APPLICATION NOTE

Multi-nuclide analysis using QuantaSmart and SpectraWorks 2 software.

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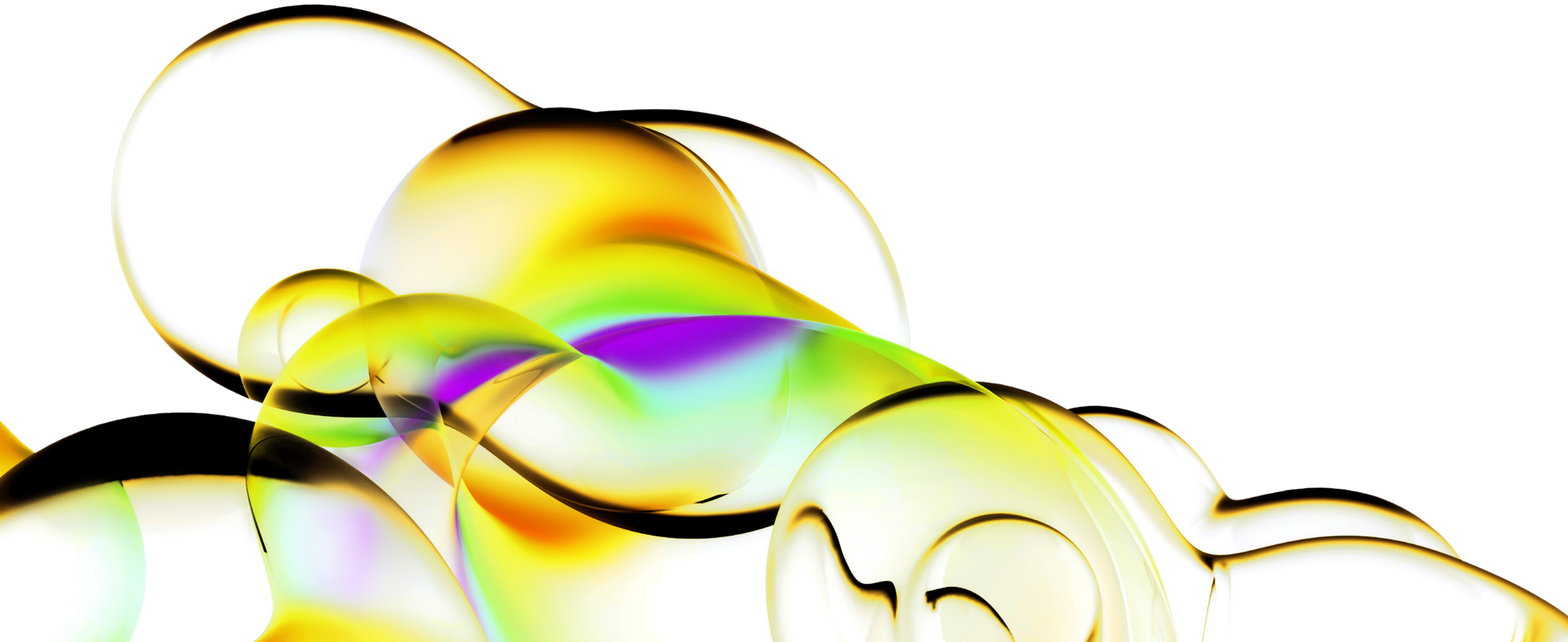
Introduction

With all Tri-Carb™ and Quantulus™ GCT systems, dual DPM measurements with samples containing two nuclides are possible using the external ^{133}Ba source. The Quantulus GCT and the Tri-Carb 5110 also offer triple DPM measurements, but can samples with more than 3 nuclides also be quantified? Because of the many spill-up and spill-down corrections that are then required, such methods are becoming less and less accurate, even with the external ^{133}Ba source, and are therefore no longer offered. Incidentally, not from other providers. Even triple label applications are very critical, since 8 quench curves are required for the corrections, but even 13 quench curves if you want to work with 4 nuclides.[1]

The sum of all errors caused by so many quench curves with spill-up and spill-down corrections can no longer be carried out with acceptable uncertainties for four or more nuclides, especially if the samples contain unfavorable isotope ratios or strong quench. See also the literature for details of possible errors in quench corrections with external standards.[1]

Many nuclides can occur, especially in waste disposal or the processing of highly radioactive mixtures. The question should now be clarified whether there is a possibility of obtaining quantitative or at least semi-quantitative results via spectral subtraction and how large the error of this method is. For a first test, libraries with energy distributions of ^{3}H and ^{14}C at different quench levels were set up and a dual-label sample with known activities of ^{3}H and ^{14}C was created. In addition, background spectra were also created at different quench levels. All samples were measured in 10 mL Ultima Gold.



By subtracting the spectrum of the nuclide with the highest energy, it should be possible to determine the activities of all nuclides successively. Of course, dual label samples can also be quantified in each LSC using the external standard method, but this comparatively simple sample should at least be able to show whether this method is suitable in principle.

For the subtraction, spectra from reference samples must have the same or very close quench level and be normalized to the intensity of the unknown sample. This is somewhat challenging and limited with only 10 different quench levels. The spectra should be normalized using Revvity's SpectraWorks 2 software. If the results are promising, finer tuning with more than 10 quench levels per nuclide was planned and the number of nuclides should be increased. QuantaSmart and SpectraWorks 2 software are shipped with all Revvity LSCs.

Experimental part

For more detailed information about the QuantaSmart and SpectraWorks 2 Software please use the corresponding Manuals and application notes.[2, 3, 4, 5, 6] First a set of ten ^{3}H and ten ^{14}C standards were measured. We did obtain the following tSIE-values from these standards:

Table 1: Measured ^{3}H & ^{14}C energy distributions

^{3}H 252395 DPM		^{14}C 126400 DPM	
CPM	tSIE	CPM	tSIE
131175	673.32	120765	674.06
114785	534.15	119001	533.84
104702	459.13	118604	455.39
90607	375.32	116478	376.40
77790	312.46	115210	312.50
57930	233.82	112133	247.89
39075	167.81	105771	168.95
20914	108.27	94806	109.81
12225	78.41	83856	80.07
4216	45.58	59181	46.83

A dual label sample was prepared which contained 7272 DPM ^{3}H and 4500 DPM ^{14}C in Ultima Gold. The tSIE-value of this sample was 544.60 which is closest to the energy distribution of the second standard in Table 1. We used plastic vials for all measurements, except for the samples in Table 1. The samples in Table 1 are commercially available quench sets in glass vials. All measurements were carried out in a Tri-Carb 4910TR using Normal Count Mode.

The two energy distributions of the second ^{3}H and ^{14}C standards and the dual label sample were loaded into the SpectraWorks 2 software as shown in Figure 1. Now, first, the higher-energy distribution of the ^{14}C reference was subtracted from the dual label energy distribution. To do this, the energy distribution of the ^{14}C reference spectrum had to be brought into line with the dual label sample by dividing all channels in the higher-energy range of the distribution until a perfect match was obtained.

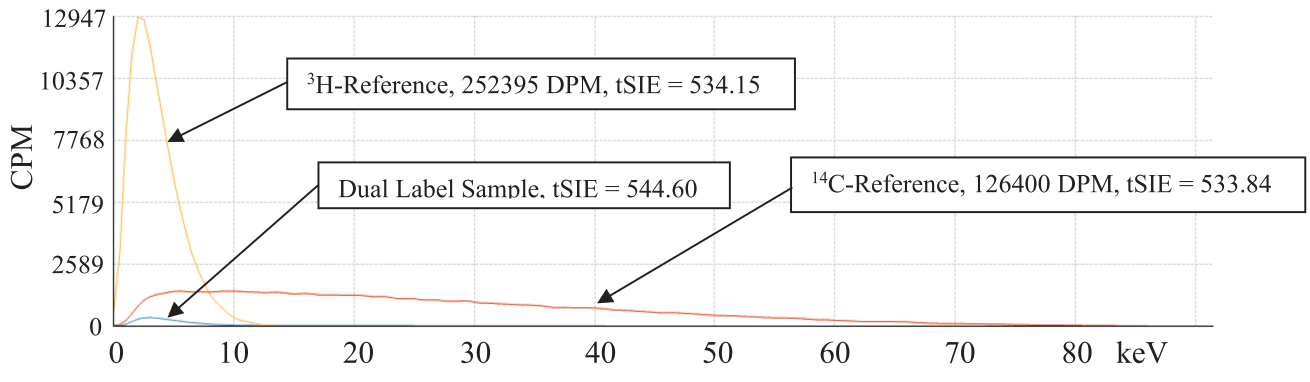


Figure 1: Both reference spectra and the dual label sample

For the sake of clarity, the ^{3}H reference spectrum was first removed from the figure. By dividing all channels of the ^{14}C reference spectrum by 27, it was possible to bring it almost congruent with the dual label sample in the higher energy range, as can be seen in Figure 2.

