

Standard Gamma-Ray Spectra for the Comparison of Spectral Analysis Software

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ABSTRACT

Three sets of standard γ -ray spectra have been produced for use in assessing the performance of spectral analysis software. The origin of and rationale behind the spectra are described. Nine representative analysis systems have been tested both in terms of component performance and in terms of overall performance and the problems encountered in the analysis are discussed.

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1 INTRODUCTION

The purpose of this work was to create a set of test γ -ray spectra with which to assess the performance of spectral analysis systems, and to test the performance of a number of such systems in order to provide guidance on how to optimise their performance.

Users of spectrometers and spectral analysis software packages may require guidance about the key characteristics and robustness of software systems which are used in the process of the analysis of γ -ray spectra. Such guidance should cover the common problem areas encountered, specific problem areas which may arise from certain software or certain spectra, and how to get the best results from using such systems with a better understanding of the implications of the software performance.

Three sets of standardised spectra, of varying complexity, have been developed. These spectra may be used to assess the performance of commonly available systems in extracting key spectral features and also in identifying and quantifying the nuclide species present. This report describes the origin of and the rationale behind the spectra used, the performance of the systems tested both in terms of component performance (e.g. spectral analysis algorithms, nuclear data, species identification and quantification) and in terms of overall performance, and the problems encountered in the analysis.

It is not intended to recommend one particular analysis package in favour of another.

2 BACKGROUND

In the field of radioactivity measurements, intercomparison exercises involving measurements of “unknown” sources are an essential tool in validating methods and methodologies. However, there is a perceived need, within the γ -ray spectrometry community, for standard test spectra for the testing of their software analysis packages alone. Furthermore, many users of γ -ray spectrometry systems lack confidence in existing test spectra because they invariably have been subjected to some form of electronic manipulation.

2.1 Environmental Intercomparisons

Environmental radioactivity intercomparisons organised by NPL [1 - 8], have highlighted widespread concerns among the user community about the spectral analysis software in use. In general, the underlying assumptions forming the basis of the software algorithms are not transparent, giving rise to the possibility that the results derived from different packages may vary significantly.

In the environmental intercomparisons, the user is testing a complete detector, acquisition and analysis system, and thus has difficulty in identifying which errors may be attributable to the software package alone. This is particularly true for a typical user with a high throughput of sources, where time constraints mean that the analysis system is often treated as a “black box”, with little optimisation of the software being attempted.

2.2 Existing Test Spectra

Work has been done under the auspices of the IAEA to create standard spectra (the IAEA G1 test spectra) and to conduct an intercomparison [9, 10]. Sanderson and Decker [11] and Sanderson [12] have also evaluated software systems using standard spectra. The American National Standards Institute (ANSI) gives advice on how to conduct testing of γ -ray spectrometry programmes [13, 14] as does the International Electrotechnical Commission [15]. In each case, serious concerns were raised about the variability of results and some characteristics of these artificially generated test spectra have been criticised, whether validly or not (this is discussed in the overview by Gilmore and Hemingway [16]). A further issue revolves around the potential to produce a single figure of merit to compare software [17].

3 METHODOLOGY

Following discussions with the user community within the UK and the manufacturers of analysis software, various commonly used packages were selected for testing. At the same time, the various functions of the packages were reviewed and matched to user requirements to produce a relevant testing scheme.

3.1 Software Selected for Test

A survey of UK users revealed that the analysis packages listed below were representative of those commonly in use.

<u>Manufacturer</u>	<u>Package</u>	<u>Version</u>
Aptec Engineering	OSQ Professional	
Canberra Packard	Genie-ESP	4.0
	Genie-PC	2.2
	S100	3.1
	SAMPO90	
EG&G Ortec	GammaVision	2.4
	Maestro2	1.3
	Omnigam	3.5
F Computing	Fitzpeaks	

It should be noted that the versions of the analysis packages selected were those available at the time of the starting of testing. All of the manufacturers listed continually modify their software and so one may find that these packages have now been superseded by newer software versions or indeed software platforms.

The omission of one often used software package, Minigam (manufactured by EG&G Ortec), was because it was considered to be a "subset" of Omnigam. Additionally, it should be noted that the S100 and Maestro packages are "intelligent multi channel analysers (MCAs)" and, as such, if not coupled with a full analysis package, require "manual", rather than automated, quantification of nuclide activities.

3.2 Software Functions Tested

The following functions of the software were highlighted for testing;

- a) Nuclide identification - testing peak location, energy calibration, interference fitting and nuclear data combined to provide the ability to identify the correct nuclide or to attribute the peak to an escape peak, a backscatter peak or a sum peak.

- b) Quantification of activity levels for identified nuclides - testing virtually every aspect of the software.
- c) Uncertainty estimates - testing the assumptions made within the software regarding uncertainties in nuclear data, energy calibrations, efficiency calibrations, background subtraction etc.

Testing the calculation of peak areas was considered to have little value when quantifying the activity levels for identified nuclides. Different packages may use slightly different algorithms for this particular calculation. However, as long as the same package, and hence the same algorithm, is used both for calibration and for peak search and identification, then any differences should cancel and hence the quantification of activities should be consistent.

It was also considered that, given the nature of the generation of the spectra as well as the plethora of formulisms available, it would be unnecessarily confusing to try and define a definitive stance on minimum detectable activities. However, the spectra are such that a user, knowing the activities present, may test their own preferred formulism in this area.

3.3 Schedule for the Generation of the Test Spectra

The spectra developed to test the effectiveness of the analysis software were "real" spectra (as opposed to artificially produced test spectra), as preferred by the majority of users. They were derived from measurements of mixtures of previously standardised nuclides selected to test different aspects of the software. The standardisations of these radionuclides are traceable through the calibration of the NPL secondary standard re-entrant ionisation chambers to primary standards of radioactivity. There thus is high confidence in the knowledge of the nuclide quantities present.

The rationale behind the use of real spectra was that it is real spectra that an end user will have to analyse in the normal course of his/her work. While artificially produced spectra may be designed to test individual aspects of a package's capability, these are unlikely to produce an adequate test when these features are found combined with other features which may interfere with the performance of the software. The spectra were obtained from measurements on the NPL high resolution γ -ray spectrometry systems, with the measurement conditions varied to produce the sort of real problems which might be expected in the field. Further details of these measurement conditions and the radionuclides used are given in Section 4.

It was decided that the test spectra should be developed as three sets of three spectra, each consisting of two test spectra and one calibration spectrum. Of the two test spectra, one would specifically test those characteristics selected. The other would be a more realistic spectrum which may be found in the field. Again, further details are given in Section 4. Following study of the first set of spectra and extrapolation to the expected effects of the subsequent two sets of spectra, it was decided to also include background spectra with sets two and three.

3.3.1 Set 1 Spectra - Test Characteristics

The first set of spectra were designed to test the basic functions of the software package. These features are;

- a) Peak identification.
- b) Nuclide identification.
- c) Activity quantification.
- d) Ability to predict escape peaks.
- e) Ability to measure overlapping peaks.
- f) Ability to cope with differing peak widths.
- g) Ability to estimate uncertainties.

3.3.2 Set 2 Spectra - Test Characteristics

This set of spectra were designed to test the functions tested by the Set 1 spectra, together with the ability to accommodate true coincidence summing.

3.3.3 Set 3 Spectra - Test Characteristics

This set of spectra were designed to test the functions tested by the Set 1 spectra, together with the ability to allow for strong scattering, particularly the presence of backscatter peaks, and high levels of x-ray activities. In designing the measurement conditions for this set of spectra, it was realised that the presence of strong true coincidence summing could not be maintained and hence far less is present than in Set 2.

3.4 Rationale for Testing

All spectra were analysed by an "expert user" at default, or near default, settings of the software packages. Such analysis provided a consistent and uniform approach. Simultaneously, where possible within commercial and practical constraints, the spectra were analysed by the manufacturers of the software. This gave an independent check on the analysis by the expert user, with the manufacturer being free to fully optimise parameters and advise on the best analysis technique associated with a given package. As mentioned in Section 3.1, all manufacturers are actively involved in the ongoing development of their products and were also able to provide information as to whether or not the platform under test was still actively supported and if updates had affected the functions of the software under test.

3.5 Figure of Merit of Software Performance

In most situations the overall performance of a particular system would be judged on the ability to identify and quantify the nuclides present and give some indication of the uncertainties associated with the measurement.

The concept of some single "marking system" or figure of merit for the overall performance is not addressed by this report. The use of the u-test statistic in Section 5 is purely arbitrary and it is used solely to assist the authors in the assessment of problems which may be faced by users. It should not necessarily be taken to indicate that one software package performs better

4 THE TEST SPECTRA

With the exception of the first set of spectra, the sets comprised four spectra; calibration, optional background, source A and source B. For the first set, the optional background was omitted. All spectra were produced using a Canberra Genie-ESP spectroscopy system using a conversion gain of 8k (approximately 0.25 keV per channel), in order not to interfere with calibration settings and everyday quality assurance. The spectra were subsequently converted to 4k channels (approximately 0.5 keV per channel), which are those considered in this work. However, the 8k spectra were analysed by some of the manufacturers and are available for use if required.

In each case, source A was designed to produce a relatively simple spectrum containing ^{60}Co , ^{85}Sr and ^{137}Cs . Though described as simple, this combination of radionuclides does give some interesting features in the spectrum. A proportion of the γ -rays following the decay of ^{60}Co are absorbed by the pair production process, resulting in annihilation quanta at 511 keV. These quanta interfere with the 514 keV γ -rays from ^{85}Sr decay. Additionally, the peak at 511 keV will be wider than a normal γ -ray photopeak, due to Doppler broadening, making it more difficult to perform a proper fit to it. In principal, though probably of negligible importance, there will be a similar interference between the 662 keV γ -ray from ^{137}Cs decay and the "first" escape peak of the 1173 keV γ -ray from ^{60}Co decay.

The second source in each set, source B, was designed to mimic a more realistic situation which might be encountered by a user on a daily basis, such as an effluent stream. Each source B spectrum was produced from a mixture of ^{125}Sb , ^{134}Cs , ^{137}Cs , ^{152}Eu and ^{154}Eu . Such a combination produces a myriad of γ -rays, many of them interfering, with a wide range of intensities, testing the ability of each software package to the full.

The names of the spectra are such that each individual spectrum can be identified from its name alone. The format is

NPL_XX_N_Y_Z

where "XX" is "BS" for a background spectrum, "CS" for a calibration spectrum and "SS" for a standard spectrum,

"N" is the set number that the spectrum belongs to, i.e. "1", "2" or "3",

"Y" denotes the source type used, either "A" or "B",

"Z" is set to "4" to indicate a 4k spectrum and to "8" to indicate an 8k spectrum.

So, for example, NPLSS2A4 is the standard spectrum in set 2 produced using a source of type A and comprised 4k channels.

Although strictly speaking this report is only concerned with the 4k spectra, many of the details given are common to both lengths of spectra. Where this is the case, "Z" has been omitted from the title of the spectra.

4.1 Set 1 - NPLCS1, NPLSS1A and NPLSS1B

These spectra, shown in Figures 1 to 3, were generated by measurement of the sources using a beryllium-windowed n-type HPGe detector of 18 % efficiency at 1333 keV. The sources were measured at 550 mm from the face of the detector in order to reduce true coincidence summing to <0.1 %. Hence no “problems” were induced in the spectra and, as such, the basic performance of the analysis packages should be tested. A known number of pulses were injected into the test input of the detector preamplifier, so that the pulser method of correction for dead time and random summing may be employed if desired. If such a correction is made, then a dead time of 800 ns for the fixed conversion time ADC should be used. The detector and source were enclosed in an area shielded by of 100 mm of lead, internally lined with 1 mm of copper and cadmium. The internal dimensions of the coffin were 920 mm width, 1225 mm depth and 905 mm height.

4.1.1 NPLCS1 Source Details

The source used for this calibration spectrum was A399/96, a 2 ml glass ampoule containing 1 ml of NPL “mixed radionuclide” solution. The solution comprised ^{241}Am , ^{109}Cd , ^{57}Co , ^{139}Ce , ^{203}Hg , ^{113}Sn , ^{85}Sr , ^{137}Cs , ^{60}Co and ^{88}Y . Produced as part of the NPL June 1996 mixed radionuclide issue, the solution was prepared by gravimetric dilution of a mixture of the radionuclides concerned, the component nuclides of which had been individually assayed using a high pressure re-entrant ionisation chamber. The chamber had been previously calibrated for these radionuclides using absolute techniques. The activity concentrations of the radionuclides contained in this solution, together with the spectrum acquisition details, are given in Table 1.

4.1.2 NPLSS1A Source Details

Ampoules of ^{60}Co , ^{85}Sr and ^{137}Cs solutions were assayed on a previously calibrated high pressure re-entrant ionisation chamber in order to determine their activity concentrations. The same ampoules were also measured by γ -ray spectrometry to check for the presence of contaminants. None were found.

Aliquots of these solutions were gravimetrically dispensed into a weighing bottle and thoroughly mixed. The masses of the aliquots were designed such that, when the resultant solution was measured, the areas of the peaks resulting from the ^{60}Co 511 keV annihilation radiation and the ^{85}Sr 514 keV γ -ray would be in the ratio of approximately 1:1. Two 2 ml ampoules, A708/96 and A709/96, each containing 1 ml of the mixture solution were prepared. A708/96 was used to generate the spectrum, whilst A709/96 was set aside for further source preparation. The activity concentrations of the radionuclides contained in this solution, together with the spectrum acquisition details, are given in Table 2.

4.1.3 NPLSS1B Source Details

The activity concentrations of selected ^{125}Sb , ^{137}Cs , ^{134}Cs , ^{154}Eu and ^{155}Eu solutions were determined by assay with a previously calibrated high pressure re-entrant ionisation chamber. The ampoules were checked for the presence of contaminants by γ -ray spectrometry. In the ^{154}Eu solution, small amounts of ^{152}Eu and ^{155}Eu were present. Similarly, in the ^{155}Eu solution, trace quantities of ^{152}Eu and ^{154}Eu were found. The results from the ionisation chamber assay were corrected for the effects of these contaminants.

As with the source preparation for NPLSS1A, aliquots of these solutions were gravimetrically dispensed into a weighing bottle and thoroughly mixed. In this case, however, the masses of the aliquots were designed such that the ratio of the individual activity concentrations in the resulting solution would approximate to those found in a typical environmental sample. The target activity ratios together with those actually achieved are given below.

Nuclide	^{125}Sb	^{137}Cs	^{134}Cs	^{154}Eu	^{155}Eu
Target ratio	2	30	6	6	3
Achieved	2	29	5	6.2	2.8

From the mixed solution, two 2 ml ampoules, A521/96 and A522/96, were prepared, each containing 1 ml of solution. The latter ampoule was set aside for further source preparation, the former was used to generate the spectrum. The activity concentrations of the radionuclides in this solution, together with the spectrum acquisition details, are given in Table 3.

4.2 Set 2 - NPLBS2, NPLCS2, NPLSS2A and NPLSS2B

These spectra, shown in Figures 4 to 7, were generated using the same detection system as for the first set of spectra. However, in this case the sources were located at the face of the detector, the end cap of which was left in place to protect the fragile beryllium window. In such a configuration, measurable true coincidence summing effects for multiple γ -ray emitting nuclides may be expected.

With the sources to be placed so close to the detector, there was a concern over large dead time effects and imprecise correction for lost events. At NPL, it has been found experimentally that dead time corrections become unreliable if the system dead time is greater than $\sim 10\%$ when using a simple live time correction, or $\sim 20\%$ when using the pulser method of dead time correction. The solutions previously used to generate the set 1 spectra, were therefore gravimetrically diluted to produce sources whose total activities would limit the system dead time to less than 10% .

4.2.1 NPLBS2 Details

A simple background spectrum taken with all components of the detection system in place. This spectrum is provided for subtraction of the intrinsic detector background if so desired. The spectrum acquisition details are given in Table 4.

4.2.2 NPLCS2 Source Details

Ampoule A399/96, which was used to generate NPLCS1, was opened and half of the solution dispensed to a weighing bottle. The remaining solution was retained in order to provide traceability between this source preparation and that for the first set of spectra. To the bottle were added aliquots of ^{54}Mn and ^{65}Zn , whose activity concentrations were known from measurements in a previously calibrated high pressure re-entrant ionisation chamber. The masses of these aliquots were selected to yield peak areas similar to that which might be expected from the ^{60}Co and ^{88}Y radiations. Due to the presence of true coincidence summing it is strongly recommended that ^{60}Co and ^{88}Y are not used in any determination of the efficiency

of detection. As before, the solution in the weighing bottle was thoroughly mixed and a 2 ml ampoule, A1034/96, containing 1 ml of solution prepared in order to provide the calibration spectrum. The activity concentrations of the radionuclides in this solution, together with the spectrum acquisition details, are given in Table 5. Those for ^{60}Co and ^{88}Y are given for completeness; as already stressed, it is strongly recommended that these values are not used.

NPLSS2A Source Details

Ampoule A709/96, as prepared during the source preparation for the first spectral set, was opened and known aliquots dispensed to 2 ml ampoules A182/97 and A183/97. A182/97 was topped up to 1 ml of solution using an appropriate carrier, yielding a dilution factor of 8.798 with a standard uncertainty of 0.07%. This ampoule was then used to generate the spectrum. A183/97 was retained in order to provide a linkage between this source preparation and that for set 1. The activity concentrations of the radionuclides in this solution, together with the spectrum acquisition details, are given in Table 6.

NPLSS2B Source Details

In a similar manner as above, ampoule A520/96, prepared during the source preparation for the first set of spectra, was opened and gravimetrically dispensed to 2 ml ampoules A180/97 and A181/97; A180/97 having carrier solution added to provide the standard ampoule geometry, at a dilution factor of 5.600 with a standard uncertainty of 0.04%, and used to generate the spectrum, with A181/97 being retained to facilitate the traceability chain. The activity concentrations of the radionuclides in this solution, together with the spectrum acquisition details, are given in Table 7.

