

Protocol optimization for ^3H , ^{14}C and $^3\text{H}/^{14}\text{C}$ dual label applications using a Quantulus GCT.

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Introduction

The Quantulus™ GCT 6220 is one of the most sensitive liquid scintillation counters on the market. But as with all analysis, especially when it comes to keeping the detection limit to a minimum, the effort to achieve this goal increases with the lowering of the detection limit. In the following, a few samples, which were measured as part of a tender requirement, are used to explain how optimal results can be obtained with the Quantulus GCT 6220.

The GCT method (Guard Compensation Technology) is based on a very precise determination of the energy-dependent background. Since this depends on the quench, the volume, the cocktail etc., it is very important that the background sample largely corresponds to the unknown samples, but without radioactivity. The details of GCT technology will not be discussed here, but if you are interested, application note 49 can be read for more details.¹⁾ A total of seven radioactive samples were measured. These samples contained 9 ml aqueous sample and 12 ml scintillation cocktail Optiphase HiSafe 3, only sample seven contained 12 ml Ultima Gold LLT. Five of these samples showed approximately the same quench and had a tSIE value between 230 and 240, whereas one sample showed a tSIE value of only 140.

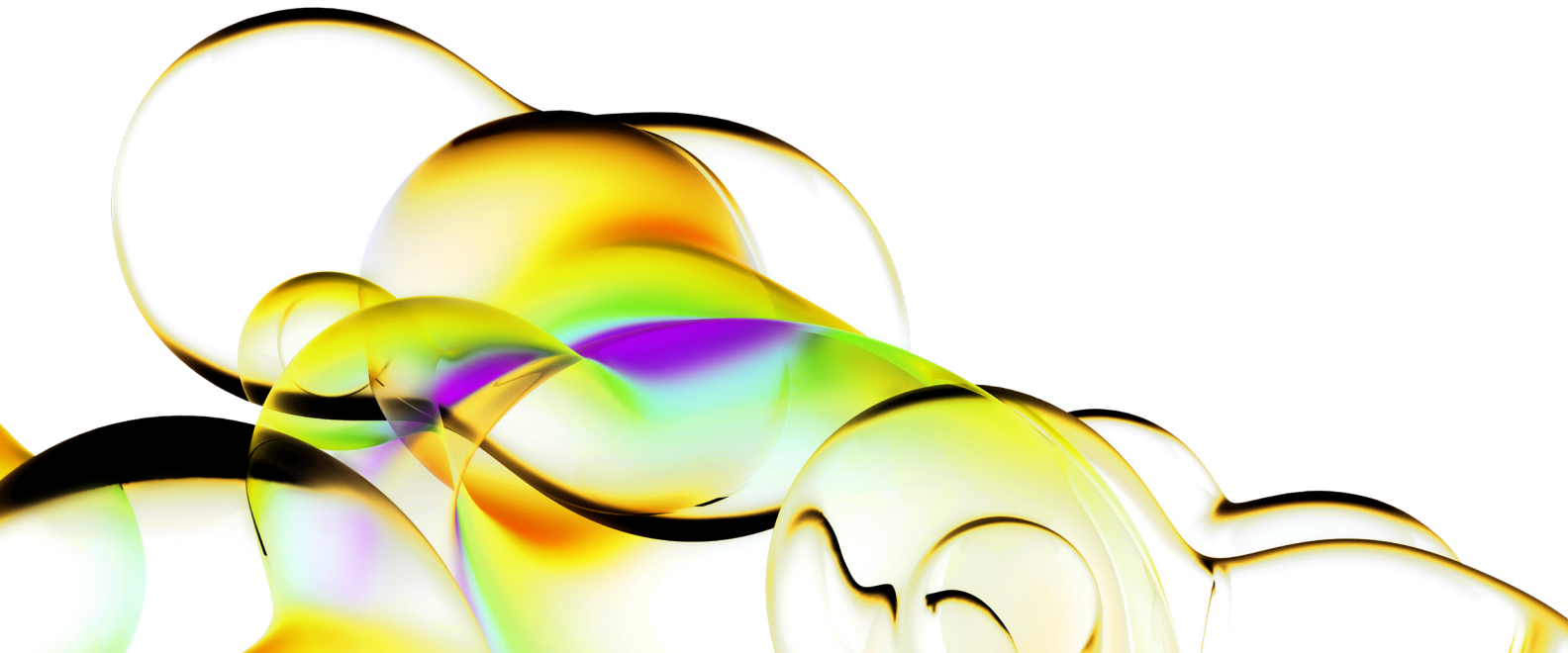


Table 1: Unknown Samples and Standard

No.	Sample	tSIE-Value
1	^3H (L)	229.0
2	^3H (H)	240.8
3	^{14}C (L)	230.1
4	^{14}C (H)	241.5
5	$^3\text{H}/^{14}\text{C}$	238.2
6	^{14}C quench	140.7
7	^{14}C Standard	279.3
8	BKG 1	242.0
9	BKG 2	161.4