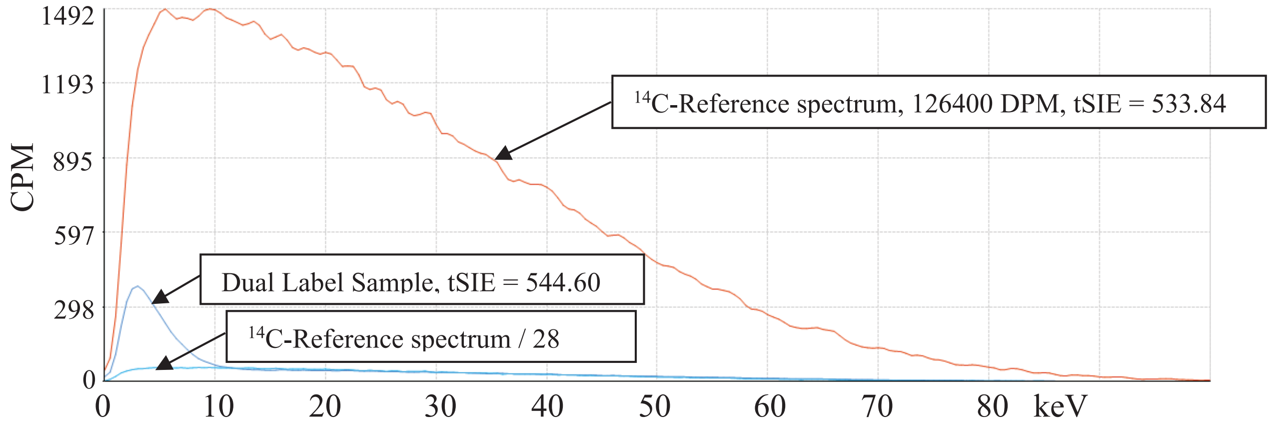


Figure 2: Normalizing the ^{14}C reference spectrum to the activity of the dual label sample

After subtracting the ^{14}C reference spectrum divided by 28, the energy distribution from Figure 3 could then be obtained. This essentially only shows the ^{3}H energy distribution and only a few (128 CPM) counts in the energy window from 20 to 100 keV. This corresponds to about 3% of the count rate of the ^{14}C sample in the dual label sample. This value can presumably be reduced if the spectral library contains more energy distributions with smaller distances between tSIE values. Table 2 indicates the activities present in the dual label sample and the values actually found.

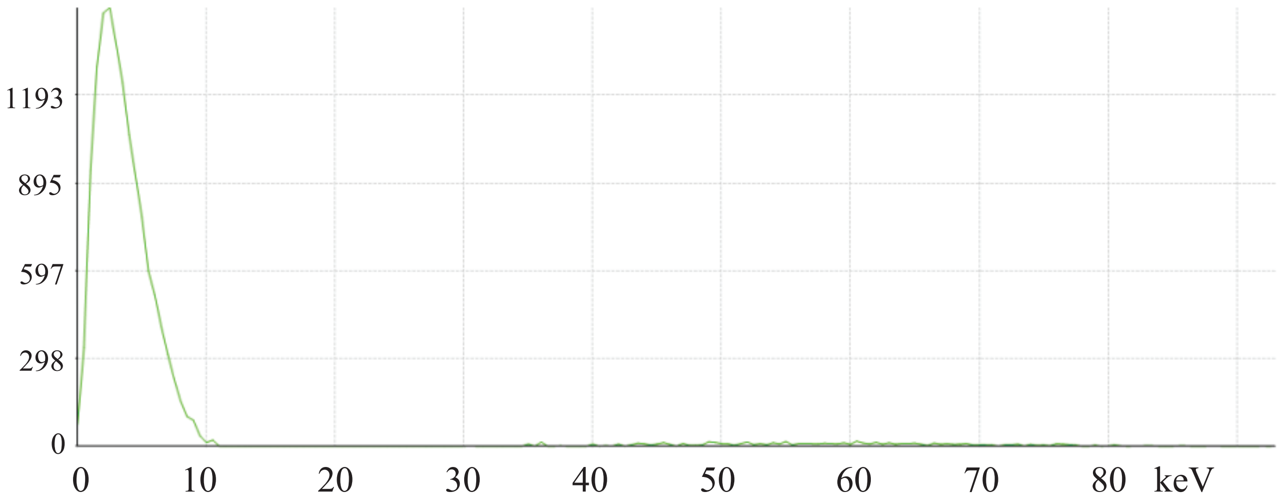


Figure 3: $^{3}H/^{14}C$ dual label sample after subtraction of the ^{14}C reference spectrum

Table 2: Result of the dual label sample

	^{3}H DPM	^{14}C DPM
Real	7272	4500
Determined	7011	4466
Difference	262 (3.6%)	34 (0.8%)

The ^{3}H sample was determined in the same way. Here the ^{3}H reference spectrum (252395 DPM) had to be divided by 36 so that the energy distributions of the reference sample and the dual label sample were almost congruent. Considering that the standards used have an uncertainty of around 2%, the results are surprisingly good. Therefore, further samples should now be measured. In addition, quench libraries (see last pages) were made with a larger number of spectra with smaller differences in quench.

Reference spectra of the nuclides ^{3}H, ^{14}C, ^{36}Cl, ^{90}Sr/^{90}Y and ^{241}Am have now been produced. If activities are to be determined in spectra of many nuclides or in the case of nuclides with low activities using this subtraction method, then the background must also be considered. Two samples with different activities of the above nuclides were prepared. The total mass of sample 1 was 14.6157g, of which 0.9201g was taken after measuring sample 1 for sample 2. Thus, Sample 2 contained 6.2953% of the activity of Sample 1.

Table 3: Activities of the Multi-Nuclide-Samples

Sample 1		Sample 2		Reference	
Nuclide	DPM	Nuclide	DPM	Nuclide	DPM
^{3}H	7785	^{3}H	490	^{3}H	173388
^{14}C	10038	^{14}C	632	^{14}C	58019
^{36}Cl	11000	^{36}Cl	693	^{36}Cl	109650
^{90}Sr§	2350	^{90}Sr§	148	^{90}Sr§	18550
^{241}Am	2350	^{241}Am	148	^{241}Am	23760

[§] The activity is related to ^{90}Sr, which is in equilibrium with ^{90}Y.

Sample 1 had a relatively severe quench with a tSIE of 229.26. A total count rate in the sample of 27638 CPM was measured in the open energy window of 0-2000 keV. This corresponds to an average counting efficiency of 77% for all nuclides. Sample 2 was measured at a higher tSIE of 560.55, which corresponds to low quench. At the tSIE value of 560.55, 1924.2 CPM were measured in the open window from 0–2000 keV, corresponding to a mean counting efficiency of 85.2%. The endpoint of the energy distribution of the heavily quenched sample 1 is about 560 keV, significantly lower than the weakly quenched sample with an endpoint of the energy distribution near 1300 keV.

However, good spectral subtraction with reference samples is tied to a spectral library that contains spectra with a comparable quench. A special dependence of the spectral form and the shift to lower energies can be seen for practically all nuclides, including α-emitters. Figures 3 and 4 show the superimposed energy distributions of samples 1 and 2. Because of the normalization to the maximum signal in Figures 3 and 4, the end point of the spectrum appears to be below 200 keV or at 400 keV rather than at 560 keV and 1300 keV as mentioned above.