4.3 Set 3 - NPLBS3, NPLCS3, NPLSS3A and NPLSS3B

The aim of these spectra, shown in Figures 8 to 11, was to additionally test the performance of the various packages when large amounts of scattering were present, such as may arise when small lead enclosures are used to shield the detector from background radiation. For these spectra an n-type HPGe detector, of 11 % efficiency at 1333 keV, was employed. The normal shielding for this detector, which consists of 100 mm thick lead with 1 mm copper and cadmium, with internal dimensions 920 mm depth, 615 mm width and 630 mm height, was considered to be too large to produce the required effect. So, a second enclosure, of 50 mm thick lead, was constructed around the head of the detector. The internal dimensions of this additional enclosure were 250 mm depth, 150 mm width and 200 mm height. No inner copper and cadmium lining was provided. The sources were placed at a distance of 150 mm from the front face of the detector within this enclosure. Again, a pulser was injected into the spectrum to facilitate correction for dead time and random summing if desired. The ADC dead time which should be assumed is 800 ns.

NPLBS3 Details

An optional background spectrum measured with all system components and the inner enclosure in place. The spectrum acquisition details are given in Table 8.

4.3.2 NPLCS3 Source Details

As some of the radionuclides in the original calibration source were considered to be too weak at the date of measurement to provide a reliable detector calibration, a fresh mixed radionuclide solution was prepared. Prepared as part of the June 1997 NPL "mixed radionuclide" standard issue, this solution comprised the normal 10 calibration nuclides, ^{241}Am , ^{109}Cd , ^{57}Co , ^{139}Ce , ^{203}Hg , ^{113}Sn , ^{85}Sr , ^{137}Cs , ^{60}Co and ^{88}Y . Though minimal true coincidence summing should be expected at a source to detector distance of 150 mm, gravimetrically dispensed aliquots of ^{54}Mn and ^{65}Zn were added to this mixture in order that the ^{60}Co and ^{88}Y radiations would not need to be used for calibration purposes if any summing was seen. In practice none was and the data from these radiations may be used. Again, the source was prepared as 1 ml of solution in a 2 ml ampoule. The activity concentrations of the radionuclides in this solution, together with the spectrum acquisition details, are given in Table 9.

4.3.3 NPLSS3A and NPLSS3B Source Details

The previously prepared ampoules A182/97 (^{60}Co , ^{85}Sr , ^{137}Cs) and A180/97 (^{125}Sb , ^{137}Cs , ^{134}Cs , ^{154}Eu , ^{155}Eu) were used to generate the spectra, thus providing a direct linkage to the second set of spectra. The activity concentrations, corrected to the new reference time of the start of acquisition, together with the spectrum acquisition details, are given in Tables 10 and 11.

5 RESULTS

The results of the analyses of the spectra by the expert user and, where available, by the manufacturer of the package under investigation are given in Tables 12 to 20 for the set 1 spectra, Tables 21 to 29 for the set 2 spectra and Tables 30 to 38 for the set 3 spectra. As a guide to the level of agreement of the values given with the NPL activity values, a u-test has been applied.

The value of the u-statistic [18] was calculated as

$$u\text{-statistic} = \frac{|\text{Analyst's result} - \text{NPL value}|}{\sqrt{\text{Analyst's uncertainty}^2 + \text{NPL uncertainty}^2}}$$

This statistic was then compared with values in the t-statistic tables [19] and assessed in accordance with the criteria in Table 39.

It must be stressed that the u-statistic does not give a definitive answer as to how well a package is fitting the peaks in the spectra, but rather highlights if a problem has occurred. For instance, a high value of the u-statistic may be obtained if summing is present in the spectrum or if the uncertainties are being underestimated.

The calculated u-statistics are given in the results tables and where each package fell in relation to the u-test criteria for each nuclide is summarised in Tables 40 to 45 for the A-series spectra and Tables 46 to 51 for the B-series spectra. The nomenclature used within these tables is "XY" where "X" is "E" for the expert user and "M" for the manufacturer, and "Y" indicates the spectral set number (1, 2 or 3). It is interesting to note that, in general, most packages will give a "correct" answer ($u \leq 1.64$) or a "wrong" answer ($u > 3.29$); intermediate values of the u-statistic do occur but are less common.

The results for each package, analysing each spectrum, will not be considered in fine detail. Rather, the general problems encountered will be examined. For information, the full text of the comments made by the expert user is given in appendix 1.

5.1 MCA Emulators versus Full Analysis Packages

Two MCA emulators were used in this work, Maestro2 and S100. Peak areas were obtained from the packages and manipulated externally to yield activity concentrations. In general, such analysis was dependant on the user's expertise and was time consuming. However, by paying careful attention to detail during the calculations the expert user was often able to spot problem areas and attempt to fine tune his results.

All the other packages tested were fully automated analysis packages. They are far more powerful analytically than the MCA emulators, having the capability of fitting analytical functions to the peaks. Thus, they may relatively easily deconvolute overlapping peaks giving a more precise analysis of a complex spectrum. One drawback that an inexperienced user may find is the large number of analysis parameters that may be varied. It could be envisaged that

such a user may get erroneous results from inappropriately varying a parameter.

5.2 ^{85}Sr Analysis

^{85}Sr has a single γ -ray at 514 keV with a high γ -ray emission probability, P_γ equal to 0.984. It is thus ideal as a calibration radionuclide, particularly as it cannot be subject to true coincidence summing. However, analysis problems may arise if there is a strong annihilation peak at 511 keV which may significantly overlap with the 514 keV γ -ray. This is the case with both NPLCS14 and NPLSS1A4. Neither of the MCA emulators could deconvolute this multiplet and, hence, this line could not be used for calibration and for NPLSS1A4 the expert user could only note the presence of ^{85}Sr rather than report an activity concentration. The other analytical packages did report activity concentrations for ^{85}Sr after deconvoluting the peaks. In general, these were relatively accurate values. However, it is noticeable that the uncertainties quoted for these activity concentrations were significantly greater than for the other nuclides in the spectrum.

It should be noted that this is a difficult deconvolution to perform. Whilst both peaks display the basic Gaussian shape with low energy tailing, the 511 keV peak is significantly wider due to the effect of Doppler broadening. The same problem will occur for a multiplet where one of the components is a single escape peak.

In NPLSS1A4, the 511 keV component is reduced in comparison to the 514 keV γ -ray with the peak areas being in the ratio of approximately 1:2. Most packages again reported the presence of ^{85}Sr , but, with a few exceptions, with an increased uncertainty. The poorer counting statistics in NPLSS2A4 partially explain this; by a simplistic estimation one would expect an increase in the uncertainty of the order of 50 %. However, many uncertainties trebled. This would seem to indicate that moving away from a unity ratio, the deconvolution process becomes more difficult. For NPLSS3A4, the situation was reversed with the ^{85}Sr content being very small. In the analysis by the expert user, all but one of the packages failed to find the 514 keV γ -ray, and from the data available from the manufacturers, the peak was only located if the peak locate threshold was lowered. This latter option requires to be approached with caution as the likelihood of non-existent peaks being reported in the spectrum increases.

5.3 Nuclide Libraries

Programs such as GammaVision and Genie-PC are supplied with large reference libraries. It is not intended that these libraries should be used in their entirety, but rather that smaller working libraries be constructed from them. This is not a problem for calibration spectra where the nuclide composition is known or in the instance where a user is searching for specific radionuclides. However, in the case of these standard spectra where, for the purpose of the analyses, the nuclide composition was not known by the expert user or the manufacturers, the choice of a working library is harder. In most cases, this problem was circumnavigated by initially running the analysis with either a blank or basic nuclide library and then using the peak energy information to tentatively identify possible nuclides that are present. A more appropriate library could then be constructed. In the case of the analyses by the expert user, this process was taken one step further by the inclusion of additional nuclides which would interfere with those nuclides identified as being present. In this manner, the software was forced to make choices about which nuclides were present. For instance, the inclusion of both ^{22}Na and ^{154}Eu in the library gives an ambiguity at 1274 keV; if a peak is present at this energy, from which

radionuclide does it arise? In general, the programs coped well and correctly identified the radionuclides present.

One problem which was found when large libraries were in use during energy calibration was if the calibration was library driven, i.e. data were taken directly from the nuclide library rather than being supplied by the user. Sometimes the calibration table was limited in size and was ordered by energy. Then it was found that the table would rapidly fill up with low energy data, much of which was superfluous, and valid high energy data would be ignored. This led to a large uncertainty in the high energy calibration through unnecessary extrapolation.

Further problems arose if the nuclide library was too small. Some default libraries do not have data for the europium isotopes. This led to a confident, but incorrect, report of the presence of ^{22}Na . For this reason default libraries were not used, the method described above being preferred. A second problem arose from the number of lines in a library being limited. Normally a maximum of approximately ten lines is sufficient to quantify a radionuclide and so γ -rays with low emission probabilities are omitted. ^{152}Eu and ^{154}Eu both produce a γ -ray at 1408 keV with emission probabilities of P_γ equal to 0.2085 and P_γ equal to 0.00023 respectively. The latter is so small that it is normally omitted from program reference libraries. However, as noted in Section 4.1.3, a small amount of ^{152}Eu is present as a contaminant in the B-series spectra. The activity ratio of these isotopes is approximately 1:155 and hence the 1408 keV peak is comprised approximately 83 % ^{152}Eu emissions and 17 % ^{154}Eu emissions. Some programs, such as Fitzpeaks, did correctly apportion this peak, but many simply ascribed it to ^{152}Eu as the data for the ^{154}Eu 1408 keV γ -ray was not present in the library.

5.4 Sources of Nuclear Data

Whilst the nuclear data used by the packages did not introduce serious errors in the results, it was noted that some packages still use nuclear data that is some twenty years old and often do not give, and therefore cannot propagate, uncertainties. With the plethora of good, up to date, data compilations readily available today, this was found to be an unacceptable situation. Discussions with the manufacturers revealed that they are becoming more aware of this situation and the unease that it causes.

5.5 False Identification of Radionuclides

This was found to be somewhat of a grey area as it is inextricably linked to several sensitivity parameters and to the quality and content of the nuclear data libraries. In general, the larger the nuclide library and the more sensitive the peak search, the more "additional" nuclides are likely to be found. If the history of the sample is known, then the data library can be suitably adjusted and the sensitivity parameters set to appropriate values; thus the effect may be minimised. If the spectra are "unknowns", as was the case here for the expert user and the manufacturers, then only experience can be used, e.g. Is the half life sensible? Are there substantial peaks from the same nuclide which were not detected?

One problem, which was often observed, is in the 80 keV to 90 keV region where one or other of the lead x-rays was ascribed to ^{109}Cd . As ^{109}Cd is a common calibration radionuclide, one way to avoid this misidentification was to include it in the library used on the calibration spectra, but to omit it from the library used in the analysis of the other spectra. The ploy of introducing

interfering radionuclides into the analysis library had no noticeable effect upon the performance of the packages.

5.6 Efficiency Calibration

The main problem which was encountered here was that of which function to use. Often there is a choice between a single polynomial of order "n", or a double polynomial of orders "n" and "m" with a specified join point or a spline fit (normally cubic). There was no easy way to choose between these functions; experience and a visual scrutiny of the degree of fit was the only solution.

It was also unclear as to how uncertainties were assessed in the efficiency calculation. This was particularly true for interpolated or extrapolated values, with the method of uncertainty propagation (that is the way in which known uncertainties are combined to produce a new uncertainty) not being clear, if indeed the uncertainties were propagated at all.

Particular care needs to be taken when true coincidence summing is present (see Section 5.7).

5.7 True Coincidence Summing

True coincidence summing (TCS) was deliberately introduced as a significant component of the set 2 spectra. The problems started with NPLCS24. Most commonly used calibration nuclides are single γ -ray emitters and thus not affected by this type of summing. However, ^{60}Co and ^{88}Y may give rise to TCS. For this reason, ^{54}Mn and ^{65}Zn were included in the source as alternatives. This then poses a fresh problem in that if ^{60}Co and ^{88}Y are omitted, the highest calibration energy available is 1115 keV and large extrapolations may be required. McFarland [20], has argued that, if this is the case, an inaccurate data point on the boundary of the data set should be retained as the lesser problem. However, for NPLCS14, there are four such points, which was considered unacceptable and hence these were omitted in the standard analysis.

The wisdom of this decision was graphically illustrated by analysing the spectra, with one of the packages, with and without ^{60}Co and ^{88}Y present in the calibration. One can easily foresee that the high energy calibration curve may be inaccurate with the extra points present, but a user could believe that negligible error would be introduced at lower energies. This was not found to be the case. Taking the 105 keV γ -ray peak of ^{155}Eu in NPLSS2B4, the calculated activity concentration was 3.29 kBq/g $\pm$ 14% (with ^{60}Co and ^{88}Y present in the calibration) and 3.63 kBq/g $\pm$ 3.5% (without ^{60}Co and ^{88}Y present in the calibration). The whole efficiency curve appears to be distorted by the inclusion of the nuclides subject to TCS.

Taking the standard spectra themselves, for NPLSS2A4 the measured values for ^{60}Co are not in good agreement with the known activity concentrations. This is indicative of the programs not coping with even the simplest case of TCS. This situation is worse for NPLSS2B4 with all measured activity concentrations being discrepant from the known values. As ^{137}Cs (no TCS) and ^{155}Eu (little TCS, for 86 keV γ -ray only) seem to be affected, this appears to indicate a non-negligible amount of random summing is present as well. The random summing could be compensated for by the use of the pulser method, but again no correction has been made for the TCS. Some packages have attempted, at one stage or another, to allow for TCS by the optional use of a global correction factor. However, this is of very limited use as TCS is both dependant upon the nuclide and the γ -ray detection efficiency. It should be noted that TCS corrections may

be rigorously calculated, but this is complex and time consuming and therefore not generally recommended for routine operations.

One solution to TCS is to compare a nuclide of unknown activity concentration directly against a standard of that radionuclide in the same geometry. In this manner, TCS effects will cancel out. For instance, using the Maestro software, if the 1173 keV ^{60}Co peak in NPLSS2A4 is compared directly against the same peak in NPLCS24, the derived activity concentration rises from 19.7 kBq/g to 21.11 kBq/g compared with a known value of 21.44 kBq/g.

5.8 Increased Amounts of Scatter

In the third set of spectra, a small ungraded shield was used, increasing the prominence of lead x-rays and increasing the amount of scatter. In general, the programs had no problem with increased scattering indicating that such shielding could be used provided the user was aware that the set-up was not suitable for measurements in the lead x-ray region of spectra. Indeed, whilst the efficiency calibration derived from NPLCS34 appeared to be normal, closer scrutiny in the x-ray region showed that there was a distortion.

The detector used was an n-type germanium, yet the derived efficiency calibration curve appeared more like that from a p-type detector with the efficiency below a turnover point at 88 keV, somewhat lower in energy than normal, rapidly falling away. Revisiting the spectrum revealed a significant unresolvable interference between the ^{109}Cd 88.03 keV γ -ray and the lead $K_{\beta 2}$ x-ray at 87.63 keV. The preferred course of action would be not to use the ^{109}Cd calibration point, but care must then be taken not to adversely affect the calculation of the ^{155}Eu activity concentration. In the event, most packages reported reasonably accurate activity concentrations, whichever method was used.

6 CONCLUSIONS AND RECOMMENDATIONS

Three sets of standard γ -ray spectra have been produced and tested with a variety of software analysis packages. It should be stressed, that the purpose of this work is not to recommend a single package, but rather to highlight the general problems that a user may encounter in their use. Selection of a given package is very much a personal choice for the user where considerations such as nature and frequency of use, and even the type of user interface, need to be addressed. Overviews of each package tested are given in the expert users notes in Appendix 1; these are the personal views of one individual and may vary from user to user.

It is recommended that the standard spectra be analysed as "blind" samples in the first instance, giving a more thorough test of the user's package and of the user. Later, knowledge of the activity concentrations of the constituent radionuclides present may be used to improve both the performance of the package and the user.

6.1 Calibration

This is one of the most vital aspects of any analysis. After using the calibration spectrum for a particular spectrum set to establish the energy, shape and efficiency calibrations, it is recommended that the spectrum be reread as an unknown spectrum and the new calibration file used to analyse it. The nuclide activity concentrations obtained in this manner should be close to the values that were entered in the calibration file, with extra uncertainty added due to fitting in the efficiency function.

At all stages of calibration, the fits to each calibrated parameter, in particular the efficiency function, should be visually inspected to ensure a realistic fit. Any outlying points or distortion of the fit should be fully investigated and consideration given as to whether points should be excluded from the fit. This is particularly true when summing is present, through measurement in a close detector geometry, as is the case in set 2 of these spectra.

These remarks on calibration not only apply to these standard spectra, but are true for any real measuring situation.

6.2 Spectral analysis

Once the calibrations have been performed, it is a relatively simple task to run the analysis of the spectra, except in the case of the MCA emulators where manual calculations are required. What is often harder is the interpretation of the results of the analysis and this can only come with experience.

6.2.1 Set 1

Set 1 of the spectra were designed to test the basic functions of the software packages. Peak identification and nuclide identification were both performed satisfactorily. Activity quantification was also performed reasonably, though there were a few, inexplicable, exceptions. None of the packages tested reported the possible locations of escape peaks, backscatter peaks or Compton edges which could potentially interfere with the analysis. The calculations to facilitate this are simple and it would be an advantage to some if such information were to be recorded by the packages.