As it was an invitation to a tender, the activities of the samples were unknown. It was only known that the samples marked with (L) contained low activities <1 Bq, while the samples marked with (H) should contain higher activities. Nothing was known about the dual-label sample. In addition to the six radioactive samples, two background samples No. 8 and 9 were also included. The tSIE of background sample 8 corresponded approximately to samples 1 to 5 and 7, but not to sample 6. For this reason, after measuring samples 1 – 5 and 7, background sample No. 8 was quenched with nitromethane to a lower the tSIE value to obtain a suitable background sample for the quenched ^{14}C sample.

Table 1 contains the measurement that was carried out first. Since a Tri-Carb™ 4910 is also available in our laboratory, all samples were measured with a 1-minute measurement time using an external standard. The external standard was measured up to a statistical accuracy of 0.5% in the 2σ -confidence range. This is considerably faster in the Tri-Carb (only a few seconds per sample) than in the Quantulus GCT, since the Quantulus only contains 1/20 of the activity of the ^{133}Ba source of the Tri-Carb.

After all samples had been measured and the tSIE values of all samples were known, it was obvious that a background sample with a tSIE value closer to 140 had to be prepared for the quenched ^{14}C sample. Excellent background correction, especially for low activity samples, requires that the quench of the blank be approximately the same as in the unknown samples. A significant proportion of the background is the so-called quenchable background,

which fluctuates depending on the quench. It can be caused by the direct interaction of background radiation with the cocktail. The radiation can be caused by ambient radiation, cosmic radiation, or radioactivity in the sample or in the vial.

Performing optimization runs

First, an SNC run was carried out so that the instrument was properly calibrated. It was ensured that the instrument had been at a temperature of 15°C for at least 6 hours. After that the sample "BKG 1" was measured in an optimization run. Here the energy-dependent counting efficiency of the guard detector and so-called strength factors are determined.¹⁾ The Quantulus GCT instruments are delivered with a pre-installed protocol "Optimize_GCT_Strength-Factors.lsa".

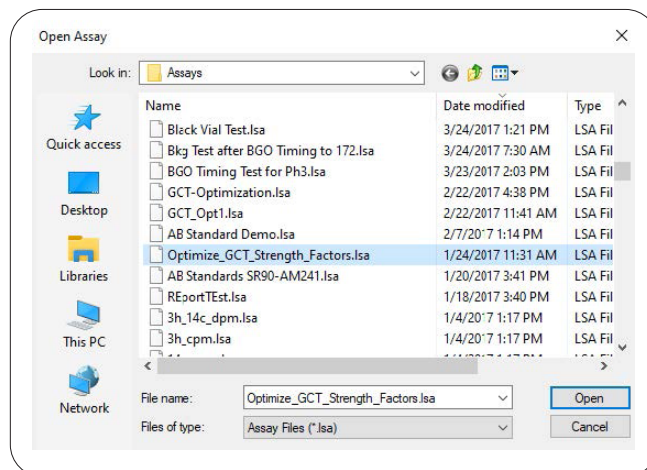


Figure 1: Opening the Optimization Protocol

This file was opened and saved with a new name using the "Save as" command. Only a few changes should be made to this newly created file, but not to the report. The preset measuring time of 240 minutes must not be reduced in any case, but it can be increased. In my experiments I used 360 minutes for better counting statistics. In addition, a new name for the optimization to be created must be specified in the "Assay Definition" window of the protocol in the "Special Files" tab.