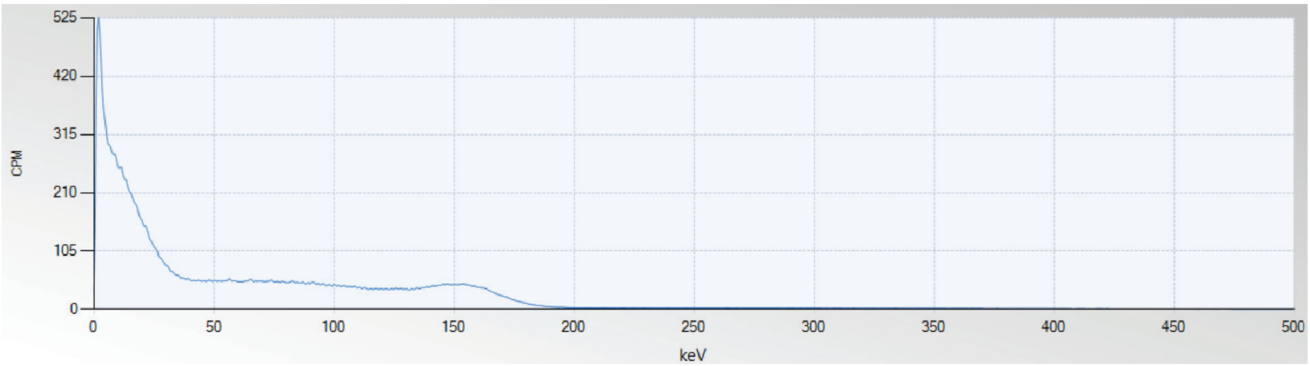


Figure 3: Energy distribution of sample 1, tSIE = 229.26

The activities of Sample 1 were taken up in 10 ml water and mixed with 10 ml Ultima Gold LLT. All samples were measured at room temperature with five repetitions of 60 minutes each.

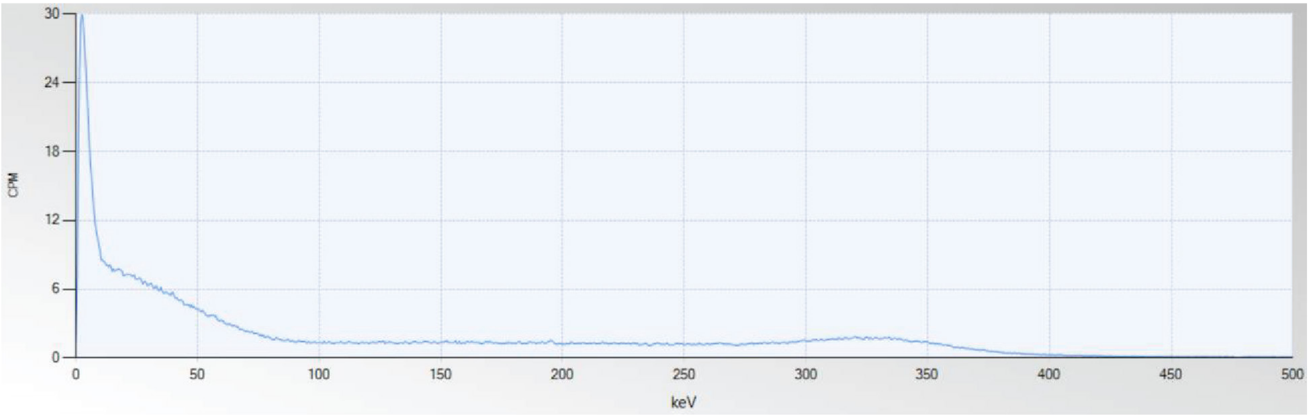


Figure 4: Energy distribution of sample 2, tSIE = 560.55

However, when the high-energy region is zoomed in more, the high-energy region from ^{90}Y to about 560 keV for sample 1 and to almost 1300 keV for sample 2 can clearly be seen. However, two problems are already apparent here. On the one hand, these sample mixtures also contain other quite high-energy nuclides such as ^{36}Cl and ^{241}Am and a pure $^{90}Sr/^{90}Y$ partial spectrum is only visible in a narrowly limited range. In the case of sample 1, this is primarily the energy range from approx. 200 - 560 keV in Figure 5, which appears suitable for overlapping with a reference spectrum.

A second problem is particularly evident in the energy distribution of sample 2 in Figure 6. Because of the limited energy range, only a small part of the total counting statistics is available. Because of the many channels that must be filled with high-energy nuclides, the number of decay events measured per channel is quite small. Therefore, this area of the energy distribution is very noisy. A smoothing function is therefore also available in the SpectraWorks 2 software to facilitate an exact superimposition of unknown sample and reference spectrum. The energy distributions were not smoothed for the present examples.

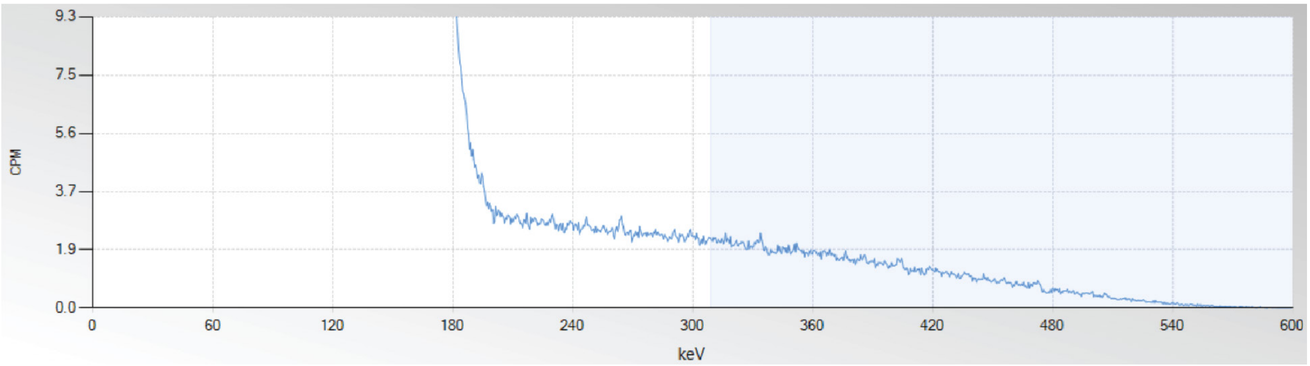


Figure 5: Sample 1 with large zoom factor for the high energy range.

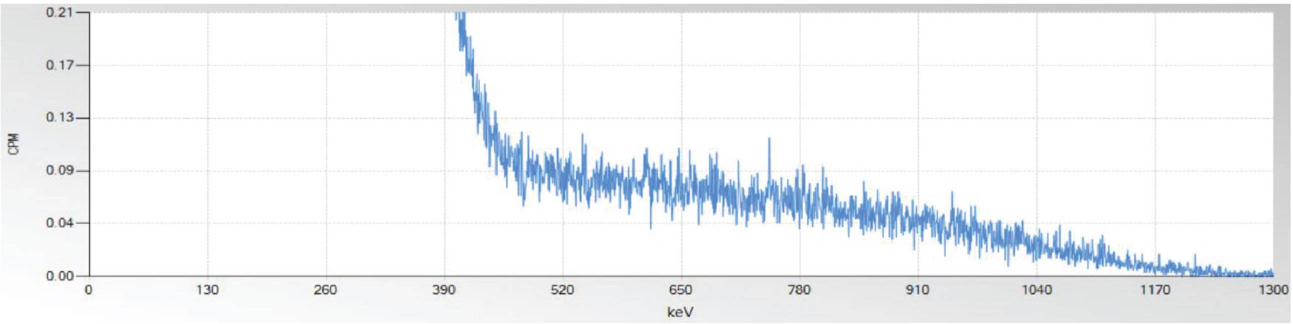


Figure 6: Sample 2 after summation of repeat measurements and with large zoom factor of the high energy range.

The analysis of sample 1 was now started again with the nuclide with the highest energy. A ^{90}Sr/^{90}Y reference spectrum with a tSIE value as close as possible to sample 1 was adapted to the intensity in such a way that the higher-energy range, especially between 240 and 560 keV, matched the sample energy distribution as well as possible, as shown in Figure 7. To do this, the spectrum of the ^{90}Sr/^{90}Y reference with an activity of 18550 DPM related to ^{90}Sr only had to be divided by 8 to coincide with the unknown sample in the high-energy range. This results in an activity of 2319 DPM for the ^{90}Sr sample. A table is provided at the end of the sample 1 study to compare the activity found and the actual activity.

