples with different quench were produced and then measured in the Quantulus™ GCT in normal count mode as shown in Table 3. All samples were measured in HDPE vials with 5 ml octane and 16 ml Ultima Gold F. The amount of nitromethane indicated in Table 3 was added to the samples.

Table 3: Background measured in the window 0-156 KeV

Volume Nitromethane [µl]	CPMA	tSIE
0	4.66	749.3
5	4.64	596.4
15	5.04	417.1
35	5.26	232.7
55	5.67	140.0
75	5.61	113.7
100	5.72	83.0
150	5.67	49.8

All background samples were measured for 300 minutes to obtain reasonable statistics. It is noticeable that there is no linear relationship between quench and background. With a low quench up to tSIE value of 600 the background is quite stable at approx. 4.65 CPM, in the range from tSIE 600 to tSIE 150 the background then rises to approx. 5.67 CPM and then remains at this level, at least up to a tSIE value of approx. 50, which corresponds to a very strong quench.

Table 4: Background measured in the window 0-18 KeV

Volume Nitromethane [µl]	CPMA	tSIE
0	2.75	749.3
5	2.56	596.4
15	2.82	417.1
35	2.91	232.7
55	3.02	140.0
75	3.07	113.7
100	3.24	83.0
150	3.40	49.8

The situation looks a little different in the ^{3}H window. Essentially, there seems to be a continuous increase in the background with stronger quench and at a tSIE of approx. 50, the highest background of 3.4 CPM is determined in the observed tSIE range. If, on the other hand, an optimized energy window is used for ^{3}H, as is typical, for example, in water analysis, then hardly any noticeable change in the background outside of the normal statistical fluctuation can be determined, as shown in Table 5.

Table 5: Background measured in the window 0-4,5 KeV

Volume Nitromethan [µl]	CPMA	tSIE
0	1.03	749.3
5	0.92	596.4
15	1.01	417.1
35	1.04	232.7
55	1.02	140.0
75	1.08	113.7
100	1.08	83.0
150	1.15	49.8

A slight increase in the background appears likely in this energy window only in the case of a very strong quench.

While the background rises with increasing quench in the open ^{3}H and ^{14}C energy window, this looks different in the completely open window from 0 to 2000 KeV. Here the background drops significantly.

Table 6: Background samples measured in the energy window from 0 to 2000 KeV

Volume Nitromethane [µl]	CPMA	tSIE
0	8.88	749.3
5	8.29	596.4
15	8.34	417.1
35	7.83	232.7
55	7.57	140.0
75	7.24	113.7
100	6.99	83.0
150	6.68	49.8

It appears as if part of the quenchable background falls below the coincidence threshold in the event of a stronger quench and is therefore lost to detection. This reduces the background in the completely open window. In the ^{3}H and ^{14}C energy windows, on the other hand, the background rises because a significant part of the quenchable background is shifted into the ^{3}H and ^{14}C window because of stronger quenching.

Conclusion

Sample volumes and ratios of sample to cocktail, the type of sample vial and the quench can have a strong influence on the background. If an identical non-radioactive sample is not available, another sample with similar properties can be used. This should either show a comparable tSIE value or have a lower quench, i.e. a higher tSIE value than the sample to be measured. In the latter case, the tSIE value can be adjusted to the tSIE value of the sample to be measured by adding nitromethane. With background samples created in this way, an exact background correction of the sample should be possible.

Literature

1. R. H. W. Edler; An Introduction to the Scintillation Technology for the Measurement of Radionuclides, 1st Edition, Bremen 2020, ISBN 978-3-00-020422-7.

[2]Copied with kind permission from R. H. W. Edler; Eine Einführung in die Szintillationstechnik zur Messung von Radionukliden, 1st Edition, Bremen 2020, ISBN 978-3-00-020422-7