As many of the peaks in the B-series of spectra are part of multiplets, it can be deduced that the packages are deconvoluting them in an adequate manner and hence, in general, this does not pose too much of a problem. In a similar manner, as described Section 5.2, the packages appear to cope with the different peak width of the 511 keV annihilation peak and its deconvolution from the 514 keV ^{85}Sr γ -ray, though there is evidence that this becomes a harder task as the ratio of 511 keV radiation to 514 keV radiation changes. There is not enough evidence in this work to quantify if this is predominantly due to the larger peak width or applies to the multiplets in general.

The ability to estimate uncertainties has been highlighted as a problem. Packages vary in whether or not uncertainties are propagated or if that is provided as an option. Some of the results obtained have obviously not had uncertainty propagation performed and as a result the uncertainties are clearly underestimated. A further problem is that it is not always clear how the uncertainties have been estimated in the first place. It is recommended that the user looks very carefully at this area when producing results and allows for any uncertainties that the program may not have taken into account. It is always better to overestimate an uncertainty than to underestimate it. The user should also check at what confidence level (68 %, 95 % etc.) the uncertainties are being reported, as this can also hinder the correct interpretation of results.

6.2.2 Set 2

The spectra in set 2 were specifically designed to test the response of the programs to true coincidence summing (TCS). It has been shown in Section 5.7 that this is a major problem. With the exception of one program, Fitzpeaks, none of the packages tested reported the possible presence of sum peaks. Fitzpeaks was unique in flagging possible sum peaks and reporting their probable origin. However, in common with the other programs, it does not perform an automatic TCS correction.

Without resorting to complex calculations, there are two solutions to this problem. One is for the user to always ensure that any sample is counted far enough away from the detector that TCS is negligible. Practical advice on this matter is provided in reference 16. The second way of avoiding the problem should be used if close geometry measurements are unavoidable, for instance when using Marinelli beakers as source containers. Interpolation of efficiency curves should not be used, if at all possible, in these cases. Direct comparison with a standardised source in the same geometry should be employed.

6.2.3 Set 3

The scattering induced in the third set of spectra did not give the analysis packages undue problems with the analysis. However, these spectra do illustrate that difficulties can occur in the lead x-ray region if these x-rays are prominent. Hence, whilst relatively small shields may be employed, they should be graded, preferably with a copper and cadmium lining, in order to reduce the lead x-rays to as low a level as possible.

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Table 1. NPLCS1 - Set 1, calibration spectrum.

Sample mass	0.98758(9) g
Reference date	1 June 1996 12:00 GMT
Acquisition date	30 July 1996 16:21 GMT
Live time	78594 s
Real time	78657 s
Pulses given	267759

²⁴¹ Am	2815 Bq/g $\pm$ 0.83%
	17399 Bq/g $\pm$ 0.50%
	598 Bq/g $\pm$ 0.40%
	978 Bq/g $\pm$ 0.21%
²⁰³ Hg	1150 Bq/g $\pm$ 0.34%
¹¹³ Sn	2768 Bq/g $\pm$ 0.30%
⁸⁵ Sr	4257 Bq/g $\pm$ 0.32%
¹³⁷ Cs	3385 Bq/g $\pm$ 0.46%
⁸⁸ Y	13613 Bq/g $\pm$ 0.17%
	4576 Bq/g $\pm$ 0.19%

Table 2. NPLSS1A - Set 1, standard spectrum, source type A.

Sample mass	1.06140(9) g
Reference date	25 July 1996 12:00 GMT
Acquisition date	7 August 1996 16:36 GMT
Live time	75197 s
Real time	75721 s
Pulses given	257756
⁶⁰ Co	204.0 kBq/g $\pm$ 0.22%
⁸⁵ Sr	1.275 kBq/g $\pm$ 0.85%
¹³⁷ Cs	14.47 kBq/g $\pm$ 0.70%

Table 3. NPLSS1B - Set 1, standard spectrum, source type B.

Sample mass	0.98419(11) g
Reference date	16 July 1996 17:08 GMT
Acquisition date	16 July 1996 17:08 GMT
Live time	56811 s
Real time	57381 s
Pulses given	195250
¹²⁵ Sb	22.90 kBq/g $\pm$ 0.71%
¹³⁷ Cs	337.7 kBq/g $\pm$ 0.69%
¹³⁴ Cs	55.77 kBq/g $\pm$ 0.68%
¹⁵² Eu	72.84 kBq/g $\pm$ 0.70%
¹⁵⁵ Eu	27.25 kBq/g $\pm$ 0.54%
¹⁶² Eu	~ 477 Bq/g

Table 4. NPLBS2 - Set 2, background spectrum.

Live time	217520 s
Real time	217565 s
Pulses given	937969

Table 5. NPLCS2 - Set 2, calibration spectrum.

Sample mass	0.99796(7) g
Reference date	27 February 1997 17:18 GMT
Acquisition date	27 February 1997 17:18 GMT
Live time	57618 s
Real time	59766 s
Pulses given	257553

²⁴¹ Am	1434 Bq/g ± 0.83%
¹⁰⁹ Cd	5909 Bq/g ± 0.51%
⁵⁷ Co	153 Bq/g ± 0.41%
¹³⁹ Ce	127 Bq/g ± 0.22%
²⁰³ Hg	10.4 Bq/g ± 0.36%
¹¹³ Sn	276 Bq/g ± 0.31%
⁸⁵ Sr	120 Bq/g ± 0.33%
¹³⁷ Cs	1697 Bq/g ± 0.46%
⁸⁸ Y	1191 Bq/g ± 0.18%
⁶⁰ Co	2117 Bq/g ± 0.20%
⁵⁴ Mn	2457 Bq/g ± 0.47%
⁶⁵ Zn	4210 Bq/g ± 0.69%

Table 6. NPLSS2A - Set 2, standard spectrum, source type A.

Sample mass	0.94303(19) g
Reference date	28 February 1997 10:01 GMT
Acquisition date	28 February 1997 10:01 GMT
Live time	16054 s
Real time	17502 s
Pulses given	75396
⁶⁰ Co	21.44 kBq/g $\pm$ 0.23%
⁸⁵ Sr	14.10 Bq/g $\pm$ 0.86%
¹³⁷ Cs	1.622 kBq/g $\pm$ 0.71%

Table 7. NPLSS2B - Set 2, standard spectrum, source type B.

Sample mass	0.96244(8) g
Reference date	28 February 1997 14:58 GMT
Acquisition date	28 February 1997 14:58 GMT
Live time	4253 s
Real time	5398 s
Pulses given	23265
¹²⁵ Sb	3.499 kBq/g $\pm$ 0.71%
¹³⁷ Cs	59.43 kBq/g $\pm$ 0.69%
¹³⁴ Cs	8.804 kBq/g $\pm$ 0.68%
¹⁵⁴ Eu	12.37 kBq/g $\pm$ 0.70%
¹⁵² Eu	4.452 kBq/g $\pm$ 0.61%
¹⁵² Eu	~ 80 Bq/g

Table 8. NPLBS3 - Set 3, background spectrum.

Live time	234414 s
Real time	234454 s
Pulses given	736610

Table 9. NPLCS3 - Set 3, calibration spectrum.

Sample mass	0.96593(12) g
Reference date	17 April 1997 14:00 GMT
Acquisition date	17 April 1997 14:00 GMT
Live time	5788 s
Real time	5824 s
Pulses given	18256

²⁴¹ Am	3536 Bq/g $\pm$ 0.54%
¹⁰⁹ Cd	21159 Bq/g $\pm$ 1.85%
⁵⁷ Co	930 Bq/g $\pm$ 0.73%
¹³⁹ Ce	975 Bq/g $\pm$ 1.07%
²⁰³ Hg	1063 Bq/g $\pm$ 0.70%
¹¹³ Sn	2768 Bq/g $\pm$ 0.70%
⁸⁵ Sr	4871 Bq/g $\pm$ 0.71%
¹³⁷ Cs	1855 Bq/g $\pm$ 0.71%
⁸⁸ Y	11928 Bq/g $\pm$ 0.51%
⁶⁰ Co	4655 Bq/g $\pm$ 0.42%
⁵⁴ Mn	3715 Bq/g $\pm$ 0.37%
⁶⁵ Zn	6337 Bq/g $\pm$ 0.69%

Table 10. NPLSS3A - Set 3, standard spectrum, source type A.

Sample mass	0.94303(19) g
Reference date	22 April 1997 15:12 GMT
Acquisition date	22 April 1997 15:12 GMT
Live time	79945 s
Real time	80265 s
Pulses given	252196
⁶⁰ Co	21.03 kBq/g $\pm$ 0.23%
⁹⁰ Sr	7.988 Bq/g $\pm$ 0.86%
¹³⁷ Cs	1.617 kBq/g $\pm$ 0.71%

Table 11. NPLSS3B - Set 3, standard spectrum, source type B.

Sample mass	0.96244(8) g
Reference date	22 April 1997 09:19 GMT
Acquisition date	22 April 1997 09:19 GMT
Live time	19579 s
Real time	19788 s
Pulses given	62157
¹²⁵ Sb	3.374 kBq/g $\pm$ 0.71%
¹³⁷ Cs	59.24 kBq/g $\pm$ 0.69%
¹³⁴ Cs	7.701 kBq/g $\pm$ 0.68%
¹⁵⁴ Eu	12.23 kBq/g $\pm$ 0.70%
Eu	4.361 kBq/g $\pm$ 0.64%
¹⁵² Eu	~ 80 Bq/g

Table 12. Set 1 - APTEC OSQ/PROFESSIONAL v6.31

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
⁶⁰ Co	204.0 ± 0.22%	215 ± 3.6% 1.42
⁸⁵ Sr	1.275 ± 0.85%	2.08 ± 3.3% 11.58
¹³⁷ Cs	14.47 ± 0.70%	15.5 ± 2.8% 2.31

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
¹²⁵ Sb	22.90 ± 0.71%	26.2 ± 3.0% 4.11
¹³⁷ Cs	337.7 ± 0.69%	331 ± 2.8% 0.70
¹³⁴ Cs	55.77 ± 0.68%	56.8 ± 2.7% 0.65
¹⁵⁴ Eu	72.84 ± 0.70%	72.0 ± 1.6% 0.67
¹⁵⁵ Eu	27.25 ± 0.54%	27.7 ± 2.5% 0.64
¹⁵² Eu	~ 477 Bq/g	-

Table 13. Set 1 - CANBERRA GENIE-ESP v4.0

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
^{60}Co	$204.0 \pm 0.22\%$	$200 \pm 0.12\%$ 7.86
^{85}Sr	$1.275 \pm 0.85\%$	$1.26 \pm 3.2\%$ 0.36
^{137}Cs	$14.47 \pm 0.70\%$	$14.7 \pm 0.66\%$ 1.64

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
^{125}Sb	$22.90 \pm 0.71\%$	$22.1 \pm 1.5\%$ 2.17
^{137}Cs	$337.7 \pm 0.69\%$	$335 \pm 0.11\%$ 1.14
^{134}Cs	$55.77 \pm 0.68\%$	$55.3 \pm 0.44\%$ 1.04
^{154}Eu	$72.84 \pm 0.70\%$	$73.0 \pm 2.0\%$ 0.10
^{155}Eu	$27.25 \pm 0.54\%$	$26.7 \pm 2.2\%$ 0.91
^{152}Eu	$\sim 477 \text{ Bq/g}$	$104 \text{ Bq/g} \pm 1.4\%$.

Table 14. Set 1 - CANBERRA GENIE-PC v2.2

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
⁶⁰ Co	204.0 ± 0.22%	204.3 ± 0.95% _{0.15}	201.3 ± 0.28% _{3.75}
⁸⁵ Sr	1.275 ± 0.85%	1.363 ± 5.7% _{1.12}	1.363 ± 2.6% _{2.37}
¹³⁷ Cs	14.47 ± 0.70%	14.47 ± 1.5% _{0.00}	14.63 ± 0.76% _{1.06}

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
¹²⁵ Sb	22.90 ± 0.71%	21.86 ± 1.5% _{2.84}	22.26 ± 1.1% _{2.18}
¹³⁷ Cs	337.7 ± 0.69%	333.3 ± 1.4% _{1.85}	335.7 ± 0.54% _{0.68}
¹³⁴ Cs	55.77 ± 0.68%	52.41 ± 0.88% _{5.63}	54.48 ± 0.36% _{3.02}
¹⁵⁴ Eu	72.84 ± 0.70%	72.17 ± 0.53 _{1.05}	71.97 ± 0.66% _{1.51}
¹⁵⁵ Eu	27.25 ± 0.54%	25.45 ± 5.2% _{1.35}	28.40 ± 2.0% _{1.96}
¹⁵² Eu	~ 477 Bq/g	503 Bq/g ± 10.1% .	475 Bq/g ± 9.4% .

Table 15. Set 1 - CANBERRA S100 v3.1

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
⁶⁰ Co	204.0 ± 0.22%	202 ± 1.1% 0.88
⁸⁵ Sr	1.275 ± 0.85%	present -
¹³⁷ Cs	14.47 ± 0.70%	14.5 ± 1.4% 0.13

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
¹²⁵ Sb	22.90 ± 0.71%	21.5 ± 1.6% 3.68
¹³⁷ Cs	337.7 ± 0.69%	330 ± 1.3% 1.58
¹³⁴ Cs	55.77 ± 0.68%	54.4 ± 1.0% 2.07
¹⁵⁴ Eu	72.84 ± 0.70%	72.0 ± 1.5% 0.70
¹⁵⁵ Eu	27.25 ± 0.54%	28.9 ± 2.1% 2.64
¹⁵² Eu	~ 477 Bq/g	539 Bq/g ± 30% -

Table 16. Set 1 - CANBERRA SAMPO90 v3.1M

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
⁶⁰ Co	204.0 ± 0.22%	200 ± 0.1% 8.14
⁸⁵ Sr	1.275 ± 0.85%	1.9 ± 6.0% 5.46
¹³⁷ Cs	14.47 ± 0.70%	13.5 ± 0.5% 7.97

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
¹²⁵ Sb	22.90 ± 0.71%	26.5 ± 0.55% 16.49
¹³⁷ Cs	337.7 ± 0.69%	93.3 ± 14% 18.42
¹³⁴ Cs	55.77 ± 0.68%	59.6 ± 1.1% 5.06
¹⁵⁴ Eu	72.84 ± 0.70%	present ¹ .
¹⁵⁵ Eu	27.25 ± 0.54%	25.1 ± 0.4% 12.07
¹⁵² Eu	~ 477 Bq/g	present ² .

1) Peaks reported but nuclide not identified.

2) Increase in sensitivity gives a reported value of 6.539 kBq/g ± 0.48%

Table 17. Set 1 - EG&G GAMMAVISION v2.4

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer ¹ _{u-test}
⁶⁰ Co	204.0 ± 0.22%	183 ± 1.9% _{2.98}	202.2 ± 0.08% _{3.77}
⁸⁵ Sr	1.275 ± 0.85%	1.28 ± 3.4% _{0.11}	1.285 ± 3.09% _{0.24}
¹³⁷ Cs	14.47 ± 0.70%	14.4 ± 2.0% _{0.23}	14.23 ± 0.55% _{1.87}

1) Counting uncertainties only.

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer ¹ _{u-test}
¹²⁵ Sb	22.90 ± 0.71%	22.3 ± 2.2% _{1.16}	22.71 ± 0.99% _{0.68}
¹³⁷ Cs	337.7 ± 0.69%	346 ± 1.9% _{1.19}	334.9 ± 0.09% _{1.19}
¹³⁴ Cs	55.77 ± 0.68%	56.1 ± 1.9% _{0.29}	54.48 ± 0.23% _{3.23}
¹⁵⁴ Eu	72.84 ± 0.70%	73.7 ± 1.9% _{0.58}	73.10 ± 0.20% _{0.49}
¹⁵⁵ Eu	27.25 ± 0.54%	25.7 ± 1.9% _{2.22}	27.82 ± 0.41% _{3.06}
¹⁵² Eu	~ 477 Bq/g	1564 Bq/g ± 11% ₋	< 58 Bq/g ₋

1) Counting uncertainties only.

Table 18. Set 1 - EG&G MAESTRO 2 v1.3

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer ¹
⁶⁰ Co	204.0 ± 0.22%	201 ± 1.0% 1.46	yes
⁸⁵ Sr	1.275 ± 0.85%	present	yes n/l
¹³⁷ Cs	14.47 ± 0.70%	14.4 ± 1.3% 0.33	yes

1) Manufacturer reported peak areas only
n/l: nuclide probably not in library.

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User	Manufacturer ¹
¹²⁵ Sb	22.90 ± 0.71%	21.7 ± 1.4% 3.48	yes n/l
¹³⁷ Cs	337.7 ± 0.69%	330 ± 1.2% 1.68	yes
¹³⁴ Cs	55.77 ± 0.68%	54.4 ± 1.4% 1.61	yes n/l
¹⁵⁴ Eu	72.84 ± 0.70%	72.0 ± 1.5% 0.70	yes n/l
¹⁵⁵ Eu	27.25 ± 0.54%	27.1 ± 1.8% 0.29	yes n/l
¹⁵² Eu	~ 477 Bq/g	525 Bq/g ± 18%	no

1) Manufacturer reported peak areas only.
n/l: nuclide probably not in library.

Table 19. Set 1 - EG&G OMNIGAM v3.5

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer ¹ _{u-test}
⁶⁰ Co	204.0 ± 0.22%	215 ± 1.9% _{2.68}	201.8 ± 0.08% _{4.61}
⁸⁵ Sr	1.275 ± 0.85%	0.89 ± 5.2% _{8.10}	1.221 ± 3.23% _{1.32}
¹³⁷ Cs	14.47 ± 0.70%	14.2 ± 2.0% _{0.90}	13.93 ± 0.60% _{4.11}

1) Counting uncertainties only.