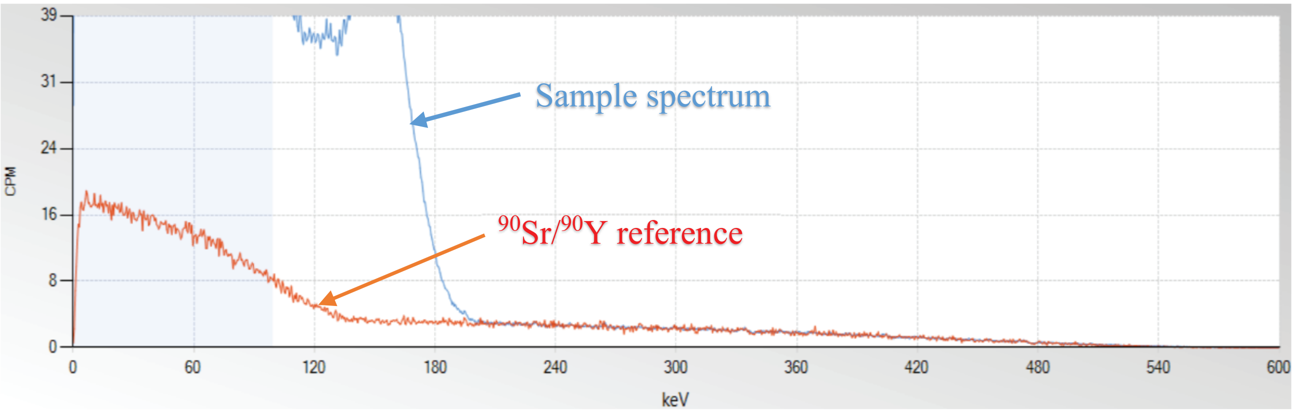


Figure 7: Sample 1 with overlaid ^{90}Sr reference sample

After subtracting the ^{90}Sr/^{90}Y energy distribution from the reference, the spectrum in the figure below is obtained. The y-axis gain was now adjusted so that ^{241}Am and ^{36}Cl could be seen clearly and the energy range was focused below 250 keV.

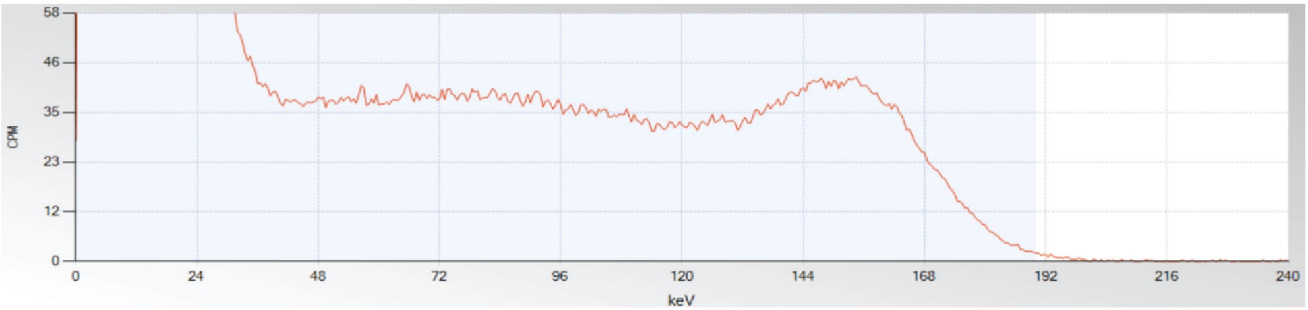


Figure 8: Sample 1 after subtraction of the ^{90}Sr/^{90}Y reference sample.

The ^{36}Cl reference sample had an activity of 109650 DPM and had to be divided by 10.5 to match sample 1 in the energy range between 50 and 100 keV. From this, an activity of 10443 DPM for the ^{36}Cl activity in sample 1 can be determined.

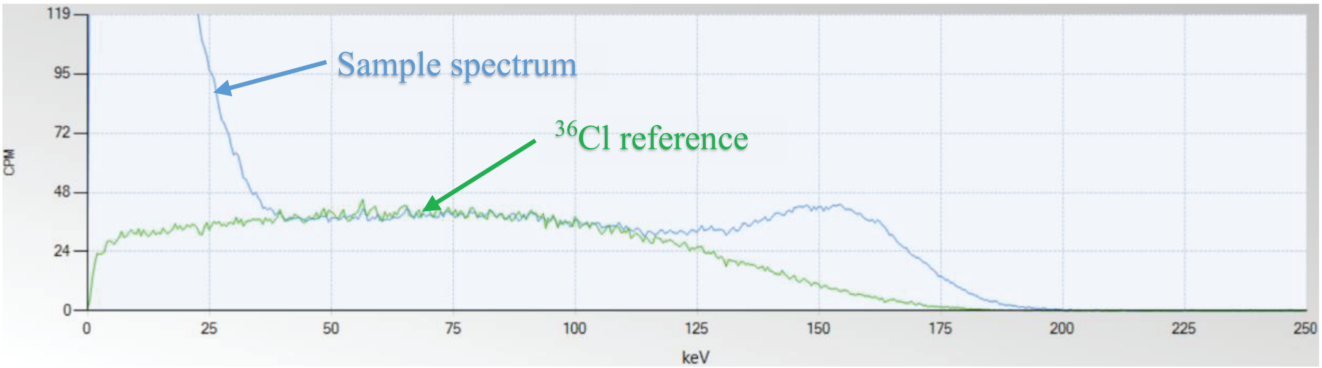


Figure 9: Sample 1 with overlaid ^{36}Cl energy distribution of the reference.

After subtracting the ^{36}Cl reference sample, the energy distribution in Figure 10 is obtained. The energy distribution between 100 and 200 keV can now be clearly seen. Since an energy distribution that does not start at 0 keV cannot be a β-nuclide, it must be ^{241}Am in this sample mixture. In addition, the energy of the peak maximum is typical for ^{241}Am at this quench level.

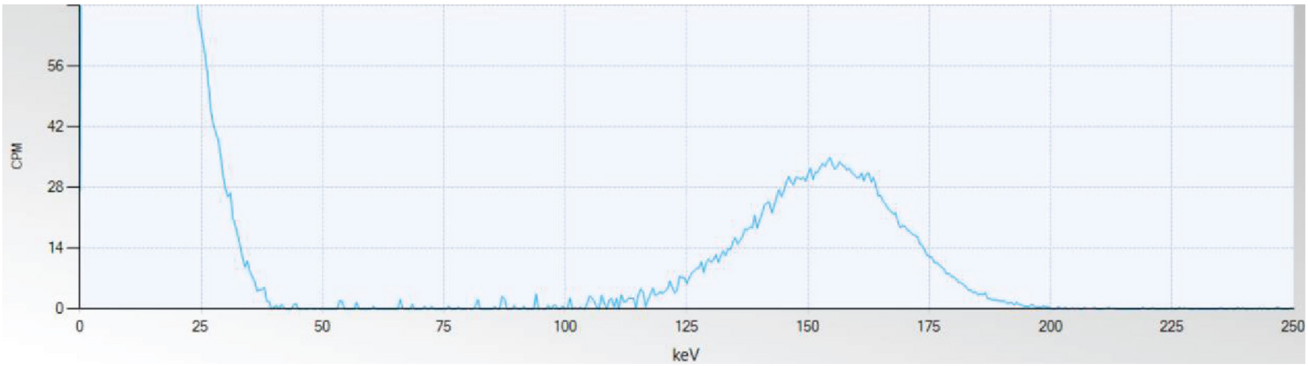


Figure 10: Sample 1 after subtraction of the ^{36}Cl reference sample.

The ^{241}Am reference sample had an activity of 23760 DPM and had to be divided by 9 to optimally fit the energy distribution between 100 and 200 keV. This resulted in an activity of 2640 DPM for ^{241}Am in sample 1.

