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Analysis of remotely accrued complex gamma ray spectra – proficiency test

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Abstract

This report presents details pertaining to an exercise conducted as part of the NKS-B programme using synthetic gamma ray spectra to simulate the type of data that may be encountered in the early phase of a nuclear accident. The aim of the exercise was to provide participants with an opportunity to exercise in the type of situation and with the type of data that may result after a nuclear accident. Attempting to conduct such exercise internationally using actual samples presents practical and logistical difficulties and a synthetic spectrum was employed to negate some of these problems. A HPGe spectrum was synthesized containing a range of typical fallout isotopes and distributed, along with calibration information, to the participant laboratories. The participants were required to submit results within three hours of receipt and with the option of submitting further results within one week. The results provided by the laboratories indicate that all laboratories were able to identify and quantify some of the isotopes but only some labs were in a position to identify and quantify virtually all the constituents of the spectrum. Results indicate that there remain some problems with aspects such as true coincidence summation and using file formats with which labs may not be familiar with. The exercise provided a useful opportunity in exploring the possibilities of using synthetic spectra for exercise purposes and offered participants the chance to practice with the sort of scenario that may result after an accident.

Key words

Gamma spectrum, HPGe, coincidence summing, nuclear accident, synthetic spectrum

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Analysis of remotely accrued complex gamma ray spectra – proficiency test (REMSPEC).

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1.0. Introduction.

Gamma spectrometry remains the primary analytical tool in emergency situations involving releases of radioactive materials. Staff members of laboratories in many countries using gamma spectrometric techniques and who may reasonably be expected to be involved in the response activities to such a release have often not been involved in the sort of measurements and conditions that are likely in the aftermath of such an incident. To some extent this situation has been unavoidable for a variety of reasons. However the advantages for laboratories and their staff to have some experience in this area remain significant, both for their own purposes with respect to handling of events and with respect to their ability to offer assistance to other countries. From a technical point of view, there are two aspects to this problem that are worth considering.

The first is that samples measured in the aftermath of an event are likely to bear little semblance to the sort of samples that the vast majority of laboratories and operators deal with daily, in terms of both spectral complexity, range of isotopes and activities. Such samples in themselves present special challenges to the laboratory and analyst. In an accident situation, speed of information provision is often important. This adds a further layer of difficulty in that not only is the sample presenting complex data but that data must be analyzed under time constraints not usually encountered in regular analyses. The second aspect relates to how the data is obtained. Recent advances in both instrumentation and data transmittal have led to the situation where an analyst may be required to analyze data from instrumentation to which he has no access. Since 2001, more and more countries have begun equipping first responders such as police, the military and emergency personnel with detection capabilities as well as establishing mobile laboratories, search units etc. Such developments mean that laboratories may be asked to analyze data from such external units who, in themselves, are unlikely to have high levels of expertise in the equipment they are using. Communications technology now means that data is easily and speedily transmittable around the world. It has long been accepted that many countries are not in a position to deal with the aftermath of a nuclear event on their own and international initiatives and agreements have sought to mitigate this problem. In the early phases after an event, one form of assistance that may be sought is technical assistance with regards to analysis. In such a scenario, a laboratory

may be asked to analyze data that has not been accrued by them or even by personnel in the same country. Laboratories should preferably not only have experience in measuring complex data sources but also have experience in and the skills necessary to analyze complex data accrued using instrumentation to which they do not have access.

Addressing these problems has been hampered by a range of problems. Generating samples simulating those that might arise from actual events has traditionally been fraught with problems due to the short half lives of isotopes involved, the technicalities of the production of such samples, the high activities involved and problems with shipping and handling. Recent years however have seen computational advances sufficient to allow the generation of high quality, realistic, synthetic spectra which may be tailored to produce data of a quality sufficient for exercise purposes. Laboratory software suites are also now flexible enough to allow most users analyze a wide range of spectral formats and facilitate the easy entry of calibration information etc.

Standard “test” gamma-ray spectra for the testing of analytical software have been available for a number of years. Some of these spectra were obtained using actual detectors and sources and some were generated using various manipulations of such spectra. Overviews of a range of test spectra and their implementation may be found in Nielsen (1982); Zagyvei et al. (1985); Sanderson (1988); Blaauw et al. (1997); Los Arcos et al. (2005) and Arnold et al. (2005). The intended function of the spectra as described in the above was the provision of spectral data for the facilitation of identification and determination of photopeaks and their areas. The spectra were not primarily intended to be representative of “real life” spectra and therefore are of limited applicability with respect to their potential use in testing analytical capabilities during an emergency situation. Synthetic spectra however have been used before in this or closely related contexts, Karhu et al (2006) and Nikkinen (2001) both describing the application of synthetic spectra for the proficiency testing of gamma analysis capabilities.