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer ¹ _{u-test}
¹²⁵ Sb	22.90 ± 0.71%	21.8 ± 2.2% _{2.17}	21.81 ± 1.33% _{3.28}
¹³⁷ Cs	337.7 ± 0.69%	204 ± 1.9% _{29.56}	322.2 ± 0.22% _{6.36}
¹³⁴ Cs	55.77 ± 0.68%	33.5 ± 1.9% _{30.06}	51.08 ± 0.22% _{11.86}
¹⁵⁴ Eu	72.84 ± 0.70%	61.8 ± 1.9% _{8.62}	54.38 ± 0.27% _{34.79}
¹⁵⁵ Eu	27.25 ± 0.54%	23.3 ± 2.7% _{6.11}	< 49 Bq/g ₋
¹⁵² Eu	~ 477 Bq/g	-	< 56 Bq/g ₋

1) Counting uncertainties only.

Table 20. Set 1 - I F COMPUTING FITZPEAKS v2.18

NPLSS1A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
⁶⁰ Co	204.0 ± 0.22%	207 ± 0.34% _{3.59}	202 ± 0.37% _{2.29}
⁸⁵ Sr	1.275 ± 0.85%	1.25 ± 2.6% _{0.73}	1.25 ± 2.6% _{0.73}
¹³⁷ Cs	14.47 ± 0.70%	14.6 ± 0.69% _{0.91}	14.6 ± 0.75% _{0.87}

NPLSS1B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
¹²⁵ Sb	22.90 ± 0.71%	22.8 ± 0.90% _{0.38}	22.0 ± 0.9% _{3.51}
¹³⁷ Cs	337.7 ± 0.69%	334 ± 0.70% _{1.12}	334 ± 0.6% _{1.20}
¹³⁴ Cs	55.77 ± 0.68%	54.8 ± 0.35% _{2.28}	54.4 ± 0.34% _{3.25}
¹⁵⁴ Eu	72.84 ± 0.70%	72.7 ± 0.55% _{0.17}	71.8 ± 0.47% _{1.70}
¹⁵⁵ Eu	27.25 ± 0.54%	27.1 ± 5.5% _{0.10}	26.9 ± 6.0% _{0.22}
¹⁵² Eu	~ 477 Bq/g	-	476 Bq/g ± 7.5% ₋

Table 21. Set 2 - APTEC OSQ/PROFESSIONAL v6.31

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
^{60}Co	$21.44 \pm 0.23\%$	$18.3 \pm 2.7\%$ 6.32
^{85}Sr	$14.10 \text{ Bq/g} \pm 0.86\%$	$13.6 \text{ Bq/g} \pm 10\%$ 0.37
^{137}Cs	$1.622 \pm 0.71\%$	$1.51 \pm 1.7\%$ 3.98

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
^{125}Sb	$3.499 \pm 0.71\%$	$5.23 \pm 2.1\%^1$ 15.37
^{137}Cs	$59.43 \pm 0.69\%$	$51.2 \pm 1.6\%$ 8.98
^{134}Cs	$8.804 \pm 0.68\%$	$6.54 \pm 1.8\%$ 17.14
^{154}Eu	$12.37 \pm 0.70\%$	$9.99 \pm 2.1\%$ 10.49
^{155}Eu	$4.452 \pm 0.61\%$	-
^{152}Eu	$\sim 80 \text{ Bq/g}$	-

1) Individual peaks show large variations.

Table 22. Set 2 - CANBERRA GENIE-ESP v4.0

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
⁶⁰ Co	21.44 ± 0.23%	20.2 ± 0.06% 24.42
⁸⁵ Sr	14.10 Bq/g ± 0.86%	12.3 Bq/g ± 15% 0.97
¹³⁷ Cs	1.622 ± 0.71%	1.60 ± 0.3% 1.76

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
¹²⁵ Sb	3.499 ± 0.71%	2.82 ± 1.1% 20.52
¹³⁷ Cs	59.43 ± 0.69%	52.9 ± 0.06% 15.88
¹³⁴ Cs	8.804 ± 0.68%	6.41 ± 0.2% 39.10
¹⁵⁴ Eu	12.37 ± 0.70%	10.4 ± 0.1% 22.59
¹⁵⁵ Eu	4.452 ± 0.61%	3.83 ± 0.3% 21.09
¹⁵² Eu	~ 80 Bq/g	-

Table 23. Set 2 - CANBERRA GENIE-PC v2.2

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer u-test
⁶⁰ Co	21.44 ± 0.23%	19.86 ± 0.90% 8.52	19.65 ± 0.70% 12.25
⁸⁵ Sr	14.10 Bq/g ± 0.86%	15.20 Bq/g ± 11% 0.66	16.11 Bq/g ± 18% 0.69
¹³⁷ Cs	1.622 ± 0.71%	1.589 ± 0.80% 1.92	1.605 ± 0.56% 1.16

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer u-test
¹²⁵ Sb	3.499 ± 0.71%	2.662 ± 1.7% 17.92	2.762 ± 1.1% 18.88
¹³⁷ Cs	59.43 ± 0.69%	52.38 ± 0.70% 12.82	52.98 ± 0.45% 13.60
¹³⁴ Cs	8.804 ± 0.68%	6.380 ± 0.77% 31.30	6.317 ± 0.35% 38.97
¹⁵⁴ Eu	12.37 ± 0.70%	9.621 ± 0.64% 25.87	9.914 ± 0.32% 26.63
¹⁵⁵ Eu	4.452 ± 0.61%	3.846 ± 2.3% 6.55	3.793 ± 0.39% 21.43
¹⁵² Eu	~ 80 Bq/g	133 Bq/g ± 5.6% .	124 Bq/g ± 5.2% .

Table 24. Set 2 - CANBERRA S100 v3.1

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
⁶⁰ Co	21.44 ± 0.23%	19.3 ± 1.5% 7.29
⁸⁵ Sr	14.10 Bq/g ± 0.86%	6.4 Bq/g ± 20% 5.99
¹³⁷ Cs	1.622 ± 0.71%	1.56 ± 2.0% 1.86

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User
¹²⁵ Sb	3.499 ± 0.71%	2.76 ± 1.7% 13.92
¹³⁷ Cs	59.43 ± 0.69%	52.9 ± 1.2% 8.64
¹³⁴ Cs	8.804 ± 0.68%	5.88 ± 1.3% 30.12
¹⁵⁴ Eu	12.37 ± 0.70%	9.87 ± 1.4% 15.33
¹⁵⁵ Eu	4.452 ± 0.61%	3.99 ± 1.6% 6.66
¹⁵² Eu	~ 80 Bq/g	101 Bq/g ± 14% -

Table 25. Set 2 - CANBERRA SAMPO90 v3.1M

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User ¹ u-test
⁶⁰ Co	21.44 ± 0.23%	19.8 ± 0.04% 32.84
⁸⁵ Sr	14.10 Bq/g ± 0.86%	13.9 Bq/g ± 7.4% 0.19
¹³⁷ Cs	1.622 ± 0.71%	1.55 ± 0.2% 6.04

1) Counting uncertainties only.

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User ¹ u-test
¹²⁵ Sb	3.499 ± 0.71%	2.73 ± 0.41% 28.22
¹³⁷ Cs	59.43 ± 0.69%	51.9 ± 0.06% 18.31
¹³⁴ Cs	8.804 ± 0.68%	5.83 ± 0.41% 46.14
¹⁵⁴ Eu	12.37 ± 0.70%	9.36 ± 0.08% 34.63
¹⁵⁵ Eu	4.452 ± 0.61%	3.53 ± 0.14% 33.40
¹⁵² Eu	~ 80 Bq/g	-

1) Counting uncertainties only.

Table 26. Set 2 - EG&G GAMMAVISION v2.4

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer u-test
⁶⁰ Co	21.44 ± 0.23%	20.1 ± 1.94% 3.41	20.7 ± 2.4% 1.48
⁸⁵ Sr	14.10 Bq/g ± 0.86%	16.1 Bq/g ± 11% 1.19	16.0 Bq/g ± 11% 1.08
¹³⁷ Cs	1.622 ± 0.71%	1.52 ± 1.96% 3.19	1.57 ± 2.5% 1.27

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer u-test
¹²⁵ Sb	3.499 ± 0.71%	2.82 ± 2.5% 9.51	2.78 ± 3.1% 8.02
¹³⁷ Cs	59.43 ± 0.69%	50.4 ± 1.9% 8.67	48.9 ± 2.4% 8.47
¹³⁴ Cs	8.804 ± 0.68%	5.93 ± 1.9% 22.53	5.85 ± 2.4% 19.35
¹⁵⁴ Eu	12.37 ± 0.70%	9.95 ± 1.9% 11.64	9.87 ± 2.0% 11.60
¹⁵⁵ Eu	4.452 ± 0.61%	3.54 ± 1.9% 12.57	3.54 ± 2.0% 12.03
¹⁵² Eu	~ 80 Bq/g	-	-

Table 27. Set 2 - EG&G MAESTRO 2 v1.3

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer ¹
⁶⁰ Co	21.44 ± 0.23%	19.7 ± 1.5% 5.81	no ²
⁸⁵ Sr	14.10 Bq/g ± 0.86%	10.4 Bq/g ± 16% 2.22	no ²
¹³⁷ Cs	1.622 ± 0.71%	1.60 ± 1.6% 0.78	yes

- 1) Manufacturer reported peak areas only.
2) Peaks seen but misassigned.

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer ¹
¹²⁵ Sb	3.499 ± 0.71%	2.86 ± 1.7% 11.70	yes
¹³⁷ Cs	59.43 ± 0.69%	52.7 ± 1.2% 8.93	yes
¹³⁴ Cs	8.804 ± 0.68%	6.02 ± 1.2% 29.67	yes
¹⁵⁴ Eu	12.37 ± 0.70%	9.86 ± 1.5% 14.65	yes
¹⁵⁵ Eu	4.452 ± 0.61%	3.94 ± 1.6% 7.46	yes
¹⁵² Eu	~ 80 Bq/g	104 Bq/g ± 18%	yes n/l

- 1) Manufacturer reported peak areas only.
n/l: Nuclide probably not in library.

Table 28. Set 2 - EG&G OMNIGAM v3.5

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer u-test
⁶⁰ Co	21.44 ± 0.23%	20.9 ± 1.5% 1.70	19.6 ± 1.8% 5.17
⁸⁵ Sr	14.10 Bq/g ± 0.86%	12.8 Bq/g ± 17% 0.60	14.7 Bq/g ± 11% 0.37
¹³⁷ Cs	1.622 ± 0.71%	1.53 ± 1.5% 3.58	1.52 ± 1.8% 3.44

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer
¹²⁵ Sb	3.499 ± 0.71%	2.66 ± 1.9% 16.19	2.77 ± 2.1% 11.53
¹³⁷ Cs	59.43 ± 0.69%	50.3 ± 1.5% 10.63	49.4 ± 1.8% 10.24
¹³⁴ Cs	8.804 ± 0.68%	5.95 ± 1.5% 26.56	5.83 ± 1.8% 24.62
¹⁵⁴ Eu	12.37 ± 0.70%	9.75 ± 1.5% 15.42	9.54 ± 1.7% 15.39
¹⁵⁵ Eu	4.452 ± 0.61%	0.365 ± 1.5% ¹ 148	3.31 ± 1.7% 18.28
¹⁵² Eu	~ 80 Bq/g	14.7 Bq/g ± 12%	-

1) Manual calculation, 105 keV peak only, yields 3.91 ± 1.6 % (u = 7.95).

Table 29. Set 2 - J F COMPUTING FITZPEAKS v2.18

NPLSS2A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer u-test
⁶⁰ Co	21.44 ± 0.23%	21.3 ± 0.21% 2.10	20.0 ± 0.70% 9.70
⁸⁵ Sr	14.10 Bq/g ± 0.86%	15.6 Bq/g ± 7.5% 1.28	15.0 Bq/g ± 7.5% 0.80
¹³⁷ Cs	1.622 ± 0.71%	1.66 ± 0.57% 2.55	1.62 ± 0.60% 0.13

NPLSS2B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer u-test
¹²⁵ Sb	3.499 ± 0.71%	3.02 ± 0.97% 15.22	2.87 ± 1.0% 16.57
¹³⁷ Cs	59.43 ± 0.69%	54.7 ± 0.71% 8.37	53.4 ± 0.42% 12.90
¹³⁴ Cs	8.804 ± 0.68%	6.61 ± 0.52% 31.78	6.36 ± 0.42% 37.28
¹⁵⁴ Eu	12.37 ± 0.70%	10.3 ± 0.66% 18.80	9.88 ± 0.49% 25.10
¹⁵⁵ Eu	4.452 ± 0.61%	4.17 ± 5.4% 1.24	3.97 ± 5.5% 2.19
¹⁵² Eu	~ 80 Bq/g	-	-

Table 31. Set 3 - CANBERRA GENIE-ESP v4.0

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
⁶⁰ Co	21.03 ± 0.23%	21.12 ± 0.15% 1.56
⁸⁵ Sr	7.988 Bq/g ± 0.86%	-
¹³⁷ Cs	1.617 ± 0.71%	1.635 ± 0.75% 1.07

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
¹²⁵ Sb	3.374 ± 0.71%	3.494 ± 2.13% 1.53
¹³⁷ Cs	59.24 ± 0.69%	58.82 ± 0.14% 1.01
¹³⁴ Cs	7.701 ± 0.68%	7.565 ± 0.37% 2.29
¹⁵⁴ Eu	12.23 ± 0.70%	12.06 ± 0.27% 1.86
¹⁵⁵ Eu	4.361 ± 0.64%	4.791 ± 0.55% 11.20
¹⁵² Eu	~ 80 Bq/g	-

Table 32. Set 3 - CANBERRA GENIE-PC v2.2

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer ¹ _{u-test}
⁶⁰ Co	21.03 ± 0.23%	21.32 ± 1.9% _{0.71}	21.02 ± 0.83% _{0.06}
⁸⁵ Sr	7.988 Bq/g ± 0.86%	-	14.44 Bq/g ± 25% _{1.79}
¹³⁷ Cs	1.617 ± 0.71%	1.564 ± 7.3% _{0.46}	1.637 ± 1.6% _{0.70}

1) Peak locate threshold lowered.

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer ¹ _{u-test}
¹²⁵ Sb	3.374 ± 0.71%	3.081 ± 4.2% _{2.23}	3.219 ± 1.8% _{2.47}
¹³⁷ Cs	59.24 ± 0.69%	56.62 ± 7.2% _{0.64}	59.08 ± 1.2% _{0.20}
¹³⁴ Cs	7.701 ± 0.68%	5.314 ± 2.8% _{15.13}	7.553 ± 0.74% _{1.93}
¹⁵⁴ Eu	12.23 ± 0.70%	11.79 ± 1.3% _{2.51}	12.15 ± 1.7% _{0.66}
¹⁵⁵ Eu	4.361 ± 0.64%	4.498 ± 2.5% _{1.18}	3.906 ± 1.7% _{6.32}
¹⁵² Eu	~ 80 Bq/g	-	-

1) Peak locate threshold lowered.

Table 33. Set 3 - CANBERRA S100 v3.1

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User
^{60}Co	$21.03 \pm 0.23\%$	$20.6 \pm 1.7\%$ _{1.22}
^{85}Sr	$7.988 \text{ Bq/g} \pm 0.86\%$	-
^{137}Cs	$1.617 \pm 0.71\%$	$1.60 \pm 2.4\%$ _{0.42}

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User
^{125}Sb	$3.374 \pm 0.71\%$	$3.21 \pm 2.4\%$ _{2.03}
^{137}Cs	$59.24 \pm 0.69\%$	$57.8 \pm 1.7\%$ _{1.35}
^{134}Cs	$7.701 \pm 0.68\%$	$7.39 \pm 1.5\%$ _{2.54}
^{154}Eu	$12.23 \pm 0.70\%$	$12.2 \pm 1.6\%$ _{0.14}
^{155}Eu	$4.361 \pm 0.64\%$	$4.57 \pm 2.5\%$ _{1.78}
^{152}Eu	$\sim 80 \text{ Bq/g}$	$122 \text{ Bq/g} \pm 16\%$ ₋

Table 34. Set 3 - CANBERRA SAMPO90 v3.1M

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
⁶⁰ Co	21.03 ± 0.23%	20.6 ± 0.10% 8.18
⁸⁵ Sr	7.988 Bq/g ± 0.86%	-
¹³⁷ Cs	1.617 ± 0.71%	1.62 ± 0.48% 0.22

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test
¹²⁵ Sb	3.374 ± 0.71%	2.85 ± 0.94% 14.58
¹³⁷ Cs	59.24 ± 0.69%	58.1 ± 0.14% 2.74
¹³⁴ Cs	7.701 ± 0.68%	7.44 ± 0.35% 4.46
¹⁵⁴ Eu	12.23 ± 0.70%	present ¹ -
¹⁵⁵ Eu	4.361 ± 0.64%	4.45 ± 0.56% 2.38
¹⁵² Eu	~ 80 Bq/g	-

1) Peaks reported but nuclide not identified.