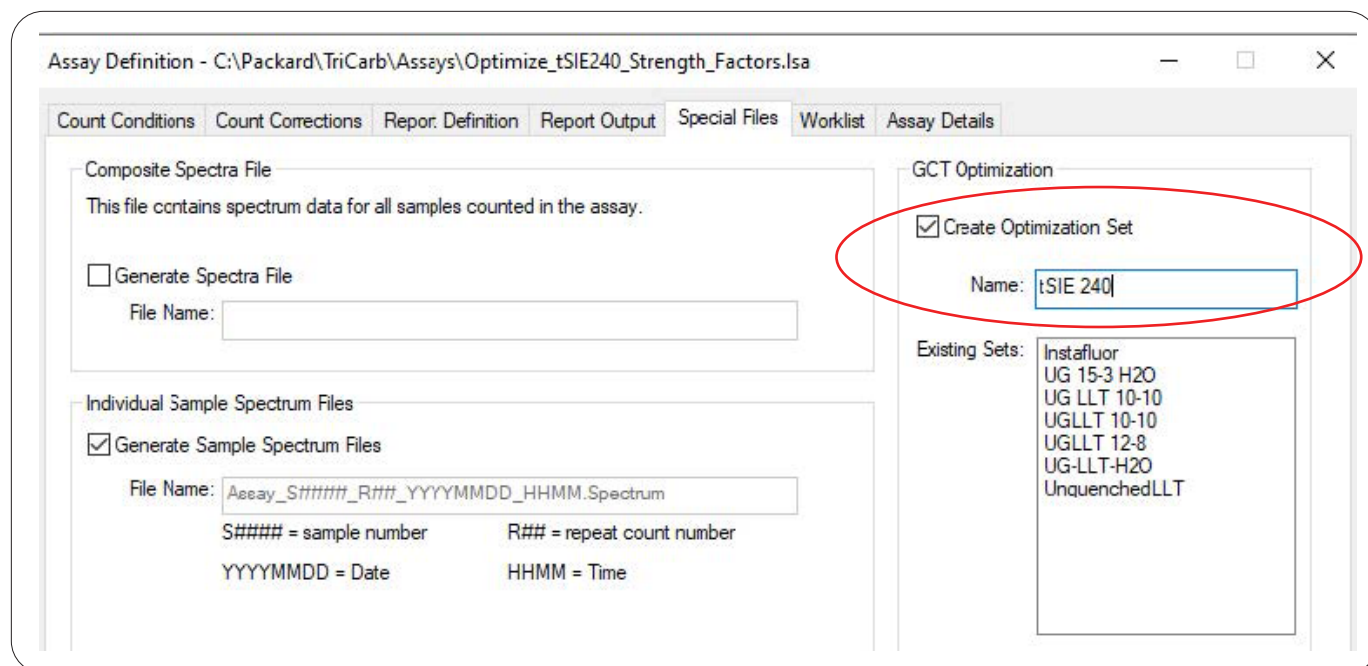


Figure 2: Saving a new „Optimization Set“ under a new name

The background sample "BKG 1" was measured for 360 minutes using the optimization protocol created in this way. After the measurement, a subdirectory is automatically created in the directory "C:\Packard\TriCarb\Libraries\GCT_Libraries" with the name you entered. After the measurement, this subdirectory contains two spectra recorded by the guard detector and the measurement chamber as well as two files with the strength factors and the energy-dependent counting efficiencies of the guard detector.

Preparation of sample protocols

A total of four DPM protocols were created. A single label DPM protocol for the ^3H , ^{14}C and ^{14}C quench samples and a dual label DPM protocol for the $^3\text{H}/^{14}\text{C}$ sample. All samples were measured in triplicates with a measuring

time of 100 minutes. All nuclides were measured in the open window, i.e. from 0-18.6 KeV for ^3H , from 0-156 KeV for ^{14}C and ^{14}C quench as well as with corresponding windows in the dual label protocol (0-18.6 and 18.6-156 KeV). The tSIE was used as the quench parameter for ^3H , ^{14}C and ^{14}C quench, but the tSIE/AEC was preferred for the Dual Label sample $^3\text{H}/^{14}\text{C}$. For details of the quench correction and use of quench parameters, please refer to the literature.²⁾ For dual label samples, the use of tSIE/AEC is strongly recommended, since an automatic window adjustment depending on the quench is then carried out. In the case of stronger quench, this prevents increasing spill down of ^{14}C counts into the low energy ^3H channel. It was also ensured that none of the quench curves used were older than 6 months. For all measurements, the storage of individual sample spectra was activated in the "Special Files" tab in the Assay Definition window.

Assay Definition -

Count Conditions | Count Corrections | Report Definition | Report Output | **Special Files** | Workist | Assay Details

Composite Spectra File
This file contains spectrum data for all samples counted in the assay.

☐ Generate Spectra File
File Name:

Individual Sample Spectrum Files
☒ Generate Sample Spectrum Files
File Name:

S#### = sample number R## = repeat count number
YYYYMMDD = Date HHMM = Time

Figure 3: Saving individual Sample Spectra

The availability of sample spectra, including the spectra of the background samples, is essential for determining the optimal energy window. All current Tri-Carb and Quantulus instruments are delivered including the SpectraWorks² software. With the help of this software, individual spectra of samples can be read. With just a few clicks of the mouse, the optimal energy window can then be determined using the background spectrum and a sample spectrum. Since all samples in these measurements were made in triplicate, the mean energy distributions were determined before calculating the optimized window to obtain even better statistics. This averaging is possible in the SpectraWorks² software in the "Calculate" main menu with the sub-item "Sum Spectra". With the help of the "Optimize Region" sub-item, the optimal energy window can then be determined using the average sample and background spectra. This optimization is based on the determination of the maximum "Figure of Merit" value (E^2/B).³⁾

For further details of the other options of the SpectraWorks² software, please refer to application note as stated in Literature #3. Table 2 shows the optimized energy windows determined for the measured samples using the SpectraWorks² software.