1.1. Objective.

The objective of the REMSPEC exercise was to conduct a proficiency test/exercise involving the distribution and analysis of gamma spectral data intended to simulate the sort of information an analyst could reasonably expect to encounter after a nuclear accident. The project intended to:

- Provide an exercise opportunity for the participants to practice the analysis of complex post-event data under time constraint,
- Provide an exercise opportunity for the participants to practice analyzing data not drawn from an instrumental setup to which they have access or with which they are familiar,
- Increase competence in the area of post-event data analysis,
- Establish the necessary skills and tools to conduct such exercises in the future,
- Identify technical and organisational aspects of post-event complex spectral analysis where the potential for improvement exists.

2.0. Description of the Exercise

The participants were asked to analyse a synthetic gamma ray spectrum designed to approximate the type of situation that could be expected for samples taken after an accident involving a major release from a nuclear facility and obtained with conventional HPGe detectors. Two spectra were provided for the exercise – an initial calibration spectrum to allow participants to prepare their systems and analysis routines and the actual test spectrum.

2.1. The Scenario

The basis for the scenario used in the exercise was that of a hypothetical accident involving a nuclear power plant on the Kola Peninsula in the Russian northwest as fully described in Larsen et al, (1999). The starting point for the exercise was the activity of a range of typical release nuclides in air some 40 km from the actual accident site during the day after the release began. It was assumed that a small volume air sample (exactly 1 m³) was taken using an un-described sampler and measurement was immediately made

on a standard HPGe detector as described later. The resultant spectrum and information pertaining to it was then used as the basis for the exercise.

2.2 Technical aspects.

As with any exercise, certain compromises had to be reached between accuracy and practicability. Regarding how the exercise was conducted, a number of aspects can be immediately seen to be “unrealistic”. The exercise was conducted at a time that suited the participants when in reality such a situation could transpire when whoever would be regarded as the best person to analyse such data at any particular lab may not be present. The dissemination of the calibration spectra and efficiency data in advance was intended to eliminate such problems as manifested themselves in previous exercises of this type but remains unrealistic. The provision of spectra in a range of formats is also unrealistic but it is known that many labs are not in a position to readily convert spectra especially to and from some of the more complex proprietary formats. With regard to the spectra themselves, it was decided not to simulate background signals due to for example, naturally occurring nuclides occurring in laboratory background. The justification for this was that the simulated sample was small and the count time short. It was assumed that background signals would not, in relation to the stronger signals of the contaminants, constitute a major part of the spectrum. All other aspects of a typical gamma spectrum were included. Traces of noble gases were present in the “sample” which may not be totally realistic for a filter paper sample but could be feasible for a sample taken using charcoal canisters or impregnated filters or for a sample that had time for ingrowth before measurement. The exercise was simplified in that no conditions were imposed on the participants that would necessitate the use of density or matrix or source-detector distance/angle corrections. This is probably a little unrealistic but it was omitted on the basis that the project was not trying to test correction methods and that in an early phase of an accident the uncertainties accrued as a result of incorrect implementation of such corrections would probably be acceptable.

2.3 The Detector

The detector model used throughout the exercise was that of a standard coaxial HPGe detector of the following dimensions: Crystal radius – 30.6 mm, crystal length – 58.5

mm, radius of curvature– 1 mm, radius of internal hole – 4.5 mm, length of hole – 48 mm, radius of curvature of hole – 4.5 mm, top dead layer – 0.85 mm, side dead layer – 0.55 mm, internal hole dead layer – 0.0003 mm, thickness of copper crystal holder – 0.8 mm, aluminium housing side wall thickness – 1.5 mm, end cap thickness – 2.03 mm, distance from crystal top to end cap internal wall – 9 mm. The geometry of the sample holder was that of a right cylindrical polyethylene container. The bottom of the geometry was 1.7 mm thick, the sides 1.3 mm thick and the density of the material (polyethylene) was described as 0.920. The diameter of the active volume of the geometry was 21 mm and the height was 10 mm.