Table 35. Set 3 - EG&G GAMMAVISION v2.4

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
⁶⁰ Co	21.03 ± 0.23%	21.7 ± 2.0% _{1.53}	21.0 ± 1.9% _{0.07}
⁸⁵ Sr	7.988 Bq/g ± 0.86%	16.8 Bq/g ± 26% _{2.01}	-
¹³⁷ Cs	1.617 ± 0.71%	1.64 ± 2.1% _{0.63}	1.57 ± 2.1% _{1.35}

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
¹²⁵ Sb	3.374 ± 0.71%	3.54 ± 4.1% _{1.13}	3.45 ± 3.8% _{0.57}
¹³⁷ Cs	59.24 ± 0.69%	60.1 ± 2.0% _{0.68}	57.8 ± 2.0% _{1.17}
¹³⁴ Cs	7.701 ± 0.68%	7.66 ± 2.0% _{0.25}	7.35 ± 2.0% _{2.25}
¹⁵⁴ Eu	12.23 ± 0.70%	12.9 ± 2.0% _{2.46}	12.3 ± 1.9% _{0.69}
¹⁵⁵ Eu	4.361 ± 0.64%	4.51 ± 2.0% _{1.58}	4.19 ± 2.0% _{1.94}
¹⁵² Eu	~ 80 Bq/g	161 Bq/g ± 13.5% ₋	-

Table 36. Set 3 - EG&G MAESTRO2 v1.3

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User u-test	Manufacturer ¹
⁶⁰ Co	21.03 ± 0.23%	20.6 ± 1.6% 1.29	yes
⁸⁵ Sr	7.988 Bq/g ± 0.86%	-	no
¹³⁷ Cs	1.617 ± 0.71%	1.62 ± 2.1% 0.08	yes

1) Manufacturer reported peak areas only.

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User	Manufacturer ¹
¹²⁵ Sb	3.374 ± 0.71%	3.28 ± 2.0% 1.35	yes n/l
¹³⁷ Cs	59.24 ± 0.69%	58.4 ± 1.3% 0.97	yes
¹³⁴ Cs	7.701 ± 0.68%	7.34 ± 1.5% 2.96	yes n/l
¹⁵⁴ Eu	12.23 ± 0.70%	12.2 ± 1.6% 0.14	yes n/l
¹⁵⁵ Eu	4.361 ± 0.64%	4.6 ± 2.5% 2.02	yes n/l
¹⁵² Eu	~ 80 Bq/g	111 Bq/g ± 11% .	yes n/l

1) Manufacturer reported peak areas only.
n/l: Nuclide probably not in library.

Table 37. Set 3 - EG&G OMNIGAM v3.5

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
⁶⁰ Co	21.03 ± 0.23%	21.0 ± 1.9% _{0.07}	3.31 ± 2.7% _{0.19}
⁸⁵ Sr	8 Bq/g ± 0.86%	-	-
¹³⁷ Cs	1.617 ± 0.71%	1.55 ± 2.0% _{2.03}	1.59 ± 1.9% _{0.84}

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer
¹²⁵ Sb	3.374 ± 0.71%	3.12 ± 3.5% _{2.27}	3.31 ± 2.7% _{0.69}
¹³⁷ Cs	59.24 ± 0.69%	56.7 ± 2.0% _{2.11}	58.3 ± 1.7% _{0.88}
¹³⁴ Cs	7.701 ± 0.68%	7.17 ± 2.0% _{3.48}	7.45 ± 1.7% _{1.83}
¹⁵⁴ Eu	12.23 ± 0.70%	12.4 ± 2.0% _{0.65}	12.5 ± 1.5% _{1.31}
¹⁵⁵ Eu	4.361 ± 0.64%	5.30 ± 1.7% _{9.96}	2.68 ± 1.6% _{32.86}
¹⁵² Eu	~ 80 Bq/g	-	-

Table 38. Set 3 - J F COMPUTING FITZPEAKS v2.18

NPLSS3A4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
⁶⁰ Co	21.03 ± 0.23%	21.2 ± 0.46% _{1.56}	21.1 ± 0.67% _{0.67}
⁸⁵ Sr	8 Bq/g ± 0.86%	-	-
¹³⁷ Cs	1.617 ± 0.71%	1.63 ± 0.82% _{0.74}	1.64 ± 0.80% _{1.32}

NPLSS3B4

If no units are given, the activity is in kBq/g. The percentage value following an activity is the standard uncertainty, providing a level of confidence of approximately 68 %.

Nuclide	NPL	Expert User _{u-test}	Manufacturer _{u-test}
¹²⁵ Sb	3.374 ± 0.71%	3.34 ± 1.2% _{0.73}	3.35 ± 1.2% _{0.51}
¹³⁷ Cs	59.24 ± 0.69%	58.7 ± 0.64% _{0.97}	59.1 ± 0.60% _{0.26}
¹³⁴ Cs	7.701 ± 0.68%	7.49 ± 0.48% _{3.32}	7.53 ± 0.44% _{2.76}
¹⁵⁴ Eu	12.23 ± 0.70%	12.2 ± 0.56% _{0.27}	12.1 ± 0.55% _{1.20}
¹⁵⁵ Eu	4.361 ± 0.64%	4.51 ± 6.0% _{0.55}	4.32 ± 6.0% _{0.16}
¹⁵² Eu	~ 80 Bq/g	-	-

Table 39. Criteria for u-tests.

Value	Conclusion
$u \leq 1.64$	The values do not differ significantly
$1.64 < u \leq 1.96$	The values probably do not differ significantly but more data are required to confirm this
$1.96 < u \leq 2.58$	One cannot say whether there is a significant difference without further data
$2.58 < u \leq 3.29$	The values probably differ significantly but more data are required to confirm this
$u > 3.29$	The values differ significantly

Table 40. A-series Spectra: $u \leq 1.64$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
⁶⁰ Co	E1 E3	E3	E1 E3 M3	E1 E3		E3 M2 M3	E1 E3	E3 M3	E3 M3
⁸⁵ Sr	E2	E1 E2	E1 E2 M2		E2	E1 E2 M1 M2	E2	E2 M1 M2	E1 E2 M1 M2
¹³⁷ Cs	E3	E1 E3	E1 E3 M1 M2 M3	E1 E3	E3	E1 E3 M2 M3	E1 E3	E1 M3	E1 E3 M1 M2 M3

Table 41. A-series Spectra: $1.64 < u \leq 1.96$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
⁶⁰ Co								E2	
⁸⁵ Sr			M3						
¹³⁷ Cs		E2	E2	E2		M1			

Table 42. A-series Spectra: $1.96 < u \leq 2.58$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
⁶⁰ Co									E2 M1
⁸⁵ Sr			M1			E3	E2		
¹³⁷ Cs	E1							E3	E2



Table 43. A-series Spectra: $2.58 < u \leq 3.29$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
⁶⁰ Co								E1	
⁸⁵ Sr									
¹³⁷ Cs						E2			

Table 44. A-series Spectra: $u > 3.29$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
^{60}Co	E2	E1 E2	E2 M1 M2	E2	E1 E2 E3	E1 E2 M1	E2	M1 M2	E2 M2
^{85}Sr	E1			E2	E1			E1	
^{137}Cs	E2				E1 E2			E2 M1 M2	

Table 45. A-series Spectra: Nuclide not reported as seen.

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
⁶⁰ Co									
⁸⁵ Sr	E3	E3	E3	E1 E3	E3	M3	E1 E3	E3 M3	E3 M3
¹³⁷ Cs									

Table 46. B-series Spectra: $u \leq 1.64$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
^{125}Sb	E3	E3				E1 E3 M1 M3	E3	M3	E1 E3 M3
^{137}Cs	E1 E3	E1 E3	E3 M1 M3	E1 E3		E1 E3 M1 M3	E3	M3	E1 E3 M1 M3
^{134}Cs	E1	E1				E1 E3	E1		
^{154}Eu	E1 E3	E1	E1 M1 M3	E1 E3		E1 M1 M3	E1 E3	E3 M3	E1 E3 M3
^{155}Eu	E1 E3	E1	E1 E3			E3	E1		E1 E2 E3 M1 M3

Table 47. B-series Spectra: $1.64 < u \leq 1.96$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
¹²⁵ Sb									
¹³⁷ Cs			E1				E1		
¹³⁴ Cs	E3		M3					M3	
¹⁵⁴ Eu		E3							M1
¹⁵⁵ Eu			M1	E3		M3			

Table 48. B-series Spectra: $1.96 < u \leq 2.58$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
¹²⁵ Sb		E1	E3 M1 M3	E3				E1 E3	
¹³⁷ Cs								E3	
¹³⁴ Cs		E3		E1 E3		M3			E1
¹⁵⁴ Eu			E3			E3			
¹⁵⁵ Eu					E3	E1	E3		M2

Table 49. B-series Spectra: $2.58 < u \leq 3.29$

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
¹²⁵ Sb			E1					M1	
¹³⁷ Cs					E3				
¹³⁴ Cs			M1			M1	E3		M1 M3
¹⁵⁴ Eu									
¹⁵⁵ Eu				E1		M1			

Table 50. B-series Spectra: u > 3.29

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
¹²⁵ Sb	E1 E2	E2	E2 M2	E1 E2	E1 E2 E3	E2 M2	E1 E2	E2 M2	E2 M1 M2
¹³⁷ Cs	E2	E2	E2 M2	E2	E1 E2	E2 M2	E2	E1 E2 M1 M2	E2 M2
¹³⁴ Cs	E2	E2	E1 E2 E3 M2	E2	E1 E2 E3	E2 M2	E2	E1 E2 E3 M1 M2	E2 E3 M2
¹⁵⁴ Eu	E2	E2	E2 M2	E2	E2	E2 M2	E2	E1 E2 M1 M2	E2 M2
¹⁵⁵ Eu		E2 E3	E2 M2 M3	E2	E1 E2	E2 M2	E2	E1 E2 E3 M2 M3	

Table 51. B-series Spectra: Nuclide not reported as seen.

Nuclide	OSQ/Pro	Genie-ESP	Genie-PC	S100	Sampo90	GammaVision	Maestro	Omnigam	Fitzpeaks
¹²⁵ Sb									
¹³⁷ Cs									
¹³⁴ Cs									
¹⁵⁴ Eu					E1 E3				
¹⁵⁵ Eu	E2							M1*	

* Upper limit given.

Figure 1. NPLCS14 - Set 1, calibration spectrum, 4k channels.

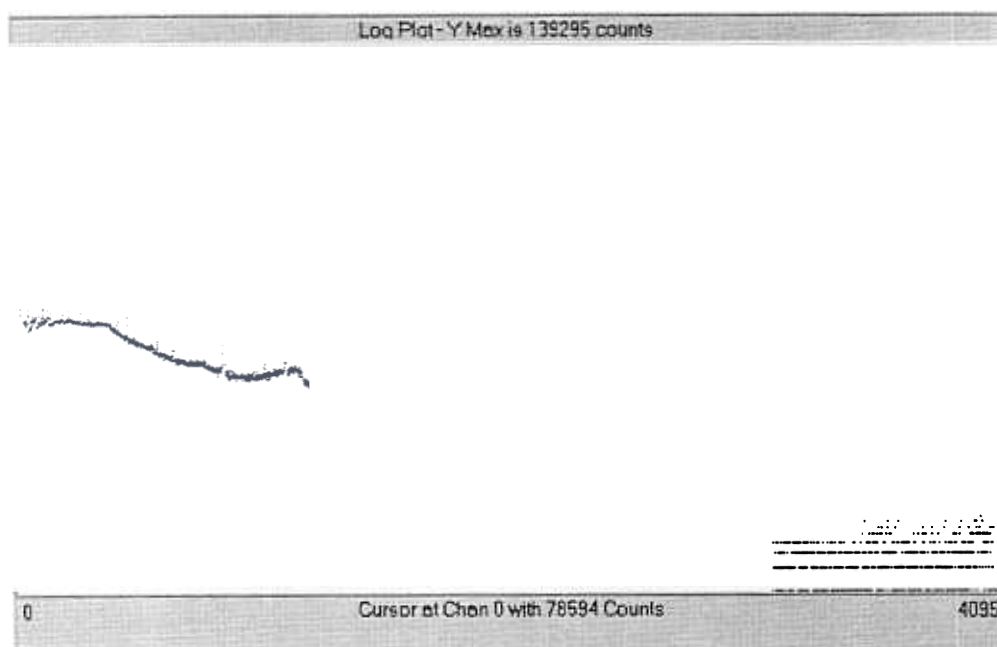


Figure 2. NPLSS1A4 - Set 1, standard spectrum, source type A, 4k channels.

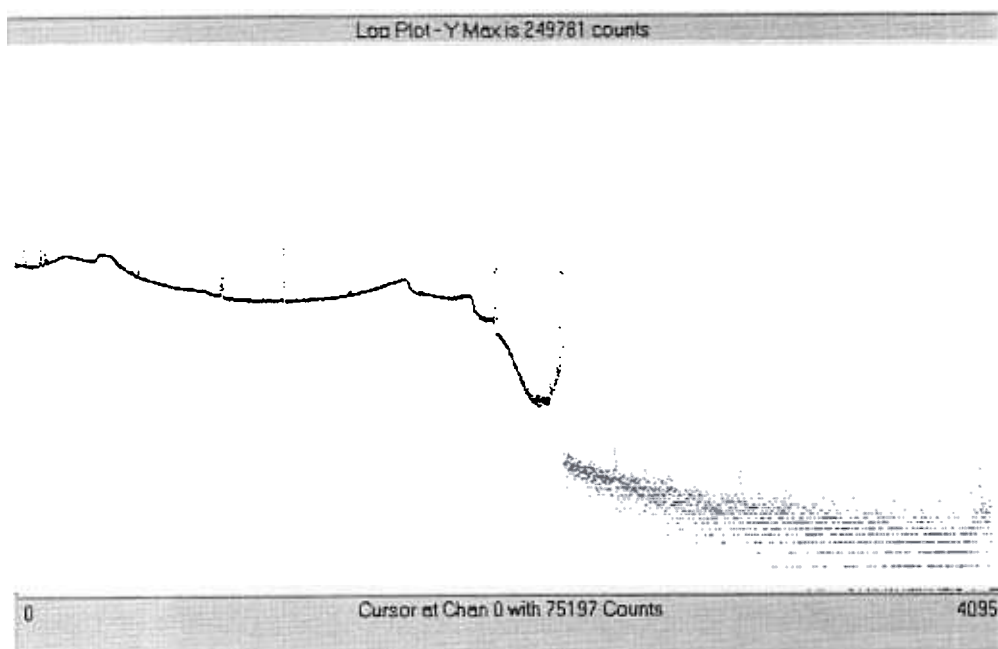


Figure 3. NPLSS1B4 - Set 1, standard spectrum, source type B, 4k channels.

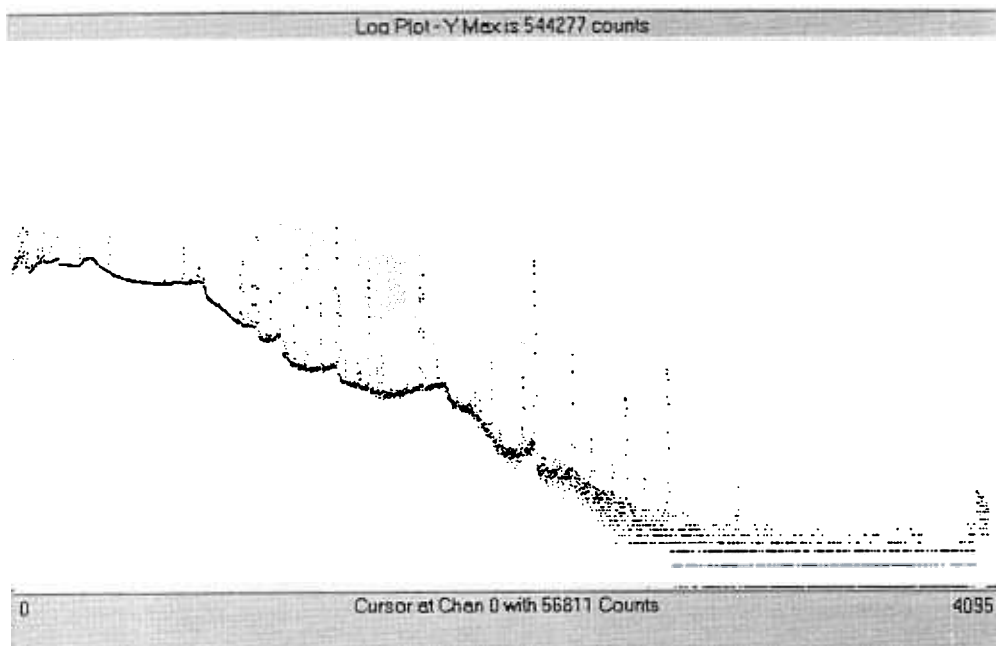


Figure 4. NPLBS24 - Set 2, background spectrum, 4k channels.

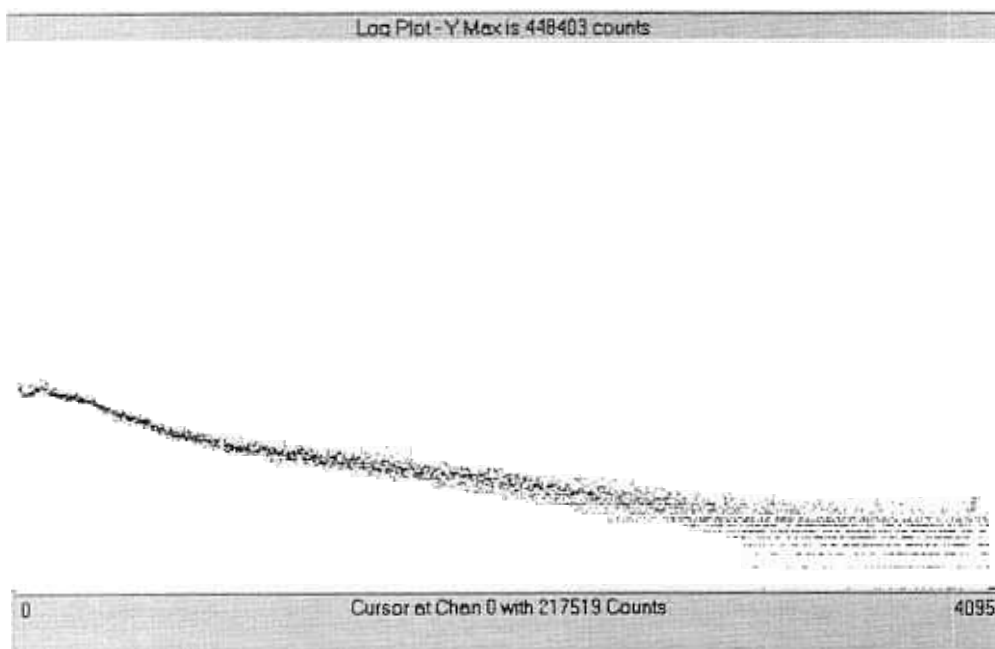


Figure 5. NPLCS24 - Set 2, calibration spectrum, 4k channels.