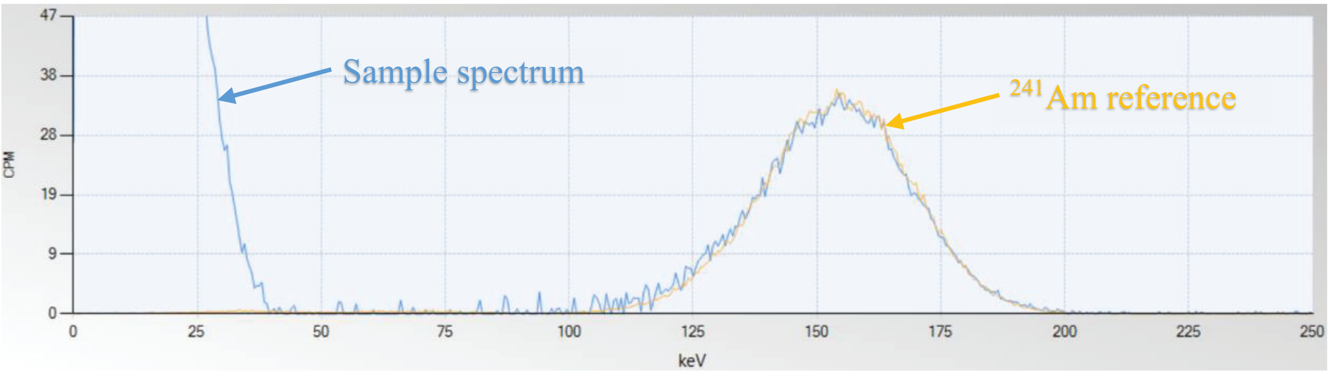


Figure 11: Sample 1 with overlaid energy distribution of the ^{241}Am reference

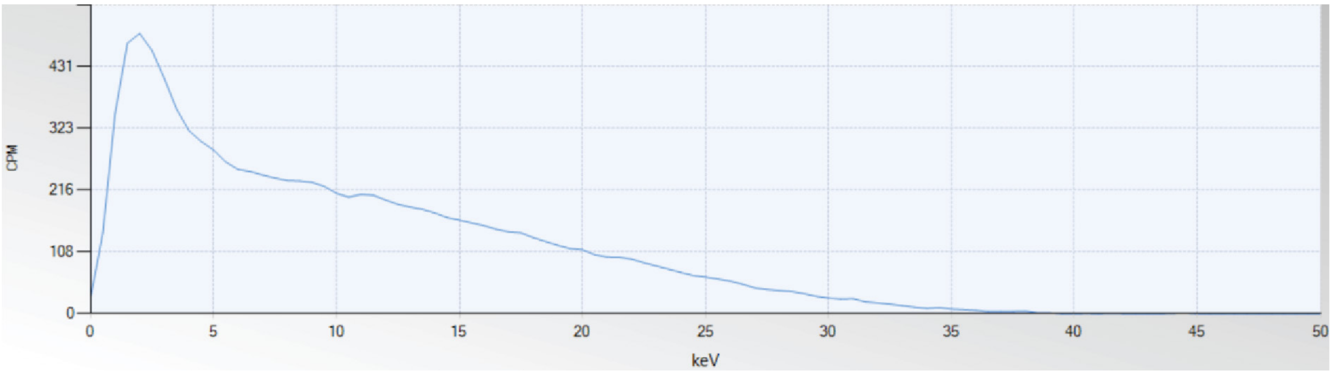


Figure 12: Sample 1 after subtraction of the ^{241}Am reference spectrum

After subtracting the ^{241}Am reference sample from sample 1, the energy distribution in Figure 12 is obtained, now containing only ^{3}H and ^{14}C. The activity of the ^{14}C reference sample was 58019 DPM and had to be divided by 5.2 to coincide with the end of the energy distribution between 10 and 35 keV. This results in the activity of ^{14}C in sample 1 being 11157 DPM.

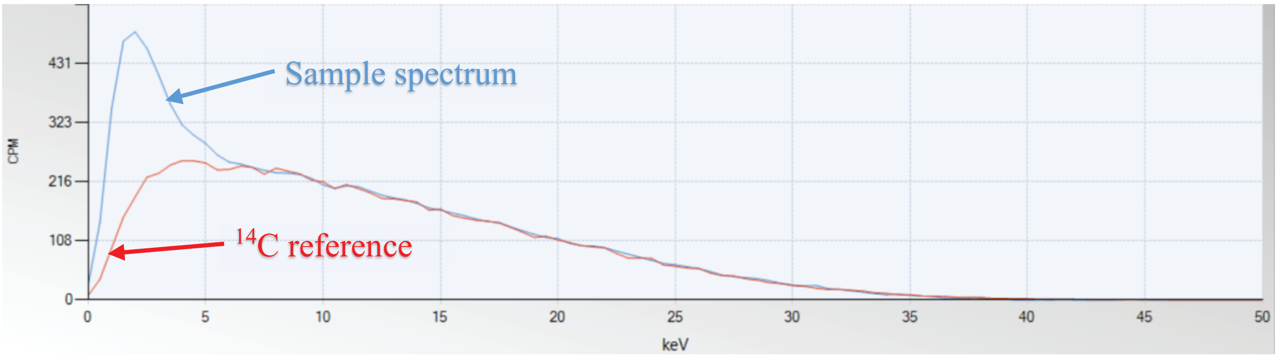


Figure 13: Sample 1 with overlaid energy distribution of the ^{14}C reference

After subtraction of the ^{14}C reference spectrum the energy distribution in figure 14 is obtained. The now only remaining ^{3}H nuclide in Figure 14 has been aligned with a corresponding ^{3}H reference sample. The ^{3}H reference sample contained an activity of 173388 DPM and had to be divided by 20.5 to match the unknown ^{3}H energy distribution. This resulted in a value of 8458 DPM for the unknown ^{3}H activity.

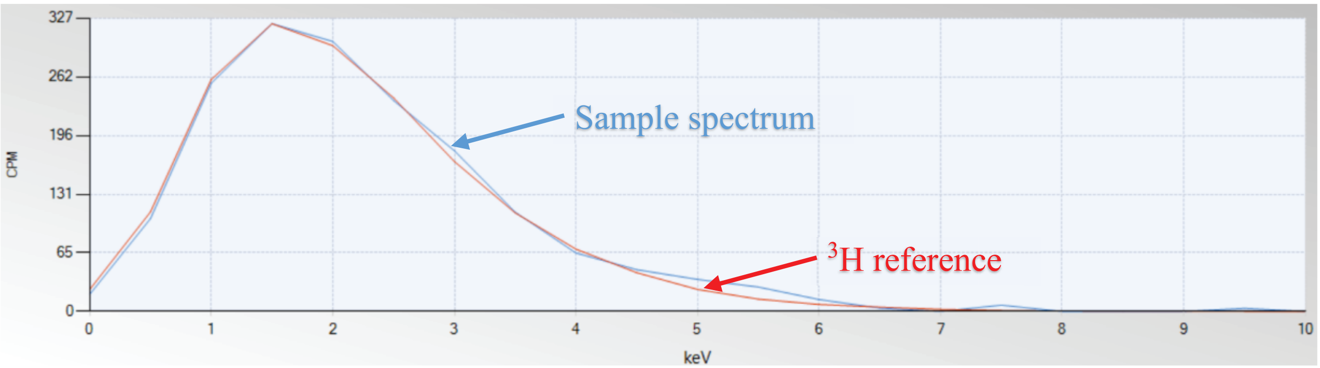


Figure 14: Sample 1 after subtraction of the ^{14}C reference spectrum overlaid with the energy distribution of the ^{3}H reference.

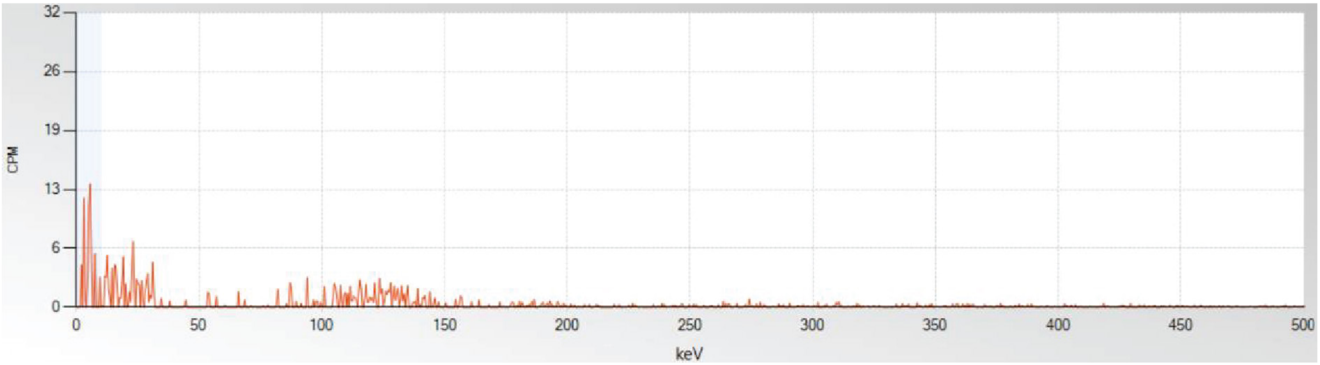


Figure 15: Remaining background after subtraction of all reference spectra

The reference spectra were recorded with very high activities and many standards were divided by 10 or higher values, so the background in these energy distributions should not have a big impact. A background corresponding to the instrument background should therefore be visible. However, this background is increased in the range of 0-30 keV and in the range of about 100-140 keV. In particular, the increase in the range of 100-140 keV is due to the too low value of the tSIE for the reference spectrum of ^{36}Cl.