For the calibration spectrum and the efficiency description of the detector, a water matrix in the above geometry was used. For the test spectrum the matrix was taken to be water equivalent. The resolution of the detector model was relatively good and was assumed to be representative of a quality HPGe detector. Peak tailing was not modelled nor was pulse pile up or other features of electronics included in the model. Electron transport was not included in the model so any Bremsstrahlung effects would not be visible. True coincidence summation effects were modelled for all nuclides in the exercise (including x-ray/gamma summation). Simulation was conducted using the VGSL implementation of MCNP as described by Plentada (2002). Validity of the coincidence factors were checked using the TRUECOINC code as described by Sudár (1999) employing the same efficiency data as was disseminated. This was conducted to ensure that the participants could reasonably expect to be able to reproduce the correction factors generated by the simulation using a third party application.

3.0 The Spectra

3.1 The Calibration spectrum

The first piece of data transmitted was a “calibration” spectrum intended, in part, to ensure that the participants could open and analyse the spectral data files used in the second and main part of the exercise and enter such data as would be required as to conduct the analysis of the complex sample spectrum. The spectrum was a simulation of approximately 100 Bq each of ^{133}Ba , ^{137}Cs , ^{88}Y and 1000 Bq of ^{40}K conducted on the

same detector, for the same geometry and matrix as would be used for the test spectrum. The spectrum also served to allow the participants to energy and shape calibrate their systems for the subsequent analysis. This spectrum was accrued over a simulated period of 10 hours approximately.

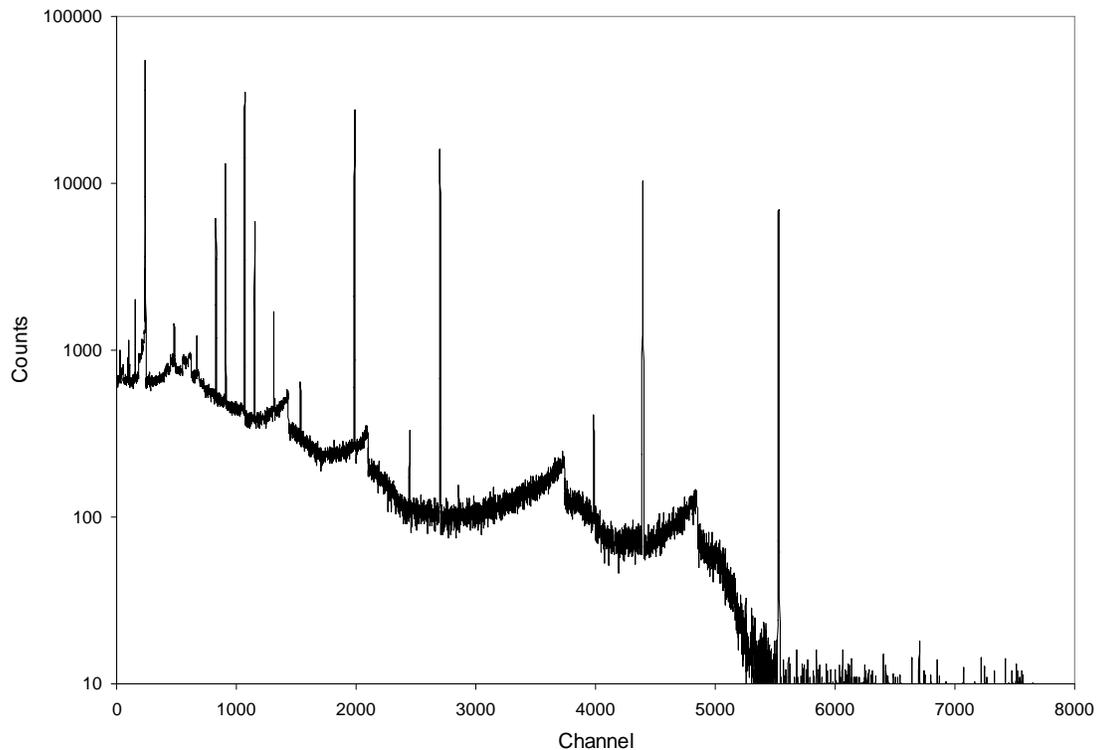


Figure 1. The calibration spectrum provided for the exercise.

As a range of spectral formats were being provided, it was intended that use of a calibration spectra could also serve to eliminate any chances of problems caused by artefacts arising from converting spectra from one format to another, avoided any problems potentially incurred by use of functions or whatever to describe energy calibration and allowed the analysts to calibrate their systems using the same routines they would use for the actual test spectrum. For the purpose of the calibration, the participants were informed that the 661 keV peak of ^{137}Cs was located at approximately channel 1990 and the 1460 keV of ^{40}K was located at approximately 4390 channels. The live time for the calibration spectrum was 37797 second's and the real time was 41577.