Table 2: Optimized Energy Windows

Sample	tSIE	Energy window
^3H (L)	229.0	0.0-4.5 KeV
^3H (H)	240.8	0.0-4.5 KeV
^{14}C (L)	230.1	3.5-40 KeV
^{14}C (H)	241.5	3.5-40 KeV
$^3\text{H}/^{14}\text{C}$	238.2	AEC
^{14}C quench	140.7	1.5-22 KeV

All samples contained 9 ml aqueous sample and 12 ml cocktail. Such mixtures are common when high sensitivity is required since the volume is included in the calculation of the detection limit in a linear manner. Special cocktails with a very high uptake capacity are required to achieve such high sample-holding capacities. For more details about cocktails please read application note as stated in Literature #4. In addition to the cocktail used here, Ultima Gold LLT is also ideally suited for this type of application.

1. The ^3H Measurement

The energy windows shown in Table 2 are significantly smaller than the open energy windows. However, these are typical windows when working with such large sample volumes in aqueous solution and the resulting medium to strong quench in the samples. The evaluations were carried out for the open energy window, the optimized energy window and the optimized energy window using the Guard Compensation Technology (GCT) with the setting GCT = High. GCT = High is usually a good setting for low-energy nuclides in the ^3H window and can therefore also be used for ^{55}Fe , ^{241}Pu and Cherenkov measurements, for example. Table 3 shows the counting rates obtained in the different energy windows. All measurements were only carried out in the so-called Normal Count Mode (NCM), the Super Low Level Count Mode (SLLCM) was not used. In the SLLCM, the background count rates are between those of the NCM and those of the NCM with GCT.

Table 3: ^3H Background Count Rates

^3H Background Count Rates		
0-18.6 KeV (NCM)	0-4.5 KeV (NCM)	0-4.5 KeV with GCT
3.09	0.97	0.21
3.25	1.15	0.34
3.58	1.12	0.35
3.31	1.08	0.30

The evaluation of all data was carried out with the help of the "Replay" option. Here, the original raw data can be opened in the form of the result files and re-evaluated in new energy windows, with new quench curves, etc.

Table 4: Activity of the Sample ^3H (H)

	^3H (H) 0-18.6 KeV	^3H (H) 0-4.5 KeV	^3H (H) 0-4.5 KeV with GCT
CPM	1579.16	1422.77	1421.76
CPM	1577.89	1420.76	1419.76
CPM	1579.00	1421.88	1420.86
Average	1578.68	1421.80	1420.79
Net CPM	1575.38	1420.72	1420.49
Counting Efficiency	22.98%	20.84%	20.84%
E^2/B	159.7	402.1	1447.7
DPM	6855.4	6817.3	6816.2
Bq	114.3	113.6	113.6

Table 5: Activity of the Sample ^3H (L)

	^3H (L) 0-18.6 KeV	^3H (L) 0-4.5 KeV	^3H (L) 0-4.5 KeV with GCT
CPM	4.97	2.72	1.85
CPM	4.90	2.64	1.75
CPM	5.14	2.64	1.78
Average	5.00	2.67	1.79
Net CPM	1.70	1.59	1.49
Counting Efficiency	21.92%	20.12%	20.12%
E^2/B	145.3	374.8	1349.4
DPM	7.74	7.89	7.42
Bq	0.13	0.13	0.12

Tables 4 and 5 show the counting efficiencies obtained using quench curves and the activities of the samples ^3H (H) and ^3H (L) determined from them, as well as the Figure of Merit, obtained from the squared counting efficiency divided by the background (E^2/B). The detection limits were calculated according to ISO 11929 for these measurements with a total measuring time of 300 minutes, and $k_1 - \alpha = k_1 - \beta = 1.645$ for 9 ml sample volume as shown in Table 6.

Table 6: ^3H Detection Limits

Sample	0-18.6 KeV	0-4.5 KeV	0-4.5 KeV with GCT
^3H (H)	4.0 Bq/L	2.6 Bq/L	1.4 Bq/L
^3H (L)	4.2 Bq/L	2.7 Bq/L	1.5 Bq/L

With a measurement time of 600 minutes, detection limits of 1 Bq/L for ^3H can be achieved with these samples. The somewhat poorer detection limit for ^3H in the sample with low activity is due to the slightly stronger quench in this sample as indicated in Table 1. This results in a somewhat lower counting efficiency and thus a slightly poorer detection limit. The very good agreement of the activity in the open and optimized window is impressive, although in the optimized window the counting statistics are worse due to the low count rate.