With more than 6 tSIE units, this energy distribution is too low, so the spectrum is shifted in terms of low energy, which is why subtraction is not perfect in the higher energy range. Nevertheless, the results are not worse than those obtained with triple label DPM measurements under comparable conditions. In particular, the results for the low-energy nuclides are often burdened with a large degree of uncertainty because of the spill corrections. However, since 5 nuclides were used in this experiment, the result can be regarded as good.

Table 4: Comparison of real and determined activity in sample 1

Measurement of Sample 1			
Nuclide	**Real activity (DPM)**	**Determined activity (DPM)**	**Recovery**
^{3}H	7785	8458	108.6%
^{14}C	10038	11157	111.1%
^{36}Cl	11000	10443	94.9%
^{90}Sr	2350	2319	98.7%
^{241}Am	2350	2640	112.3%

Table 5: Quench parameter of sample 1 and reference spectra

Measurement of Sample 1			
Nuclide	**tSIE value sample**	**tSIE value reference**	**Difference**
^{3}H	229.26	226.96	2.30
^{14}C		226.84	2.42
^{36}Cl		222.99	6.27
^{90}Sr		230.38	-1.12
^{241}Am		228.48	0.78

With more reference spectra for the sample quench, the results can be improved. If the tSIE values deviate from the sample by more than 5 tSIE units, things become critical, and the reference sample can no longer be perfectly matched to the measurement sample. Sample 2 was now examined analogously. First, based on the energy distribution in Figure 6 (see above), a correspondingly normalized reference spectrum of the highest-energy nuclide ^{90}Sr/^{90}Y was subtracted from the unknown energy distribution in such a way that at most a noise signal remained. To do this, the ^{90}Sr reference spectrum had to be divided by 240. After subtraction, the following energy distribution was obtained. The activity for ^{90}Sr was found to be 154.6 DPM. ^{90}Sr was in secular equilibrium with ^{90}Y which also results in an activity of 154.6 DPM for this nuclide.

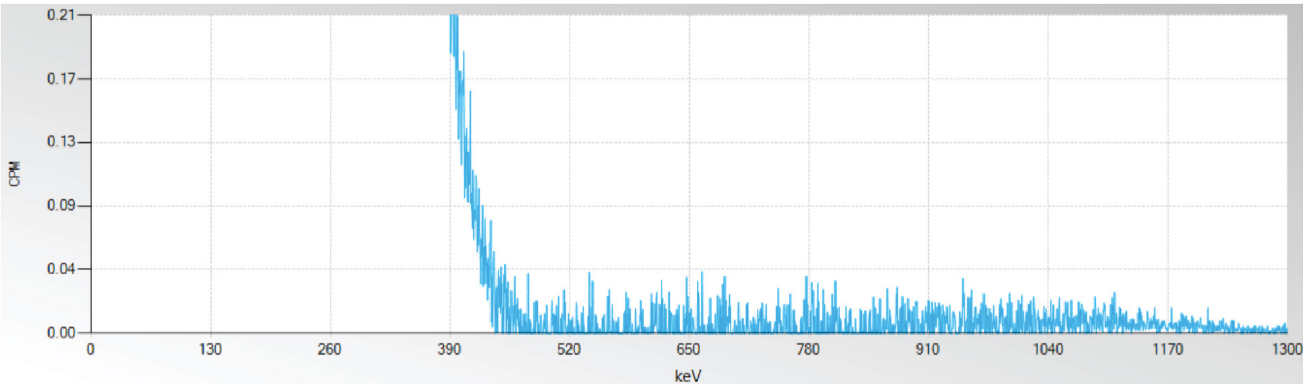


Figure 16: Sample 2 after ^{90}Sr/^{90}Y subtraction

This subtraction removed the ^{90}Sr/^{90}Y portion from the energy distribution. The figure below shows the energy distribution obtained in a different energy resolution, focused on the remaining nuclides ^{3}H, ^{14}C, ^{36}Cl and ^{241}Am. The ^{36}Cl reference, which should be subtracted next, is already superimposed.

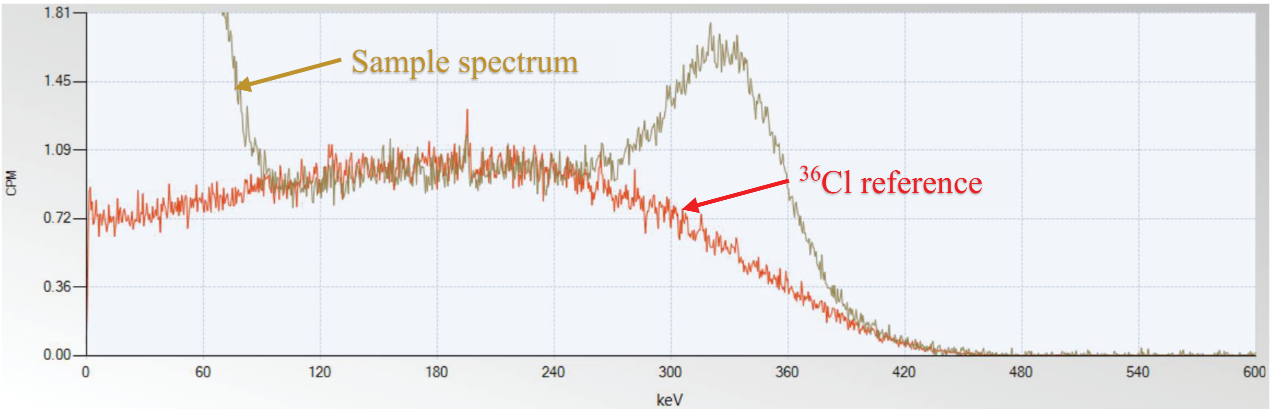


Figure 17: Sample 2 with overlaid ^{36}Cl reference

The ^{36}Cl reference with an activity of 109650 had to be divided by 170 to match the sample spectrum. The ^{36}Cl activity was therefore 109650/170 = 645 DPM. The resulting sample spectrum after subtracting the ^{36}Cl reference is shown in Figure 18. It also contains the ^{241}Am reference which had to be divided by 155 to match the sample.

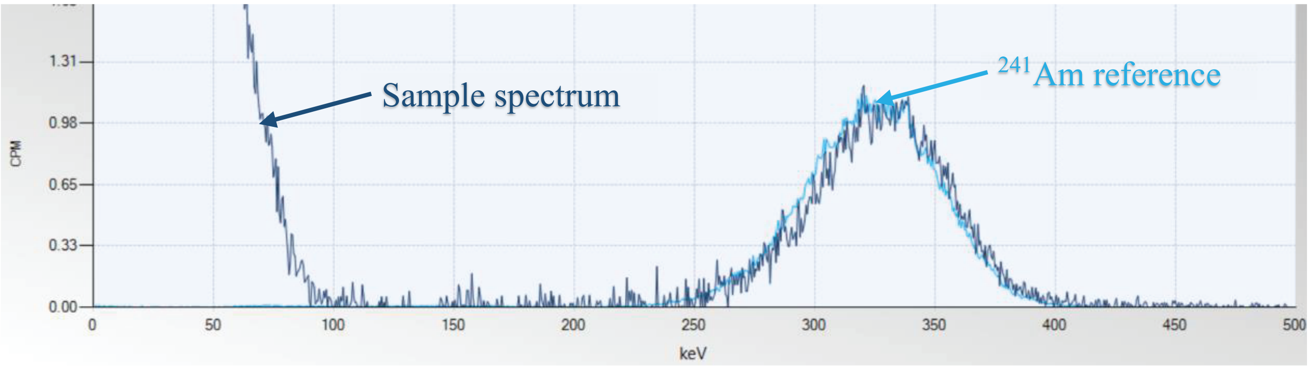


Figure 18: Sample 2 after subtraction of ^{36}Cl with overlaid ^{241}Am reference

This results in an activity for ^{241}Am in the sample of 153.3 DPM. As can already be seen in Figure 18, a slight low-energy shift of the ^{241}Am peak of the reference can be seen, which means that too little activity is subtracted in the high-energy flank. As can be seen in Table 7, the tSIE value of the reference is 24 tSIE units too high and too far away from the tSIE value of the sample. In such cases, if the normalization is focused on the maximum peak height, a fairly accurate activity can still be determined, although this leads to a higher background in certain areas, while too much signal is subtracted in other areas. If the difference in the tSIE is even greater, the changing peak shape also leads to larger errors in the sample activity.