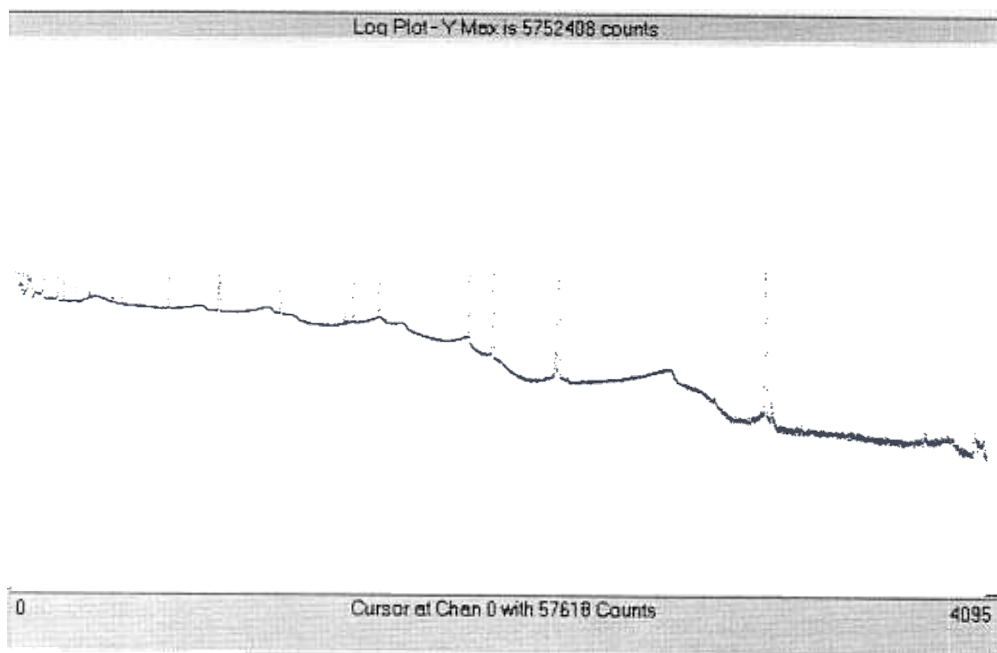


Figure 6. NPLSS2A4 - Set 2, standard spectrum, source type A, 4k channels.

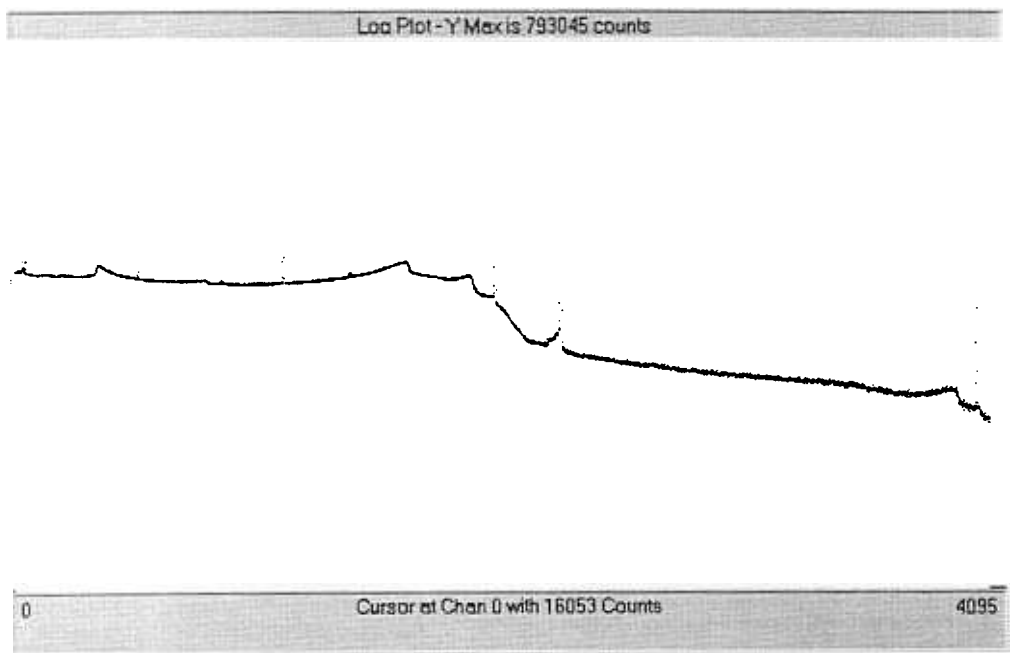


Figure 7. NPLSS2B4 - Set 2, standard spectrum, source type B, 4k channels.

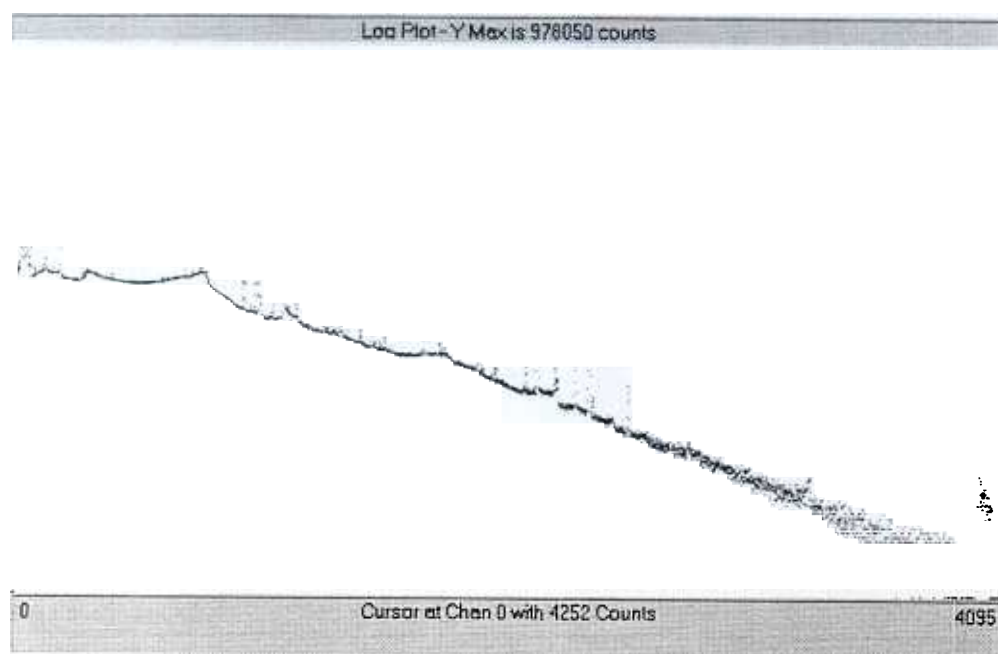


Figure 8. NPLBS34 - Set 3, background spectrum, 4k channels.

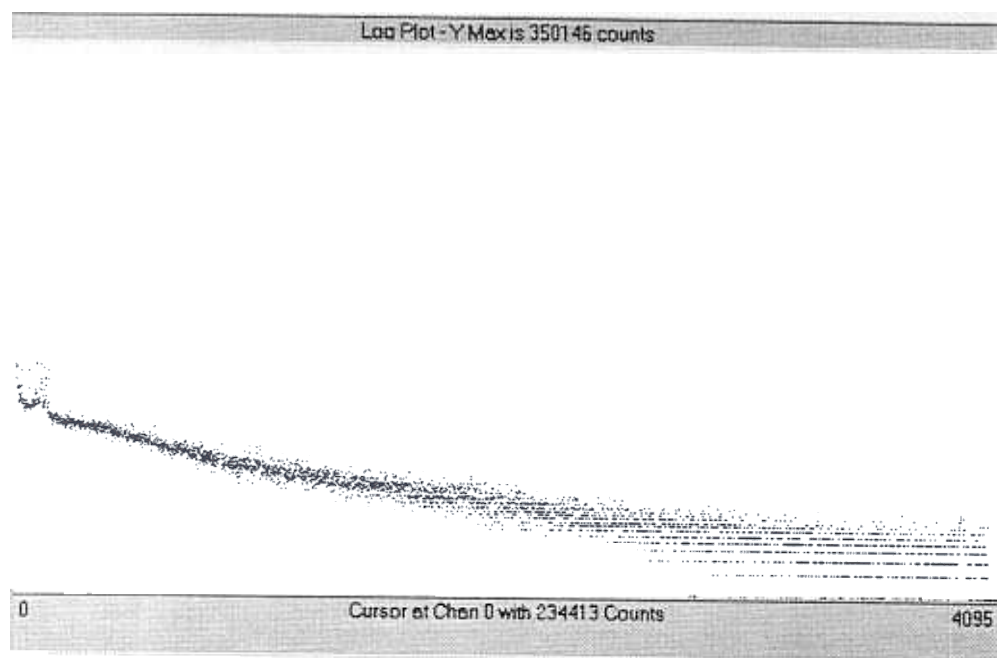


Figure 9. NPLCS34 - Set 3, calibration spectrum, 4k channels.

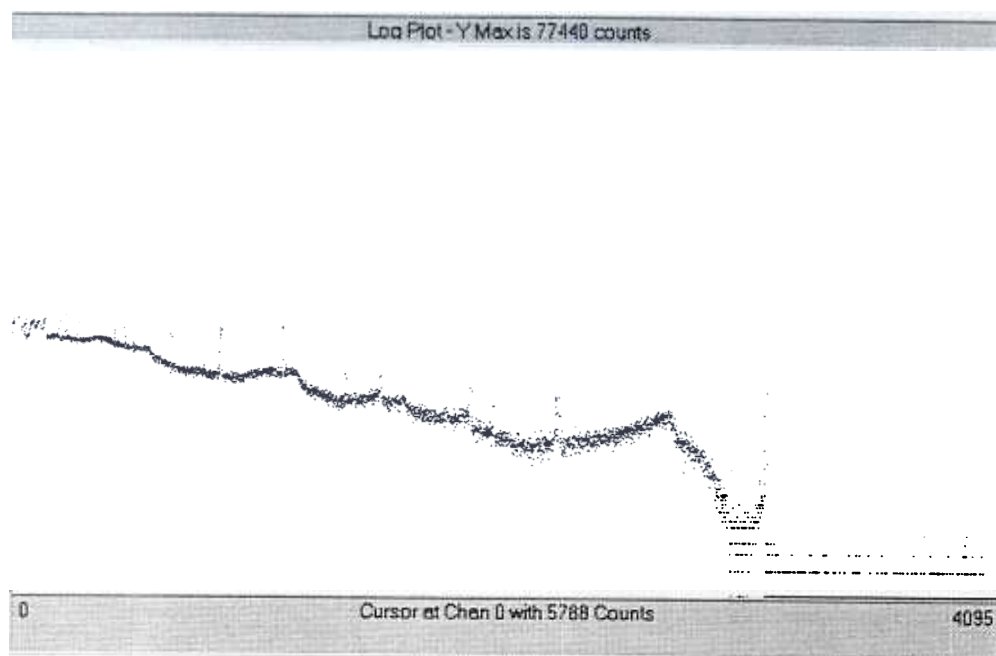


Figure 10. NPLSS3A4 - Set 3, standard spectrum, source type A, 4k channels.

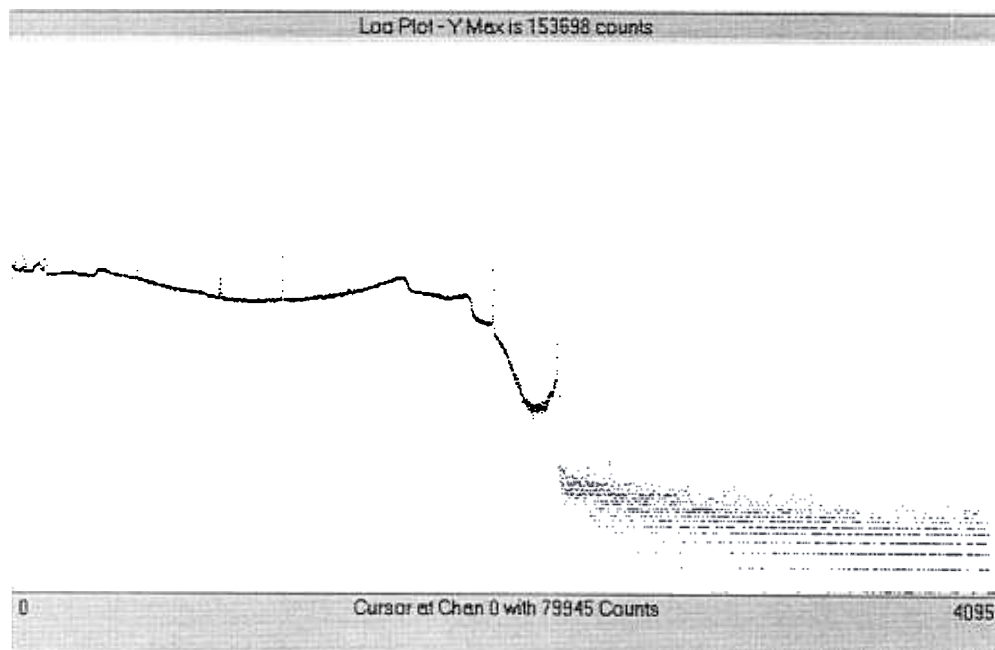
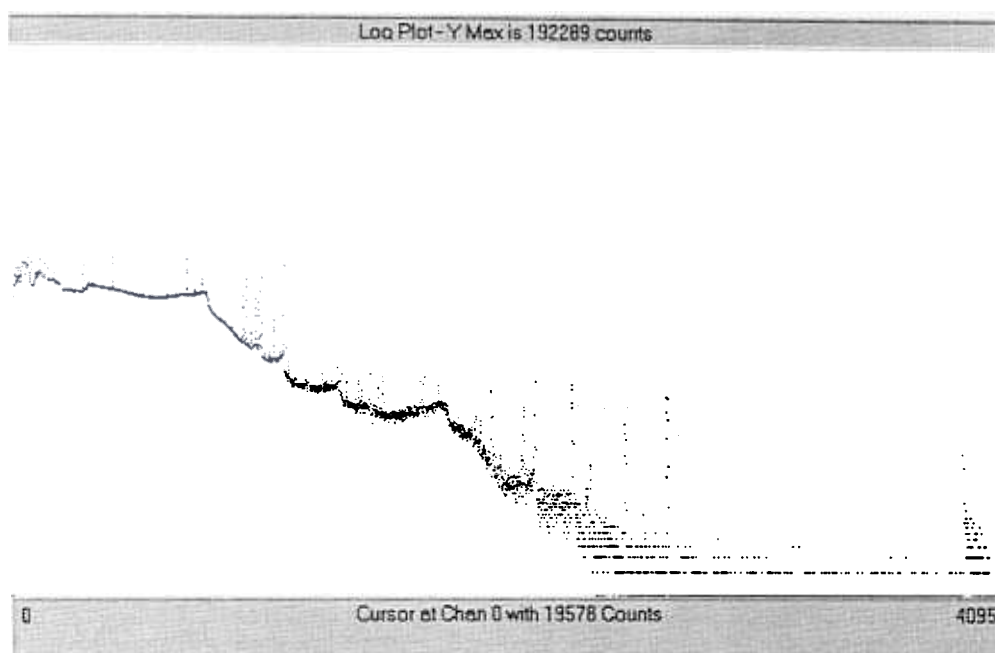


Figure 11. NPLSS3B4 - Set 3, standard spectrum, source type B, 4k channels.



APPENDIX 1. NOTES ON THE PROGRAMS AND THE ANALYSIS; A PERSONAL VIEW

If the reader requires more information on the mechanisms and techniques mentioned in these notes, then the first two references can be recommended.

These notes include what can be only selected hints and tips on the programs and their operation; some program manuals run to 350 pages and it would be both difficult and inappropriate to précis and comment on their subtleties.

1 Choice of Programs to be Used

In 1996 the NPL conducted a survey of analysts in the UK to find out what software was in use for the analysis of high resolution gamma spectra. The programs reported in this survey are those considered in this exercise. There are two broad categories; emulators and full analysis programs.

2 Emulators

The first group is those known as MCA Emulators, and their main function is not analysis but the acquisition of spectra. Examples here are *Maestro 2* and *S100*. In addition to acquisition, they allow a simple measurement of peak area and resolution, and, when energy calibrated, a simple form of nuclide identification. These facilities have been utilised in these tests. Peak areas were extracted and manipulated externally in order to derive radionuclide activities.

A disadvantage of such a calculation by hand (or by spreadsheet) is that it could be more prone to user carelessness than an automatic process, and additionally it is of course true that the calculation takes very much longer and is quite inappropriate for a busy laboratory measuring routine samples. However, the process is not all loss; there is a significant gain due to the detailed attention that each stage of the calculation must receive. Blind computer inanities, often due to poor setting up, are avoided.

3 Full Analysis Programs

The second group is much more comprehensive in its analytical power. Recent programs in this group are very good, and are much more user-friendly than earlier ones. A major advance compared to the emulators is the ability to fit the data in a peak in the spectrum to some appropriate analytical expression, and in particular to use the fitting process to analyse overlapping peaks, so that the separate contribution made by each individual peak to such a multiplet can be found. As far as one can see the algorithms in use for the calculation of areas, etc., are correct (this has not always been the case). The user is able to vary many parameters used in the analysis. This is excellent if the user understands the function of each parameter and the likely result of changing it, but can lead to serious difficulties for the inexperienced.