Table 8: Activity of the Sample ^{14}C (H)

	^{14}C (H) 0-156 KeV	^{14}C (H) 3.5-40 KeV	^{14}C (H) 3.5-40 KeV with GCT
CPM	11740.75	10754.45	10750.21
CPM	11737.46	10762.75	10758.56
CPM	11735.23	10755.87	10751.69
Average	11737.81	10757.69	10753.49
Net CPM	11731.75	10754.01	10752.74
Counting Efficiency	88.17%	79.46%	79.45%
E^2/B	1282.1	1717.3	8491.9
DPM	13305.8	13533.9	13534.0
Bq	221.8	225.6	225.6

2. The ^{14}C Measurement

Here too, the different windows were used analogously to the ^3H measurement to make the effect of the optimization clear. Table 7 shows the background count rates in the different windows.

Table 7: ^{14}C Background Count Rates

^{14}C Background Count Rates		
0-156 KeV (NCM)	3.5-40 KeV (NCM)	3.5-40 KeV with GCT
5.82	3.59	0.60
5.85	3.49	0.58
6.52	3.95	1.05
6.06	3.68	0.74

As already described above, the different evaluations were carried out again with the Replay function in the QuantaSmart software. Although the setting GCT = Low often delivers better results for ^{14}C , very good results could be obtained in this case with GCT = High, since a large part of the ^{14}C energy distribution is already in the ^3H window which typically results in better performance using the GCT = High setting. Tables 8 and 9 contain the activities determined for ^{14}C (H) and ^{14}C (L).

Table 9: Activity of the Sample ^{14}C (L)

	^{14}C (L) 0-156 KeV	^{14}C (L) 3.5-40 KeV	^{14}C (L) 3.5-40 KeV with GCT
CPM	9.09	6.24	3.23
CPM	8.46	5.84	2.77
CPM	8.62	6.26	3.24
Average	8.72	6.11	3.08
Net CPM	2.66	2.44	2.34
Counting Efficiency	87.76%	79.24%	79.23%
E^2/B	1270.2	1707.8	8444.9
DPM	3.03	3.08	2.95
Bq	0.05	0.05	0.05

The detection limits according to ISO 11929 result from these measurements with a total measuring time of 300 minutes, and $k_1 - \alpha = k_1 - \beta = 1.645$ for 9 ml sample volume as shown in Table 10.

Table 10: ^{14}C Detection Limits

Sample	0-156 KeV	3.5-40 KeV	3.5-40 KeV mit GCT
^{14}C (H)	1.4 Bq/L	1.2 Bq/L	0.6 Bq/L
^{14}C (L)	1.4 Bq/L	1.2 Bq/L	0.6 Bq/L

Also, in the ^{14}C measurement, the sample with less activity had the stronger quench, but since the counting efficiency of ^{14}C decreases somewhat less and, above all, the relative difference is significantly smaller, there are no significant differences in the detection limit.

3. Measurement of the ^{14}C Sample with higher quench

Since the quenched ^{14}C sample showed a significantly stronger quench, an additional optimization run was carried out for this sample with a background sample with comparable quench, as described above. Afterwards, this sample was again measured together with the unknown sample in the open window. With the help of the stored spectra, the optimal window in the range of 1.5-22 KeV was again determined with the SpectraWorks² software, as indicated in Table 2.

Since this already corresponds almost to the open ^3H window, the setting GCT = High was selected again for GCT. The background count rates found in the open and optimized windows were consistently lower for the more quenched sample than for the measurements shown in Table 7.

Table 11: Background Count Rate of the quenched ^{14}C Sample

^{14}C Background Count Rate		
0-156 KeV	1.5-22 KeV	1.5-22 KeV with GCT
5.67	3.12	0.23
6.45	3.31	0.50
5.83	3.24	0.33
5.98	3.22	0.35

Only one sample of unknown activity was available for the quenched ^{14}C sample. Table 12 shows the activities determined. The optimizations carried out so far have been limited to the optimization of the energy window and the use of GCT technology to be able to carry out an energy-dependent background correction. There is also the option of using the Pulse Amplitude Comparison (PAC) to reduce the background even further.