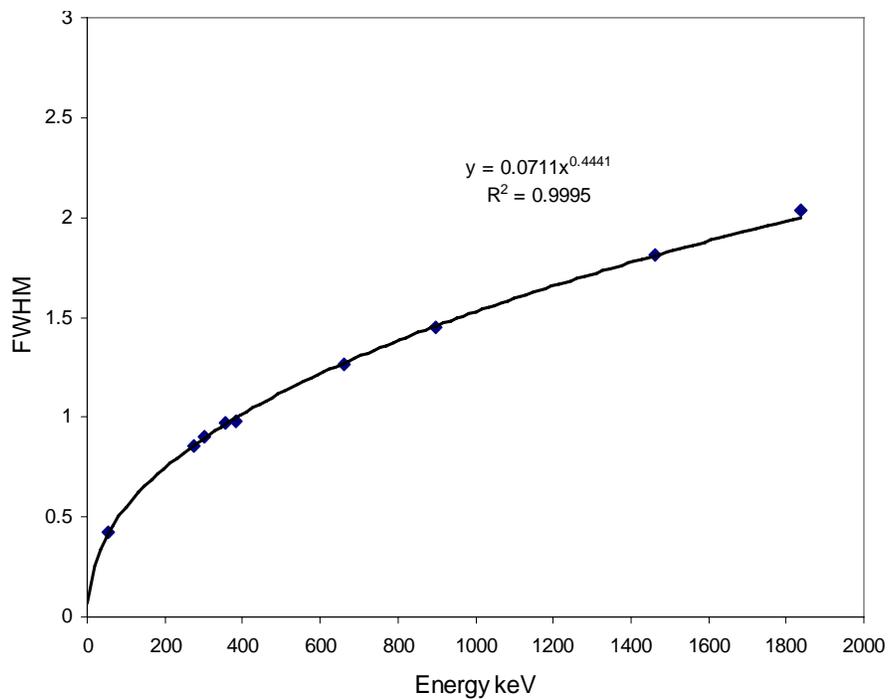
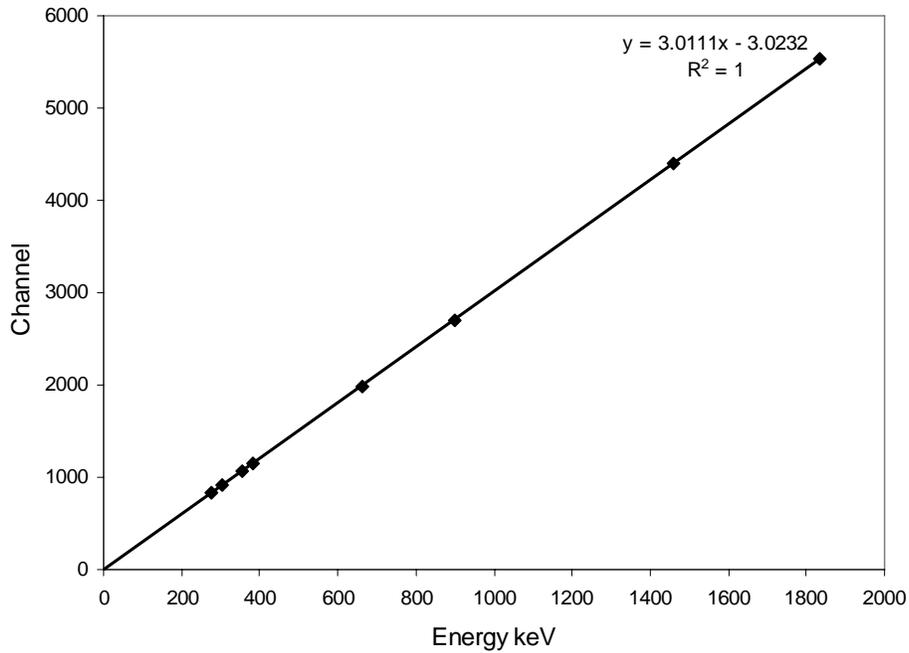


Figure 2. Energy and shape functions for the distributed spectra.