The user will notice family resemblances in programs from same company. Thus, the Windows program *GammaVision* has similarities to the earlier DOS program *Omnigam*.

4 The Spectra

As has been described in the main report, each set of three spectra consists of a calibration spectrum (..CS..) and two 'unknowns'; one simple (..A..) and one more complex (..B..). The calibration spectrum contains known nuclides in known quantities, this information being provided. The unknowns were counted under identical conditions, and the exercise is to determine the identity of the nuclides and their concentrations. The "answers" are provided, but it would be more instructive to the user if, in the first place, the analysis were run blind.

5 The ^{85}Sr Difficulty

This nuclide is a common component of multinuclide calibration sources (eg QCY48) as it decays with effectively a single gamma-ray; this is at 514.01 keV and has a usefully high emission probability of 0.984(4). In addition,

- a) there are low energy Rb X-rays at 13 - 15 keV, but these would only give a possible summing problem with a thin-windowed low-energy detector,
- b) there is a second gamma-ray at 868.3 keV, but with such a small emission probability, P_γ equal to 0.00012, that this is rarely seen and in any case is not in cascade with the 514 keV transition.

However 514 keV is very close to the annihilation peak at 511 keV, and it is apparent in the NPLCS14 and NPLSS1A4 spectra that there is a significant 511 peak and that there is significant overlap. This doublet is something that neither *Maestro* nor *S100* can deconvolute, and consequently the report in both tests on NPLSS1A4 does not attempt to quantify the nuclide and merely says that ^{85}Sr is present. Of course, the user could extract the counts per channel data and separate the peaks using an external fitting program. The other analytical packages do produce an answer for ^{85}Sr , presumably after deconvoluting the pair. The results table shows that most programs give a good value but with a significantly greater uncertainty than those reported for other nuclides in that spectrum.

A particular problem in this deconvolution is that while both the individual peaks will have a basic Gaussian shape plus tailing, the peak width parameters will be quite different in value due to Doppler broadening of the 511 keV peak. This is clearly unlike most doublets in a spectrum, and is a situation that an analytical program might be able to recognize by looking for and noting 511 keV as a special case. The same situation will arise with other multiplets where one of the components is a single escape peak. In those spectra that contain both ^{60}Co and ^{88}Y , there is a multiplet of the latter kind from the single escape 1325.06 keV from the ^{88}Y and the 1332.50 keV from the ^{60}Co . These are reasonably separated, for example thirteen channels peak to peak in NPLCS24, but the normal peak search will register them in one Region of Interest. The user will search the program manual in vain for information on these special cases.

In spectrum NPLSS2A4, again both 511 and 514 keV peaks are seen, but now the 511 is relatively small and an attempt was made to quantify the area of the 514 keV peak in both *Maestro* and *S100*. As can be seen from the results, this had only a limited success; despite the large uncertainties, the u-test shows real differences from the known value. Indeed values were low compared to the results from all other programs. The low values will arise from the overestimation of the background continuum under the peak. In NPLSS3A4, the ^{85}Sr content is very small. It was not picked up by most of the peak search routines; only *GammaVision*

commendably provides a positive sighting, and somewhat imprecisely at that. If the user looks closely at an expanded spectrum displayed on a linear vertical scale, then it can be seen (using that invaluable commodity, hindsight) that the large 511 keV peak is asymmetric with a high-energy tail; this tail must contain these few counts from ^{85}Sr .

A separate problem with ^{85}Sr is that of identifying it. Both ^{85}Sr and ^{85}Kr decay by emitting the same gamma energy (actually a transition in their common daughter ^{85}Rb). Thus a program will only uniquely identify one of these if it contains only that one in its search library. A default library in *Fitzpeaks* contains both nuclides, and the program helpfully calculates the activity of each, suitably flagged, and then allows the user to choose between them. The user makes this choice using his knowledge of the history of the sample, admittedly not an option in these test spectra, although a standardized solution source is perhaps unlikely to contain a radioactive gas.

6 Correction for Decay During the Count

This is a small correction when the half life is long compared to the counting time. It corrects the sample activity to the start time of the acquisition. For our nuclides and acquisition times, the largest factor appears for ^{203}Hg in the NPLCS14 spectrum. The correction value here is 1.00679, a small but not negligible number. The shortest half-life in the TEST library assembled for these trials is the 2.697 days of ^{198}Au . If this were present in spectrum NPLSS1B4 which was collected over 0.9925 days, the correction factor would be 1.133.

The user would be wise to always choose to have this correction carried out; it will usually arise as an option in the package. Note that if you wish to check the number yourself, the counting time required for the calculation (see reference 1) is the real or clock time not the live time.

7 Nuclide Libraries

It is self-evident that a computer package can only identify and quantify nuclides that it knows about, that is, those that are in its library. It does not follow that every radionuclide known to man should be in your working library. Programs such as *GammaVision* and *Genie PC* come with a very large reference library, but these master libraries are much too large to be used directly. Many ambiguities would lead to many misassignments. These reference libraries are intended to act as a source library from which the user can extract nuclides and nuclear data to suit his or her own situation.

For fast efficient computation, a user might prepare a number of libraries;

- a) one just containing nuclides used in the calibration, thus a small library;
- b) one, perhaps called the main analysis library, containing the nuclides that are specifically being sought in the sample, again probably not a large library - it might contain only three or four nuclides;
- c) one for tentative identification of otherwise unidentified nuclides, this could be very much larger and include background nuclides, escape peaks, and 511 keV as a special entry.

Fitzpeaks, uniquely, has an additional optional library for cascade (true coincidence) summing, for use at low count rates where random summing is negligible. Here an effective emission

probability is calculated for a 'pseudo-nuclide' at the sum peak and this is used to give quantitative results.

With an artificial exercise like the present one, where nuclides are in the first place not known, constructing a sensible analysis library must be an iterative process. An energy calibration can be carried out, since nuclides in the calibration spectrum are known by definition. This is followed by a rough and ready analysis with any large library. Together with published tables of nuclides, such as Browne and Firestone [3] and others [1, 2, 4 and 5], and bearing in mind efficiency variations and emission probabilities as well as the history of the sample, it will be possible to identify the radionuclides. Now assemble a proper working analysis library. While a small working library operates very efficiently, of course unexpected nuclides will be missed. It is thus essential to ensure that a list of unidentified peaks be printed out in the analysis report, and that the user looks through this as a matter of routine. Check the program manual to see whether the order of energies for each nuclide in the library is important.

For the purposes of this exercise a test library was compiled. This contained nuclides

- a) that had been found in the unknowns (by a process such as that above),
- b) that were known to be in the calibration,
- c) other nuclides incorporated to test the software.

The nuclides were:

^{22}Na , ^{40}K , ^{46}Sc , ^{51}Cr , ^{54}Mn , ^{56}Co , ^{57}Co , ^{58}Co , ^{60}Co , ^{59}Fe , ^{65}Zn , ^{75}Se , ^{85}Sr , ^{88}Y , ^{95}Nb , ^{103}Ru , ^{109}Cd , $^{110\text{m}}\text{Ag}$, ^{113}Sn , ^{124}Sb , ^{125}Sb , ^{131}I , ^{133}Ba , ^{134}Cs , ^{137}Cs , ^{139}Ce , ^{152}Eu , ^{154}Eu , ^{155}Eu , ^{198}Au , ^{203}Hg , ^{241}Am

The "other nuclides" were a mixture of common single energy and multi-energy emitters. Some were chosen deliberately to have energies that were effectively the same as those found in the standard spectra. Thus ^{22}Na 's only gamma at 1274.54 keV would be indistinguishable from ^{154}Eu 's high emission probability (relatively speaking) gamma at 1274.44 keV, and the region near 122 keV is, in principle, congested with ^{75}Se at 121.12 keV, ^{152}Eu at 121.78 keV, ^{57}Co at 122.06 keV, and ^{154}Eu at 123.07 keV. All members of the latter group have healthy quantities of other gamma energies, which a semi-intelligent program should be able to use in an identification.

It should be emphasized that this library would be a very poor choice under normal circumstances. It was used as the calibration library, and difficulties arose (see below); normally only the known calibration nuclides should be in this library. It was also used as the analysis library; again for this purpose it is too large (32 radionuclides, about 120 energies; the preliminary analysis showed fewer than ten nuclides in the unknowns).

As an example of calibration difficulties with an overlarge library, consider energy calibration in *Omnigam*. It appears to be library directed. Entries in the calibration table are set up for all energies in the library. But the table is restricted to 97 lines. With our test library most of these lines are quite useless and do not correspond to peaks in the spectrum. The user has to spend time deleting the perhaps 87 superfluous lines. Worse, the 97 energies are listed in energy order starting from zero energy, and as there are many low energy points and only a few high energy ones, the table is full by about 1000 keV. Thus good data from the higher energy points would not be used, and that part of the calibration line would be prone to all the additional

uncertainties of extrapolation.

Another problem that arose in these measurements was rooted in the opposite situation of too small a library. ^{152}Eu and ^{154}Eu both produce a gamma-ray at 1408 keV; this appears as a prominent peak in ^{152}Eu (1408.02 keV, P_γ equal to 0.2085(9)), and a very minor peak in ^{154}Eu (1408.31 keV, P_γ equal to 0.00023(3)). In fact this latter is so small it is not reported in TecDoc-619 [4] nor Debertin and Helmer [2] nor in old listings like Erdtmann and Soyka [6] and is not seen in the program reference libraries. Library compilers can justifiably argue that nine or so energy entries are more than sufficient to identify and quantify a radionuclide. The low emission probability energies can be found in the comprehensive listings of Browne and Firestone [3], where ^{154}Eu is reported as having an impressive 164 X-ray and gamma-ray lines.

The B-series of spectra contain small amounts of ^{152}Eu in the presence of much larger amounts of ^{154}Eu ; the activity ratio, according to the NPL, is about 1 : 155. This means that at 1408 keV the minor ^{154}Eu peak will contribute about 17 % of the peak area. A correction was made in the manual calculations of *Maestro* and *S100*, the correction quantity being derived from the large ^{154}Eu peak at 1274 keV and appropriate efficiency and emission probability factors. It is highly unlikely that any of the other programs made any such correction.

The dilemma remains. It would not be good practice to include all the ^{154}Eu energies in an analytical library, for the reasons expressed above, yet as we have seen a minor line of a dominant nuclide can seriously affect the accuracy of measurement of a trace nuclide. Perhaps this is yet another situation where the supervision and intervention of an experienced user is crucial.

8 Sources of Nuclear Data

Where possible, the TEST library was compiled from the program's reference library. Thus the nuclear data used were those provided with the package and were not necessarily best evaluated data. Until very recently, it has been rare to find up-to-date nuclear data in the analysis packages, and even rarer to find a reference to the data source. With the current demand for quality assurance in all measurements this rather carefree attitude is not acceptable.

An honourable exception to these strictures is *Fitzpeaks*. Here each nuclide is fully and individually referenced. Furthermore the half-life, energy, and emission probability have uncertainties (at one sigma) associated with them, thus enabling the calculation of the overall uncertainty attached to any derived activity. Unhappily, more typical (as in the versions of *GammaVision* and *OSQ/Professional* used in these tests) is use of the data listing of Erdtmann and Soyka [6]; this was fine in its day, but that day was 20 years ago. Uncertainties on the data should always be sought and all too typical are the 'yields' (that is emission probabilities) given in *OSQ*, where the program lists values to a nominal six decimal places but without uncertainties. *OmniGam*, admittedly not a recent program but still widely used, allows only a single uncertainty (the "nuclear uncertainty") on all points in the calibration information. It is thus not possible to make full use of the calibration information given with the present calibration spectra.

Gamma emission probabilities have a direct impact on activity results. Differences between new and old data listings are small for well known nuclides, but may not be negligible even with these. For example, comparing TecDoc-619 [4] to Erdtmann and Soyka [6], we find +0.56 % for

661.66 keV in ^{137}Cs , and +2.5 %, +1.6 %, and -1.4 % for 723.30, 1004.72, and 1274.44 keV, respectively, in ^{154}Eu . Very occasionally, there is a real error in the program's reference library. Thus in one package, now happily said to be fixed, there were nuclear data given for ^{152}Eu and $^{152\text{m}}\text{Eu}$. Unfortunately, the compiler had used data for two isomers, labelling one of them as the ground state, and thereby had omitted the real ground state information completely; an extraordinary mistake, especially for such a common radionuclide.

9 False Identification of Radionuclides

When a spectrometry system produces spurious but plausible concentration values for nuclides that are in fact not present, this can have worse implications (financial, loss of credibility etc.) than simply producing inaccurate or imprecise results for nuclides that *are* present. When these series of measurements were being planned, it seemed an obvious idea to assess the programs in terms of the number of false identifications that appeared. In principle this was possible due to the fact that the spectra had been produced with unusual attention to nuclidic purity as well as activity traceability. The use of the otherwise unrealistic TEST library, as described above, is part of that plan.

In practice it has been concluded that this sort of comparison could be grossly unfair. The problem is that while of course the library contents play a crucial role, a program will have several sensitivity parameters which would affect the outcome, and it would be almost impossible to standardize particular values and their effect on identification across all the programs. As an example, in *GammaVision* there is a "peak search sensitivity", a "peak uncertainty cut-off" and a "library match width factor". The "peak search sensitivity" is an integer from 1 to 5 based on comparing "the magnitude of the second difference (second differential of the peak shape) with the weighted error of the channel counts"; the value 1 will find many false peaks, and 5 will miss genuine small peaks. In the event, we used 3, but translation of this sensitivity into another program's seems difficult. Another example: The "library match width factor" in *GammaVision* is in units of FWHM (sensibly), other programs use keV, or may allow a choice (eg *Genie-PC*).

Most amusement can be had with assignments made by *Maestro*. This is admittedly very unsporting as the program does not pretend to be at all sophisticated in this regard. It appears to allocate the nuclide that is nearest in its internal list of energies, and is thus very dependent on what is in that default library; the liaison may be several keV away. Thus 880.5 keV (^{154}Eu) was identified as $^{110\text{m}}\text{Ag}$ (884.7 keV), and more mysteriously a large 1173.1 keV peak in a calibration spectrum was allocated to ^{132}I . Most of the common suspects were identified properly, but clearly care and a measure of scepticism is needed.

The false peaks identified in the outputs from NPLSS3A4 are given here; these results are reported to give a feeling for the scale of the problem, and bearing in mind the warning given above, no general conclusions should be drawn. *GammaVision*: ^{155}Eu , ^{46}Sc , ^{65}Zn ; *Genie-PC*¹: ^{205}Bi , ^{208}Bi , ^{243}Am ; *Genie-ESP*²: ^{100}Pd , ^{109}Cd , ^{126}Sn , ^{208}Bi , ^{237}Np , ^{243}Am ; *Fitzpeaks*: none; *Maestro*: seven nuclides, see above; *Sampo 90*: none; *Omnigam*: ^{155}Eu ; *OSQ*: none, except when using "forced

¹ and ²: neither Genie program used the TEST library

MDA" when 16 extra nuclides were positively reported, although most of these gave a value derived from one energy only and all other energies for that nuclide showed very diverse "less-than" values.

As far as one can see, the device of incorporating several radionuclides with a gamma energy at about 122 keV in the test library did not cause any significant difficulty. The radionuclides ^{57}Co and ^{75}Se were never reported as found in any of the automatic programs; difficulties in measuring ^{152}Eu can be attributed to the small quantity involved; ^{154}Eu behaved no worse than any other multigamma nuclide. The other attempt to sow confusion with ^{22}Na and ^{154}Eu did appear at first to produce a satisfactory problem with *Sampo 90*, as described below, but further tests completely undermined this hypothesis. The programs coped well with both these stratagems.

A predictable peak in the background spectra is due to ^{40}K , and we should expect to see this in all the "unknowns" (sensitivity factors, counting times, and counting rates allowing). Indication of ^{40}K is, of course, a true not a false identification. If again we consider only NPLSS3A4, ^{40}K is reported in *GammaVision* ($46.6 \text{ Bq} \pm 29 \%$), *Fitzpeaks* ($35.8 \text{ Bq} \pm 22 \%$), *Omnigam* ($40.0 \text{ Bq} \pm 32 \%$), *OSQ* ($50.8 \text{ Bq} \pm 19 \%$), and by hand *Maestro* ($21 \text{ Bq} \pm 40 \%$). The background spectrum NPLBS34 when run through *GammaVision* showed ^{40}K as $23.5 \text{ Bq} \pm 14 \%$. In most cases the u-test indicates that there is probably no difference from the background value. Any small amount of ^{40}K present could originate in the ampoule material.

10 The Efficiency Curve

The programs often allow a choice of fitting function for the efficiency versus energy curve. Many different functions are in use or have been proposed [1, 2], most of them grouped under "polynomials" and "exponentials". Once the efficiency data table has been assembled, the user should always try the various options and look at the graphical plot on both linear and log scales. It may be wise to print out the data table before deleting any outlying points in an effort to get a better fit, so that if need be the values can be put back with minimum distress.

Note that an "interpolative" option will show zero uncertainties. This does not mean that it will give a more accurate result. The line simply goes straight from point to point in a step-wise fashion, and all the smoothing benefit gained from constructing a graphical curve is lost. One definite recommendation is that for n-type detectors, such as the one we have here, the low energy region below the efficiency knee is best served by a "linear" fit, if that option is available. As described below, great care is needed with any function if extrapolated values are required. With some functions a small change in data values at high energies can induce a large change in efficiency values in the distant low energy region below the first data point. Scrutinize the displayed shape for reasonableness at every step.