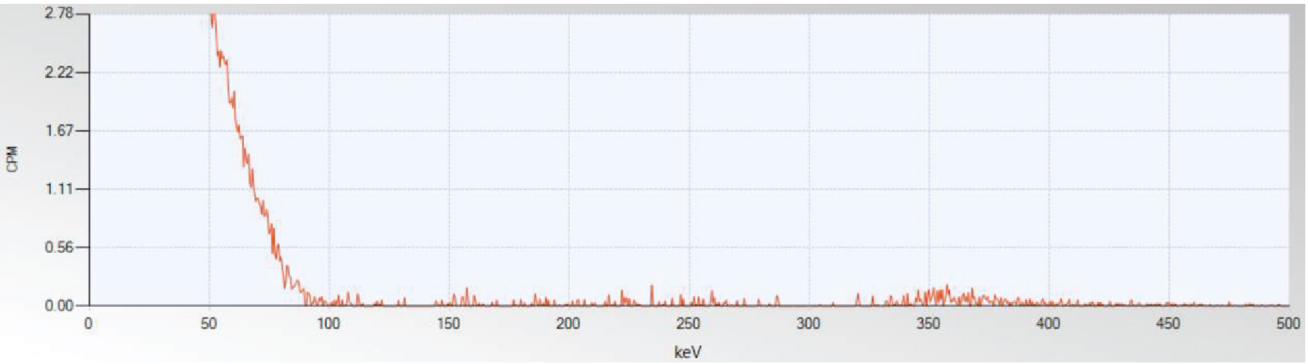


Figure 19: Sample 2 after subtraction of the ^{241}Am reference

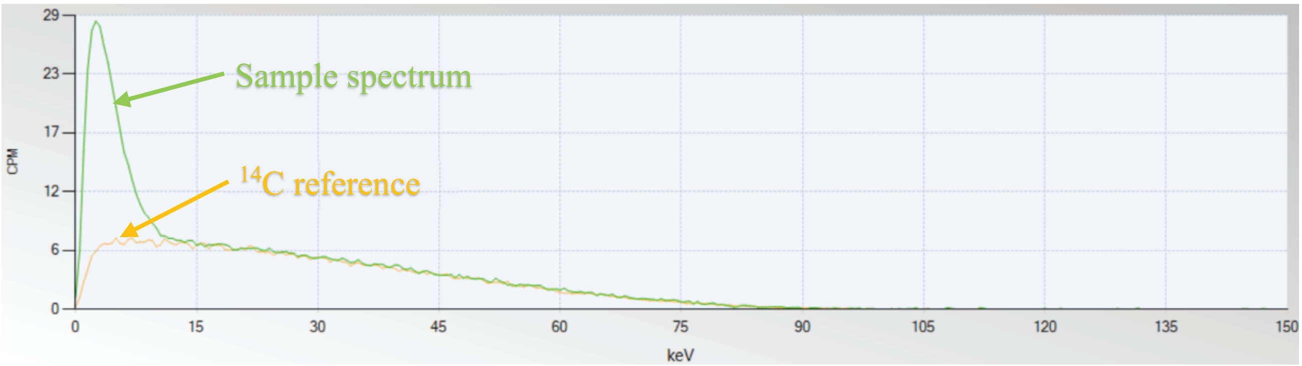


Figure 20: Sample 2 after subtraction of the ^{241}Am reference with overlaid ^{14}C reference

The ^{14}C reference in Figure 20 had to be divided by 90 to match the sample. This results in an activity of ^{14}C in the sample of 644.7 DPM. The resulting spectrum, containing only ^{3}H, is shown in Figure 21.

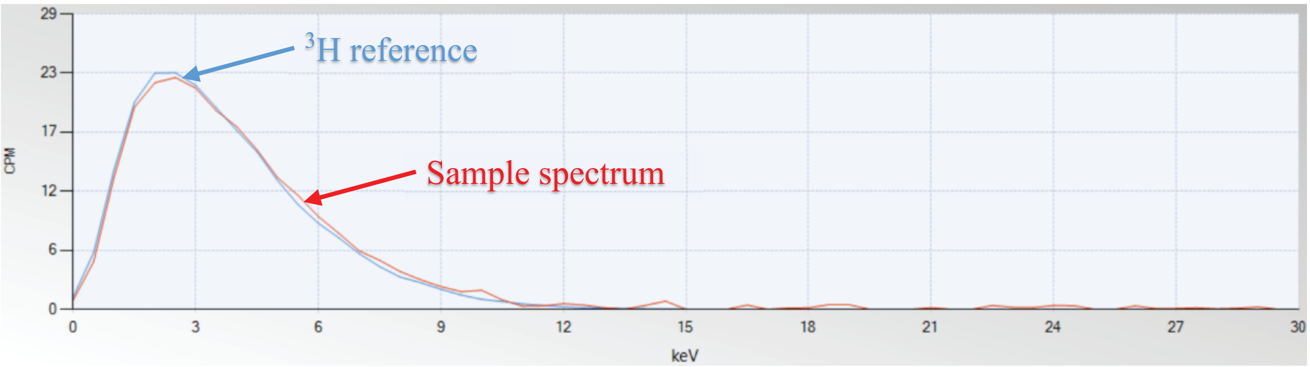


Figure 21: Sample 2 after subtraction of ^{14}C with overlaid ^{3}H reference

To match the spectrum of the ^{3}H reference in Figure 21 with the unknown sample, the ^{3}H reference spectrum had to be divided by 355. The ^{3}H activity in sample 2 was found to be 488 DPM.

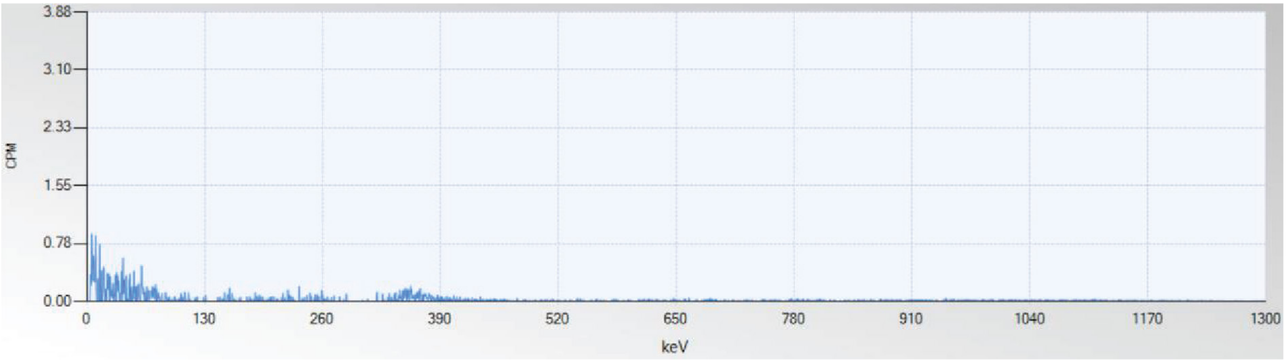


Figure 22: Sample 2 after subtraction of all reference spectra

Table 6: Comparison of real and determined activity in sample 2

Measurement of sample 2			
Nuclide	**Real activity (DPM)**	**Determined activity (DPM)**	**Recovery**
^{3}H	490	488	99.6%
^{14}C	632	645	102.1%
^{36}Cl	693	645	93.1%
^{90}Sr	148	155	104.7%
^{241}Am	148	153	103.4%

The results are surprisingly good when compared to Sample 1. The remaining background here corresponds more to the typical background. Only between approx. 320 and 390 keV too little ^{241}Am was subtracted due to the low-energy shift of the reference compared to the sample. Nevertheless, the recovery in a mixture of 5 nuclides can be regarded as very good. This is particularly remarkable because two of the reference samples showed a clear deviation in the tSIE value as shown in Table 7. The fact that this did not result in any major errors is due to the fact that all samples were quenched quite slightly, and the resulting energy shift was limited. Basically, our spectral library contained too few energy distributions in the range of low quench.

Table 7: Quench parameter of sample and reference spectra

Measurement of sample 2			
Nuclide	**tSIE value sample**	**tSIE value reference**	**Difference**
^{3}H	560.55	564.95	-4.40
^{14}C		561.76	-1.21
^{36}Cl		574.02	-13.47
^{90}Sr		563.27	-2.72
^{241}Am		585.26	-24.71

Summary

The examples presented here show that the determination of activities in nuclide mixtures can be performed with the SpectraWorks 2 software for both quenched and low-quenched samples. However, it could also be shown that the quality of the results depends on the existence of very good spectral libraries. If possible, these must have the same tSIE value as the sample to be examined. Deviations of a maximum of 5 tSIE units seem to lead to good results in most cases. The intensity of the reference spectra can be adjusted in the software by division to the activity of the unknown sample. For this type of analysis, it is necessary to start successively with the energy distributions with the highest energy and in this range the nuclide should be as free as possible from other superimpositions to enable good spectral matching. Most likely, switching to low-level instruments with lower background values can further improve the sensitivity of this procedure.