Table 12: Activity of the quenched ^{14}C Sample (tSIE = 140.7)

	^{14}C 0-156 KeV	^{14}C 1.5-22 KeV	^{14}C 1.5-22 KeV with GCT
CPM	16424.11	15339.25	15335.67
CPM	16432.07	15340.64	15337.04
CPM	16427.80	15334.44	15330.88
Average	16427.99	15338.11	15334.53
Net CPM	16422.01	15334.89	15334.18
Counting Efficiency	82.16%	77.01%	77.01%
E^2/B	1128.2	1839.9	16784.5
DPM	19987.8	19912.9	19911.9
Bq	333.1	331.9	331.9

PAC

PAC should not be explained in detail here; reference is also made to application note as stated in Literature #5. However, this method is based on the comparison of the counting events measured on the two PMTs. If enough photons are generated per decay, the same number of photons should be detected on average at both PMTs. In the case of crosstalk between PMTs, however, the number of photons at the photomultiplier at which the signal is generated is higher. The crosstalk photons can be generated by interaction with external radiation or by activity in the glass of the PMTs. By comparing the two signals from the two PMTs, such signals with a ratio of the number of photons clearly different from 1 can be discriminated as the background. PAC can therefore lead to a significant improvement in sensitivity to higher-energy nuclides with enough photons. For ^3H , this method is only of limited use, since the number of photons generated can be small. Color quench must also not be present in the sample, since color in the sample also leads to an asymmetrical number of photons on the individual PMTs and in a colored sample a large portion of the actual decay events would be discriminated as background.

PAC can show significant effects, but also requires the recording of a corresponding optimization measurement and the recording of a new quench curve or a new measurement of standards for each selected PAC value because efficiencies are not only quench depending but also significantly depending on the PAC value.

4. Measurement of a ^{14}C Standard with PAC = 150

For this measurement, the background sample BKG1 was measured again in an optimization run with a measuring time of 360 minutes but with the PAC value 150. This parameter can be set again in the "Assay Definition" window when a new protocol is created or edited. It is on the "Count Corrections" tab.

With the setting PAC = 150, background measurements have now been carried out. The choice of the value 150 was determined by measurement with PAC values between 140 and 200 giving the best result with a value of 150. The optimal value can only be determined by carrying out measurements and calculating the resulting E^2/B values.

Figure 4: Setting of the PAC-Value on the „Count Corrections“ Tab.

The background values obtained with these settings are given in Table 13. The activities determined are shown in Table 14. Since the counting efficiencies in glass and plastic vials can be significantly different when using PAC, commercial quench curves measured in glass vials are often not very suitable for correct activities when using plastic vials. With constant quench, it is often easier to measure a vial with a standard of known activity under the same conditions. Only plastic vials were used in the measurements. 15.9 mg of a ^{14}C standard with an activity of 498000 DPM/g were weighed in, corresponding to an activity of 7918.2 DPM or 132 Bq.

The samples were measured in the same volume of 9 ml water and 12 ml Ultima Gold LLT because Optiphase HiSafe 3 was not available in our laboratory.

Table 13: ^{14}C Background Count Rates at PAC = 150

^{14}C Background Count Rates at PAC = 150		
0-156 KeV	1.5-22 KeV	1.5-22 KeV mit GCT
4.00	1.19	0.17
3.78	1.36	0.26
3.48	1.08	0.08
3.75	1.21	0.17

Table 14: Data of the ^{14}C Standard measured with PAC = 150

	^{14}C 0-156 KeV	^{14}C 6.5-41 KeV	^{14}C (H) 6.5-41 KeV with GCT
CPM	6221.44	4893.90	4892.42
CPM	6212.41	4878.67	4877.14
CPM	6251.52	4910.30	4908.77
Average	6228.46	4894.29	4892.78
Net CPM	6224.70	4893.08	4892.61
Counting Efficiency	78.61%	61.80%	61.79%
E ² /B	1646	3156	22459
DPM	7918.5	7917.6	7918.1
Bq	132.0	132.0	132.0

As can be seen from Table 1, a ^{14}C sample in the same water/cocktail ratio in Ultima Gold LLT shows a higher tSIE value than the Optiphase HiSafe 3 cocktail. This can lead to slightly higher counting efficiencies when measuring ^{14}C in Ultima Gold LLT but can have greater effects when measuring ^3H .

Table 15: ^{14}C Detection Limits with PAC = 150

Sample	0-156 KeV	3.5-40 KeV	3.5-40 KeV mit GCT
^{14}C (H)	1.4 Bq/L	1.2 Bq/L	0.6 Bq/L
^{14}C (L)	1.4 Bq/L	1.2 Bq/L	0.6 Bq/L