11 Problems of the Sets: Set 1

This set was designed to test relatively straightforward spectra, and has few problems. The ^{85}Sr difficulty has been addressed already in these notes. This apart, there do not appear to be any generic complications in the analyses of the major nuclides. The small amount of ^{152}Eu which appears as a contaminant did produce widely varying answers, from zero to over three times the estimated real value. Some programs made apparently inexplicable blunders, which are described under Section 14 of these notes.

Of the basic functions of 3.3.1, "peak identification" and "nuclide identification" worked reasonably well. Section 9 has described how false identification can be reduced or eliminated by varying analysis parameters. "Activity quantification": again reasonable, subject to the qualifications noted above. "Ability to predict escape peaks": escape peaks were never reported and thus are not obviously part of any program. "Ability to measure overlapping peaks": many energies in the 1B spectrum are part of multiplets; the programs must have deconvoluted them properly to give the generally good results. "Ability to cope with differing peak widths": described under the ^{85}Sr difficulty; probably satisfactory. "Ability to estimate uncertainties": uncertainties were reported with all results; it was not always clear how these numbers were arrived at, in particular whether the uncertainties of the efficiency calibration were being calculated in a comprehensive and valid fashion. Some specific comment on this is made under Section 14, notes on the programs. The user needs to be alert to the differing multiples of sigma used as the default in the various programs.

12 Problems of the Sets: Set 2, Summing

The major aim of Set 2 was to test the response of the programs to true coincidence summing. The prepared sources were deliberately counted close to the detector. This impacts on the analysis in two ways. Firstly, cascading gammas from multigamma nuclides in the "unknowns" may sum, taking counts from the full energy peaks and reducing the apparent activity of these nuclides. Secondly, those nuclides in the calibration source that have cascading gammas may sum likewise with the effect of reducing calculated values for the efficiency at the full energy peaks. Paragraph 4.2.2 of the report "strongly recommends" that the ^{60}Co and ^{88}Y peaks in the calibration spectrum should not be used, these being the only calibration nuclides that would sum in this way. Without them, the efficiency calibration will be correct for single gamma-ray nuclides, but will require extrapolation at high energies as the top data point is at 1115 keV. With the ^{60}Co and ^{88}Y values included, the program will construct some sort of mean calibration line that falls between the single gamma nuclides and the multigamma nuclides and is correct for neither.

McFarland [7] looked at the effect of including or omitting inaccurate points. In the case of polynomial functions, an inaccurate data point on the boundaries of the set, such as we have with ^{60}Co and ^{88}Y , is probably better included if the alternative is extrapolation. If extrapolation is inevitable, then the exponential type of function is preferred to a polynomial. Inaccurate data within the bulk of the energy table are best removed. These conclusions must depend on the degree of inaccuracy; however McFarland tested a 5 % error, not dissimilar to our degree of summing. On the other hand we would be using four inaccurate data points not one, and the recommendation must stand not to use the summing-affected data in the efficiency curve.

The results when subjected to the u-test show that with the spectrum NPLSS2A only ^{85}Sr had a large number of measurements that were not significantly different to the known NPL value and one would guess that the main reason for this apparent agreement is the large counting uncertainties due to the low activity. The agreement with the reference value for ^{137}Cs is generally quite reasonable as expected for a single gamma nuclide. The agreement for ^{60}Co is very poor, in nearly all cases $u > 3.29$ so that 'the values differ significantly'. The programs are not coping with what must be the simplest possible case of true coincidence summing.

In NPLSS2B4, the u-test shows all the analysis results are significantly wrong, yet the programs are in reasonable agreement with each other. If there is an error, everyone is making it. In round

figures ^{134}Cs is low by about 30 %, ^{125}Sb and ^{154}Eu low by about 20 %, and ^{137}Cs and ^{155}Eu low by about 12 %. The latter nuclides should show no true coincidence summing (^{137}Cs does show x-rays but the single 661.7 keV gamma-ray does not sum with them; in ^{155}Eu the 86.6 keV gamma may sum with x-rays, but the 105.3 keV does not and it is this latter that the programs almost invariably use); it would appear that the effect here is one of random summing. If this is so, then the low apparent activity of ^{125}Sb , ^{134}Cs , and ^{154}Eu must be due to a combination of random summing and true coincidence summing. It is clear from the NPLSS2B4 results that no program has a routine for correcting for these major effects. The presence of a pulser peak in all the spectra should facilitate correction for the random summing part of the current difficulty. It is hoped that making these spectra available with known activities and a known summing problem will help the programmers in their difficult task.

If a standard of the nuclide sought is available then the problem of true coincidence summing can be sidestepped by doing a comparative count [1], ignoring the efficiency curve altogether. Even though an efficiency point for, say, a ^{154}Eu energy may be wrong absolutely, it is correct and reproducible and usable for ^{154}Eu at that energy and in that geometry. We can only make use of this method for summing nuclides in this set for ^{60}Co in NPLSS2A4 and NPLCS24. Taking the ratio of counts per second per gram for the 1173 keV peak in the *Maestro* data (not using the 1332 keV with the multiplet problem), ^{60}Co in NPLSS2A4 is $21.11 \text{ kBq/g} \pm 0.24 \%$; the NPL value is $21.44 \pm 0.23 \%$. As expected the result is much closer to the true value, although the small uncertainties produce a large u-statistic. A general criticism of the analysis programs is that the user has no option but to go through the efficiency curve routine, a procedure that is known to be flawed for true coincidence summing.

13 Problems of the Sets: Set 3

The aim of this set is to test the effect of lead shielding which is both close to the detector and does not have an internal graded shield. The main effect is that Pb x-rays become very prominent. (K_{α} : 72.80 keV (P_x equal to 0.280) and 74.97 keV (P_x equal to 0.472); K_{β} : 84.79 keV (P_x equal to 0.167) and 87.63 keV (P_x equal to 0.048)). The contrast with set 2, where graded shielding is in place and consequently no Pb x-rays are visible, is marked. There is also a small increase in the backscatter peak. Do the x-rays interfere in any way with measurements of ^{109}Cd at 88.03 keV, ^{155}Eu at 86.45 keV, ^{203}Hg at 72.89 and 82.5 keV? Does the backscatter peak have an effect on the measurement?

The radionuclide ^{109}Cd is only present in the calibration spectrum. Running the normal efficiency routine shows no glaring problem. Only if the user looks rather carefully at the efficiency curve does anything appear unusual. The curve has a maximum in the 100 keV region and falls off slightly below this. This seems to be familiar enough until the user realises that the detector is an n-type yet the shape is much more like that of a p-type, and also the maximum is at the 88 keV point which is an unusually low energy for an efficiency knee. Going back to the spectrum display shows that there is a significant 84 - 88 keV multiplet, and the higher energy has the larger area peak. This is the opposite to what is seen in the normal Pb K_{β} x-rays. The ^{109}Cd at 88.03 keV must be being augmented by the $K_{\beta 2}$ x-ray at 87.63 keV. The safe action is to delete that point from the calibration.

If the 88 keV point were left in then the activity of ^{155}Eu might be compromised. This is only a possibility rather than a certainty, as while the 86.54 keV energy is more abundant than the 105.3 keV (P_{γ} : 0.327 and 0.218, respectively), it is possible that the analysis library compiler has

omitted the lower energy line just because of this x-ray problem. In the event all the programs on analysing NPLSS3B4 give ^{155}Eu concentrations which are somewhat high, but only two, *Genie-ESP* and *Omnigam*, give a u-statistic that implies that the calculated values deviate significantly from the known values. Similar reasoning would omit the x-rays of ^{203}Hg from the calibration library; these are low abundance in any case.

The backscatter "peak" caused no difficulty. There is a very small peak in NPLSS3B4 at about 188.2 keV which is close to the maximum of this distribution, with an unusually shaped background continuum. Unfortunately (for our purposes) this is of no practical consequence. The peak is likely to be due to ^{154}Eu , and is one of the many minor members of that extensive clan; it is not present in the libraries and is thus not used in the calculation.

14 Program Notes

These notes are not intended as a definitive assessment of any program, but as helpful comments on some characteristics as noted by one person.

It is very important in this work to make sure that the calibrations are set up properly. The user may consider a general check such as the following. After using the calibration spectrum to establish the energy, shape and efficiency calibrations for a set, start again; read the calibration spectrum into the system as an unknown and use the new calibration files to analyse it. The nuclide concentrations obtained should be close to the values that were entered in the calibration file, with extra uncertainty added due to fitting in the efficiency equation.

Maestro

Both DOS-based *Maestro II* and *Maestro for Windows* were tested. They gave virtually identical results. The Windows version was usually used as being a little easier to operate.

The "peak search" routine will find peaks that a visual scan using one vertical scale would miss. However some care is needed when reading peak information data from the screen. In a multiplet, the peak information that is displayed when "info" is requested refers (helpfully) to an individual peak and not the whole Region of Interest (ROI). The size of the ROI, in channels, may be different, usually smaller, if the spectrum is energy calibrated.

Sometimes the peak search routine will put a single ROI about adjacent peaks which on visual inspection may not appear to overlap significantly. The user may be tempted to obtain information on each individual peak. A misleading characteristic appears when reading peak information from such an ROI. If the cursor ("marker" in Ortec-speak) is anywhere within the ROI, and "info" is requested, the information obtained will always be that of the largest peak. This is the case even when the cursor has been moved by clicking on "peak" and is clearly sitting on a minor component of a multiplet. The way round this is to delete the large ROI, step the cursor to one peak (it goes to the peak maximum), insert an ROI which will be smaller and set symmetrically about the maximum, and then ask for information. Note the data, delete that ROI, step to the other peak and repeat. Beware that peak areas obtained will be flawed to a greater or lesser extent. As an example of the imprecision of determining areas from a multiplet in this way, an ROI containing 1325 and 1332.5 keV gave the area of the ^{60}Co peak as 1036343 ± 1146 counts when using the multiplet ROI, yet when an individual ROI was set up on the same peak, this area was read as 1015751 ± 1045 , some 2 % smaller. Both these values crudely

exclude the interference from the other peak present. These procedures are described as "semi-quantitative".

There are minor annoyances in the *Maestro* display. Thus

- a) the cursor line is displayed in front of the peak information which can then be easily misread, especially, we found, 3s and 8s (move the cursor to one side, the data remains displayed),
- b) for peaks that are close together, a second block of peak information will be written on top of the first, making both illegible (click to an ROI out of that expanded region and then click back into it),
- c) sometimes the first line of the block of data is off the top of the screen and this is not revealed by changing the scale of the vertical display (keep the peak within the lower half of the expanded screen, perhaps on a log scale, before asking for 'info' to ensure all five lines of data can be read).

These same routines in the *GammaVision* software appear with, sadly, the same idiosyncrasies.

S100

As was stated in Section 2, this emulator program is very similar in operation to *Maestro*. There are some differences in acquisition mode, where it usefully can display peak area and peak resolution continuously, and has a better routine for energy calibration than *Maestro*. On the other hand, dead time is not displayed continuously as it is with the other emulator. The actual package available for this work did not have a "peak search" option and all ROIs were found visually and entered manually. This degree of interactivity might be expected to produce better values, but in practice it can be seen that the results obtained were very similar to those of *Maestro* and to the other more complex programs.

Users might note that the uncertainty shown on the screen for the net peak area is $1.65 \times \text{sigma}$; this was corrected to one sigma for our comparative tables. The program, unlike *Maestro*, will read spectra in a number of other manufacturers' formats. This was helpful here as our old version of the program would not read the Canberra CNF files, and the spectra were loaded in Ortec CHN format.

Fitzpeaks

One of the most comprehensive and yet easiest packages to use. It will accept a wide range of other manufacturers' file formats and the CHN files were tested.

The excellent use of nuclear data and libraries is noted above. There are numerous practical details that are rare or missing from other programs. For example, at high count rates peak widths are automatically allowed to broaden in order to stop spurious peaks being added in the peak search. The detector efficiency calibration does not allow a choice of function, but claims to determine the overall uncertainty of any calculated efficiency value using a variance/covariance matrix. However it must be said that while the efficiency calibration report shows the difference of the fitted value from the input data value, it does not give the calculated uncertainty.

The program has a more informative approach to summing than other programs. For example, in the present tests, the report on NPLSS2B4 noted the presence of sum peaks, named the nuclides involved (^{134}Cs and ^{154}Eu) and gave the probable single gamma energies involved in each sum. However in common with all other programs, *Fitzpeaks* does not (cannot) automatically do a summing correction. This is a program that appears to be in a state of continuous evolution. This makes reference to the help file essential and the operations manual a little difficult to follow, especially as it has no index.

Sampo 90

This is an ageing program that has been superseded by others, but which is full of interest with a unique operational interface. The shape calibration is particularly sensitive to the initial value chosen for a parameter WGUESS (width guess), and it is worth trying a different value here if the displayed fitted shapes look poor. There is an optional specific shape calibration set up for calculations using 511 keV. This was not implemented in our test.

Most results agree reasonably well with those from other programs, with two major exceptions. The ^{137}Cs value in NPLSS1B4 is massively wrong, and the program failed to recognise ^{154}Eu in that spectrum and in NPLSS3B4. At first it was thought that the problem with ^{154}Eu might be due to the deliberate addition of ^{22}Na to the analysis library in an attempt to force this crisis (see Section 7). But rerunning the analysis with the ^{22}Na removed from the library gave the same result. Thus, the mystery remains. The list of unidentified peaks contains all major members of the ^{154}Eu set of gamma transitions, but this pattern went unrecognised.

A further detail that reinforces one's sceptical attitude to computer output. The report gives a confidence value for each nuclide. This is not necessarily related to the reliability of the result; for ^{22}Na in NPLSS1B4 the value of this parameter was 0.9995, demonstrating a very high confidence in identifying a nuclide that was not present at all.

Omnigam

Another old and superseded DOS program, and not as easy to use as recent Windows programs. Several comments have already been made regarding libraries, calibrations, and summing corrections. In the GERPAR menu, automatic background method was selected, and to allow for uncertainty in the input data for the calibration, 0.5 % was entered as additional systematic uncertainty. The user should be careful in interpreting some ambiguous terms; "calibration date" is not the date of the calibration but the date at which the calibration standard activities were specified; "collection time" is the time the sample was collected, not the time the spectrum was collected.

With regard to the results, there is general agreement with other programs, but as with *Sampo 90*, difficulties appear with spectrum NPLSS1B4, where some, but not all, nuclides are seriously and inexplicably underestimated.

GammaVision

This program worked well without significant eccentricities. There did not appear to be a mechanism for entering uncertainty data with calibration information, therefore the effect of this is missing from the reported values. These values are generally amongst the most reliable, as

the tables show. As with all the programs, the summing problems of NPLSS2B4 were ignored, and thus all values are low. The ability to incorporate a summing factor that is present in the predecessor program *Omnigam* is missing from this one, perhaps a tacit admission that the parameter was of limited use. The ROI "info" display of *Maestro* is also present in *GammaVision* (described as semi-quantitative analysis) together with the annoyances described earlier. The data analysis reproduced in the output report can be particularly prodigal but the user soon appreciates that it is not necessary to have 35 A4 sheets of paper per spectrum. If one had to search for criticism then a minor complaint would be that the index to the manual is quite inadequate; this, it must be said, applies to all the manuals seen, and indeed some program manuals do not have an index at all.

OSQ

This program is still under development. This perhaps accounts for curiosities such as the sixteen significant figures helpfully provided for factors in the calibration equations, and an interesting and educational user manual, full of excellent advice, but a little difficult to use. There are good things such as allowing the entry of uncertainties in the calibration data, and the mathematical procedures used are presented in greater detail than in the other programs. In the event, the results were generally very similar to those of other programs. Note that the default situation is that uncertainties are given to two sigma (scaled to one sigma here). Another unique feature is that the channels used to estimate the background under a peak are not the outer channels within the Region of Interest, as with *Maestro* and *S100*, but are channels outside the ROI but adjacent to it.

Care is needed with an option called "forced MDA" in "identification set up". When this was in place with NPLSS3B4, the result for ^{125}Sb rose from 3.22 to 11.4 kBq/g. This appears to be due to a weighted average which included an erroneously identified peak with a small emission probability whose individual contribution was no less than $142 \text{ kBq/g} \pm 0.6 \%$.

Genie-PC and *Genie-ESP*

These are nominally the same program run on different operating systems, *Genie-PC* on PCs running OS/2 and *Genie-ESP* on VAX workstations running VMS. In practice, as the results from the spectra here demonstrate, the same spectral input produces different output values from the two systems. The user should be prepared for large output files from either system, as each analysed spectrum file contains not just the results but also all the original spectrum data and all the information that has been used in the calculation including analysis and calibration libraries.

In these tests, data collection was carried out on a *Genie-ESP* system, and the information transferred to *Genie-PC* for test purposes. Some difficulties arose. *Genie-ESP* files, such as calibration files and nuclide libraries, will be accepted by *Genie-PC* but will function there only to a certain degree. Some of the data in the file appear not to be read properly into the *Genie-PC* routines; for example some nuclides in the certificate file are ignored. This can be fixed by putting the file into the appropriate file editor and making a copy. The copy, now presumably enriched with minor reformatting, will work.

A second functional difference became apparent. A *Genie-PC* analysis requires a low energy tail parameter produced by the peak shape calibration. This parameter was not produced in the

version of *Genie-ESP* used. This meant that a spectrum calibrated in *Genie-ESP* could not be analysed in *Genie-PC*. The solution is to transfer only uncalibrated spectra.

The results of both of these programs were good, agreeing with the known concentration values where other programs agreed, and elsewhere disagreeing with the known values to much the same extent as everyone else. For *Genie-PC*, one inexplicably low result appeared for ^{134}Cs in NPLSS3B4.

15 References

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