Table 4: ^{3}H Spectral library

^{3}H reference with 173390 DPM						
CPM	**Counting efficiency %**	**tSIE**		**CPM**	**Counting efficiency %**	**tSIE**
82048	47.32	564.95		54947	31.69	318.76
78580	45.32	522.88		54549	31.46	315.92
75928	43.79	493.61		53630	30.93	309.43
75217	43.38	485.68		52589	30.33	303.29
74627	43.04	479.27		52138	30.07	300.68
73067	42.14	461.97		51514	29.71	297.07
72581	41.86	456.65		49850	28.75	287.45
70639	40.74	439.70		48896	28.20	281.92
69391	40.02	429.37		47838	27.59	275.81
68489	39.50	421.82		47440	27.36	273.54
67778	39.09	416.01		44908	25.90	258.89
66738	38.49	407.38		43902	25.32	253.05
65229	37.62	394.85		42515	24.52	245.04
64640	37.28	389.95		41284	23.81	237.94
63669	36.72	381.88		39273	22.65	226.96
62906	36.28	375.48		37799	21.80	219.64
61675	35.57	366.44		36135	20.84	211.30
61363	35.39	364.11		34799	20.07	204.67
59768	34.47	352.84		32649	18.83	193.97
58797	33.91	345.95		31002	17.88	185.74
57531	33.18	337.11		28263	16.30	172.02
57167	32.97	334.47		26477	15.27	163.28
56092	32.35	326.85		22697	13.09	145.63
55433	31.97	322.19		16906	9.75	118.59

Table 5: ^{14}C Spectral library

^{14}C reference with 58019 DPM						
CPM	Counting efficiency %	tSIE		CPM	Counting efficiency %	tSIE
55025	94.84	561.76		53000	91.35	309.46
54898	94.62	524.22		52989	91.33	308.68
54631	94.16	485.75		52879	91.14	303.44
54584	94.08	478.73		52797	91.00	299.82
54549	94.02	473.97		52623	90.70	291.79
54462	93.87	461.18		52588	90.64	290.33
54433	93.82	456.91		52461	90.42	284.18
54370	93.71	447.97		52351	90.23	279.08
54254	93.51	428.58		52310	90.16	277.21
54126	93.29	408.71		52176	89.93	271.08
54033	93.13	391.22		52118	89.83	268.50
53992	93.06	386.98		51875	89.41	257.21
53952	92.99	380.69		51747	89.19	251.39
53894	92.89	371.33		51631	88.99	245.86
53760	92.66	360.88		51387	88.57	238.30
53650	92.47	353.50		50981	87.87	226.84
53598	92.38	349.97		50714	87.41	219.41
53534	92.27	345.67		50506	87.05	213.51
53424	92.08	338.15		50157	86.45	203.56
53389	92.02	335.90		49798	85.83	193.47
53331	91.92	331.88		49357	85.07	181.10
53215	91.72	324.30		49003	84.46	171.06
53168	91.64	320.92		47622	82.08	152.73
53093	91.51	316.02		42058	72.49	98.96

Table 6: ^{36}Cl Spectral library

^{36}Cl reference with 109650 DPM						
CPM	**Counting efficiency %**	**tSIE**		**CPM**	**Counting efficiency %**	**tSIE**
107260	97.82	574.02		107545	98.08	333.09
107468	98.01	520.27		107501	98.04	321.46
107512	98.05	501.96		107490	98.03	319.12
107600	98.13	491.19		107479	98.02	315.25
107643	98.17	481.81		107457	98.00	311.33
107665	98.19	474.68		107446	97.99	306.75
107676	98.20	464.07		107424	97.97	301.99
107674	98.20	457.00		107413	97.96	297.35
107686	98.21	447.27		107391	97.94	292.66
107709	98.23	436.97		107358	97.91	284.32
107707	98.23	432.20		107325	97.88	276.44
107741	98.26	418.28		107327	97.88	274.46
107819	98.33	407.50		107303	97.86	266.35
107895	98.40	400.43		107282	97.84	259.37
107897	98.40	397.73		107271	97.83	253.05
107906	98.41	385.00		107249	97.81	246.53
107874	98.38	379.42		107227	97.79	238.82
107830	98.34	373.67		107183	97.75	222.99
107753	98.27	363.19		107161	97.73	214.41
107742	98.26	361.49		107051	97.63	204.46
107731	98.25	359.75		106865	97.46	191.58
107643	98.17	348.01		106536	97.16	169.11
107600	98.13	341.62		106262	96.91	150.80
107556	98.09	334.85		105779	96.47	118.32

Table 7: ^{90}Sr Spectral library

^{90}Sr/^{90}Y reference with 18550 DPM (only related to ^{90}Sr)						
CPM	**Counting efficiency %**	**tSIE**		**CPM**	**Counting efficiency %**	**tSIE**
36697	98.91	563.27		36438	98.22	310.80
36549	98.51	512.70		36428	98.19	302.92
36635	98.75	495.24		36343	97.96	298.08
36554	98.53	485.22		36475	98.32	292.17
36583	98.61	469.08		36309	97.87	284.89
36398	98.11	460.74		36246	97.70	276.23
36606	98.67	451.30		36288	97.81	270.62
36343	97.96	437.66		36332	97.93	262.75
36556	98.53	431.27		36366	98.02	258.24
36519	98.43	418.91		36117	97.35	250.02
36524	98.45	412.75		36236	97.67	245.37
36367	98.02	399.11		36258	97.73	237.48
36446	98.24	395.24		36271	97.77	230.38
36402	98.12	384.40		36187	97.54	221.56
36527	98.46	375.36		36086	97.27	213.79
36421	98.17	364.72		36157	97.46	205.54
36368	98.03	356.56		36004	97.05	198.15
36286	97.81	345.07		36113	97.34	190.72
36321	97.90	337.11		36007	97.05	183.55
36427	98.19	331.09				

Table 8: ^{241}Am Spectral library

^{241}Am reference with 23760 DPM						
CPM	**Counting efficiency %**	**tSIE**		**CPM**	**Counting efficiency %**	**tSIE**
23685	99.68	581.39		23681	99.67	294.49
23602	99.33	549.57		23590	99.29	286.20
23588	99.28	526.47		23713	99.80	277.34
23713	99.81	502.61		23613	99.38	270.32
23544	99.09	480.30		23666	99.60	261.58
23626	99.43	461.81		23616	99.39	253.95
23605	99.35	442.41		23577	99.23	246.53
23544	99.09	423.60		23635	99.47	239.65
23627	99.44	410.31		23654	99.56	232.70
23693	99.72	393.36		23662	99.59	224.01
23570	99.20	378.98		23636	99.48	217.99
23648	99.53	367.50		23636	99.48	204.28
23584	99.26	355.53		23596	99.31	197.75
23638	99.49	345.67		23529	99.03	194.31
23620	99.41	335.80		23578	99.23	187.05
23572	99.21	325.45		23590	99.28	179.73
23623	99.42	314.75		23706	99.78	175.40
23587	99.27	303.48		23690	99.71	168.23

Background measurements							
CPM	**tSIE**	**CPM**	**tSIE**	**CPM**	**tSIE**	**CPM**	**tSIE**
31.70	585.26	25.12	268.29	25.02	159.59	24.62	103.37
26.01	507.80	27.39	255.35	25.16	158.16	23.93	102.40
28.73	463.34	26.77	251.13	25.04	148.14	24.42	99.84
25.77	436.90	25.61	243.31	25.34	142.71	23.79	98.28
26.61	413.96	25.40	238.08	27.09	139.66	23.63	94.61
26.48	391.20	24.97	228.48	25.26	140.20	24.25	91.58
26.20	359.17	25.00	218.17	25.57	133.89	24.63	91.22
24.96	355.25	31.01	213.03	25.13	130.82	24.35	88.11
29.30	347.63	24.46	203.95	24.45	126.03	24.46	85.23
25.54	329.93	24.87	197.35	24.77	121.84	24.07	83.44
25.39	310.52	25.12	187.23	24.02	118.07	23.83	82.69
25.49	307.30	25.01	183.02	25.16	115.11	23.79	79.56
30.83	295.63	25.32	175.74	24.27	112.38	24.26	78.06
25.45	289.45	24.98	171.24	24.22	109.60		
25.10	277.24	25.95	164.93	24.48	104.74		

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