5. Measurement of a Dual Label $^3\text{H}/^{14}\text{C}$ Sample

The tSIE/AEC was used as the quench parameter for this sample. Based on the quench curves, the measurement window is adapted to the quench in the sample. This procedure always leads to a small ^3H counting efficiency even in the higher energy ^{14}C window, so it must be corrected spill down from ^{14}C into the ^3H window but also spill up of small amounts of ^3H into the ^{14}C window. Internally, 4 quench curves are therefore required for the corrections. For details of this procedure, however, reference is made to the literature.²⁾ The crucial point should be mentioned here. This is the fact that the spill down of ^{14}C is kept low and constant over almost the entire quench range. In most cases, the counting efficiency of ^{14}C in the ^3H window is only approx. 20% or less. If, on the other hand, the preset windows of 0-18.6 KeV and 18.6-156 KeV are used, the counting efficiency of ^{14}C in the ^3H window can increase to 80%. So almost all the ^{14}C is in the ^3H window. The ^{14}C contribution must be considered as a background for the ^3H measurement and may therefore significantly degrade the detection limit of ^3H , especially if ^{14}C is contained in the sample in excess. For this reason, the use of the tSIE/AEC is strongly recommended for all dual and triple label applications. The energy windows used by the QuantaSmart software are not printed out because they can be slightly different for each measurement. However, it is possible to display the windows during the live measurement in the Spectraview window with the "Apply AEC" button.

Table 16: $^3\text{H}/^{14}\text{C}$ Background Count Rates

$^3\text{H}/^{14}\text{C}$ Background Count Rates		
Measurement window	BKG1 with tSIE/AEC	BKG1 with tSIE/AEC and GCT
CPMA	1.26	0.27
CPMA	1.29	0.29
CPMA	1.27	0.24
Average CPMA	1.27	0.27
CPMB	3.31	0.51
CPMB	3.00	0.31
CPMB	3.05	0.39
Average CPMB	3.12	0.40

During the $^3\text{H}/^{14}\text{C}$ measurements, the energy window was set with tSIE/AEC with the existing quench to 0-4.5 for ^3H and 4.5-45 for ^{14}C . The counting rates and efficiencies in the two energy windows are shown together with the activities in Table 17. This table also contains the counting efficiencies of ^{14}C in the ^3H window and of ^3H in the ^{14}C window, with the help of which the detection limits of ^3H and ^{14}C can be determined. It should be noted that in dual label applications the detection limit not only depends on the sensitivity of the liquid scintillation counter but also on the isotope ratios. If there is a very large excess of the higher-energy nuclide, there is a lot of spill down into the window of the low-energy nuclide and the detection limit for the low-energy nuclide may thus deteriorate significantly, especially if the sample is also heavily quenched.

Table 17: Activities of ^3H and ^{14}C in the dual label sample.

	$^3\text{H}/^{14}\text{C}$ with tSIE/AEC	$^3\text{H}/^{14}\text{C}$ with tSIE/AEC and GCT
CPMA	5523.54	5521.81
CPMA	5498.01	5496.34
CPMA	5524.42	5522.74
Average CPMA	5515.32	5513.63
Net CPMA	5514.05	5513.36
CPMB	19288.16	19283.63
CPMB	19352.98	19348.57
CPMB	19296.55	19292.12
Average CPMB	19312.56	19308.11
Net CPMB	19309.44	19307.70
Counting Efficiency ^3H in A	22.20%	22.54%
Counting Efficiency ^3H in B	0.54%	0.54%
Counting Efficiency ^{14}C in A	16.69%	16.68%
Counting Efficiency ^{14}C in B	71.24%	71.23%
E^2/B $^3\text{H}^\dagger$	387	1905
E^2/B $^{14}\text{C}^\dagger$	1627	12580
DPM ^3H	4486.2	4426.2
DPM ^{14}C	27070.8	27072.6
Bq ^3H	74.8	73.8
Bq ^{14}C	451.2	451.2

The activities in Table 17 were determined in the same way used in the QuantaSmart software for Tri-Carb and Quantulus GCT instruments.

$$D_L = \frac{A \cdot E_{HB} - B \cdot E_{HA}}{E_{LA} \cdot E_{HB} - E_{LB} \cdot E_{HA}}$$

$$D_H = \frac{B \cdot E_{LA} - A \cdot E_{LB}}{E_{LA} \cdot E_{HB} - E_{LB} \cdot E_{HA}}$$

D_L is the activity of the low-energy nuclide ^3H and D_H is the activity of ^{14}C . A and B are the counting rates in the energy window A and B and E_{LA} , E_{LB} , E_{HA} and E_{HB} are the counting efficiencies of the two nuclides in the respective two energy windows, which are obtained from the corresponding quench curves. If you add the counting rates and counting

efficiencies into the above two formulas, you get the activities as given in Table 17. Please refer to the literature to derive the formulas.²⁾ As can be seen, the ^{14}C activity is about a factor 6 greater than the ^3H activity. Thanks to tSIE/AEC this only leads to a ^{14}C counting efficiency in the ^3H window of 16.7%, but because of the large excess of the ^{14}C the count rate of ^{14}C still dominates the count rate in the ^3H window. This has a significant influence on the detection limit of ^3H , as can be seen from Table 18, whereas the detection limit of ^{14}C is only slightly increased compared to the single label ^{14}C measurement.

Table 18: ^3H and ^{14}C Detection limits in a dual label application

Sample	tSIE/AEC	tSIE/AEC with GCT
^3H	151 Bq/L	1.2 Bq/L
^{14}C	1.8 Bq/L	1.2 Bq/L

[†] When determining the figure of merit, the background was used without taking the spill into account.

According to table 18 GCT cannot significantly improve the detection limit of the low-energy nuclide with a high excess of the higher-energy nuclide in dual label applications since the background is no longer dominated by the instrument background but by the spill down from ^{14}C into the ^3H window. The instrument background becomes almost negligible when calculating the detection limit of the low energy ^3H if the activities of the higher-energy nuclides are clearly above the instrument background.

Summary

As can be clearly seen from the above measurements, the optimization of the measurement window significantly improves the performance of the measurement. This is obvious due to the larger Figure of Merit and the lower detection limits. This optimization is worthwhile in any case because it is comparatively little time-consuming and results in significant improvements in sensitivity. In the case of higher-energy nuclides such as ^{14}C or nuclides of even higher energy, the optimization of the PAC value can also make sense if you want to get the highest possible sensitivity with your scintillation counter. However, the time required for such an optimization is higher. The following table 19 shows a comparison of the measured values with the actual activities reported to us by the customer afterwards.

In addition, we were informed that the results from the Quantulus were the best in comparison with the other providers. A relatively large percentage error in the ^3H sample ^3H (L) can be explained by the low activity. Even small deviations result in a large percentage error.

The very large absolute and relative error of the ^3H activity of the dual-label sample is also noticeable.

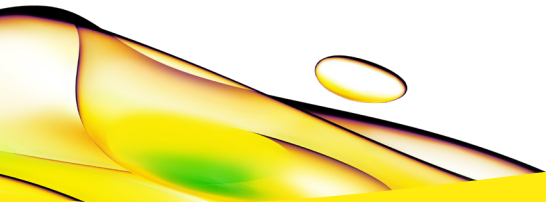
Again, this can easily be explained by the type of sample. As can be seen, the 451.7 Bq ^{14}C sample contained approximately four times more ^{14}C activity than ^3H activity of 111.4 Bq. Because of the counting efficiency of ^{14}C in the ^3H window of 16.69%, 75.4 Bq ^{14}C are measured in the ^3H window. This corresponds to about 4500 CPM ^{14}C in the ^3H window. This signal must be viewed as the background for the ^3H measurement. The ^3H count rate in this window is only about 1000 CPM, which is more than a factor of four smaller than the background. In addition, the high ^{14}C contribution in the ^3H window has a small percentage uncertainty, but in absolute terms this value can be in the order of magnitude of the ^3H activity or even exceed it due to the excess of ^{14}C . With such a poor signal-to-noise ratio and high uncertainty, no precise measurement can be expected. This has a considerable influence on the detection limit of ^3H , which was calculated to be 151 Bq/l. Compared to the single label samples, the detection limit for ^3H has increased by about a factor of 100, while the ^{14}C detection limit has remained at least in the same order of magnitude.

Table 19: Overview of Measurements

Sample	Measured Activity (Bq/L)	Real activity according to the customer	Deviation in %
^3H (L)	0.12 +/- 0.04	0.20 +/- 0.04	40
^3H (H)	113.6 +/- 6.4	111.40 +/- 4.00	1.8
^{14}C (L)	0.05 +/- 0.01	0.05 +/- 0.01	0.0
^{14}C (H)	225.6 +/- 6.5	225.85 +/- 7.24	0.1
$^3\text{H}/^{14}\text{C}$	73.8 +/- 29.8 (^3H); 451.2 +/- 17.1 (^{14}C)	111.40 +/- 4.00 (^3H); 451.7 +/- 14.48 (^{14}C)	33.8; 0.1
^{14}C quench	331.9	338.78 +/- 10.86	2.0

Literature

1. Revvity LSC Application Note, How does GCT work in the Quantulus GCT 6220?, Revvity LAS (Germany) GmbH, July 2017.
2. 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.
3. Revvity LSC Application Note, SpectraWorks²: Advanced Spectral Analysis for Liquid Scintillation Counters, Revvity LAS (Germany) GmbH, July 2017.
4. Revvity LSC Application Note, Cocktails for Liquid Scintillation Counting, Revvity LAS (Germany) GmbH, August 2017.
5. Revvity LSC Application Note, Pulse Amplitude Comparator (PAC) – Influence of this Parameter on the Sensitivity of Tri-Carb and Quantulus GCT Scintillation Counters, Revvity LAS (Germany) GmbH, January 2018.



revvity