3.2 The Test Spectrum

The nuclides of Table 1. were included in the test spectrum and were based upon the information in Larsen et al. (1999). For ^{134}Cs the electron capture branch was not simulated due to its low probability and insignificant gamma emissions and only the β –

decay was employed. For ^{131m}Te the significant IT branch results in no major gamma lines and was not simulated in the spectrum. Decay/ingrowth over the counting period itself was not simulated.

Isotope	Modeled activity Bq/m³.
^{131}I	3046.50
^{132}I	2937.0
^{133}I	2443.60
^{135}I	217.6
^{134}Cs	321.9
^{136}Cs	73.4
^{137}Cs	251.8
^{103}Ru	297.8
^{127}Sb	218.0
^{140}Ba	914.1
^{140}La	209.1
^{141}Ce	66.4
^{143}Ce	43.0
^{91}Y	376.0
^{91}Sr	58.9
^{95}Zr	80.6
^{95}Nb	409.3
^{131m}Te	202.0
^{132}Te	2850.0
^{131}Te	45.6
^{91m}Y	36.9
^{135}Xe	193.0
^{133}Xe	27.6

Table 1. Isotopes and activities modelled for the test spectrum NKSSPEK1.

Given the nuclides involved and the short time, it was assumed that the majority of contributions or decays would be insignificant. Participants were instructed to deactivate (if possible) features in their software facilitating decay/in growth over counting although it is unlikely that inclusion of such operations would have significantly changed the final results. Uncertainties in the modeled activities are not included in the simulation process (i.e. there is no uncertainty in the amounts modeled in the Monte Carlo process). The

sampling/reference time for the spectrum was 01.01.08 at 03:45 am. Participants were instructed to determine activities for the isotopes at the time the sample was measured.

Energy keV	Peak Efficiency	Uncertainty	Total Efficiency	Uncertainty
40	0.0042851	0.000128553	0.0048728	0.000146184
60	0.045309	0.00135927	0.055006	0.00165018
80	0.081261	0.00243783	0.10146	0.0030438
90	0.091632	0.00274896	0.1157	0.003471
100	0.096717	0.00290151	0.12397	0.0037191
110	0.099771	0.00299313	0.12997	0.0038991
120	0.099382	0.00298146	0.13223	0.0039669
130	0.09917	0.0029751	0.13421	0.0040263
160	0.094255	0.00282765	0.1346	0.004038
190	0.084078	0.00252234	0.12983	0.0038949
220	0.075996	0.00227988	0.12669	0.0038007
250	0.067948	0.00203844	0.12368	0.0037104
360	0.049032	0.00147096	0.11725	0.0035175
560	0.034108	0.00102324	0.10959	0.0032877
760	0.026523	0.00079569	0.10312	0.0030936
960	0.021961	0.00065883	0.096955	0.00290865
1160	0.019313	0.00057939	0.091812	0.00275436
1360	0.016825	0.00050475	0.088379	0.00265137
1560	0.015443	0.00046329	0.087689	0.00263067
1760	0.013952	0.00041856	0.083728	0.00251184
1960	0.012622	0.00037866	0.081255	0.00243765
2160	0.011456	0.00034368	0.078912	0.00236736
2360	0.010562	0.00031686	0.077289	0.00231867
2460	0.010073	0.00030219	0.078917	0.00236751

Table 2. Efficiency data provided to participants (absolute values.).

Background was not simulated as the scenario assumed that the detector was well shielded and that background would not constitute a significant problem over the relatively short period of time for which the spectrum was accumulated (1 hour). It was decided not to simulate a spectrum whereby the sample had been allowed to decay as this was deemed unrealistic in so far as in an emergency samples will probably not wait for periods before being measured in the early phases. In so far as was practicable, the spectrum included parent-daughter pairs that could be expected to be present 10 hours after the accident but activity ratios were those provided by the simulations of Larsen et al (1999). The participants were not asked to determine efficiency themselves but were provided with efficiency data in the form of peak and total efficiency data (see Table 2) plus uncertainties for a range of energies as text files. These files were distributed along with the calibration spectrum in the first phase of the exercise. The participants were expected to construct their own energy/shape calibration files for their own systems based

on the data provided in the calibration spectrum. They were also expected to construct their own efficiency curves from the data provided which was, relative to the small number of points usually obtained in gamma spectrometric calibrations, fairly extensive. The Monte Carlo process does not output uncertainty values (efficiency values are simulated to an uncertainty less than 1%) so an arbitrary 3% uncertainty was given for all efficiency values as it was decided this represented the sort of uncertainty margin in a standard calibration of a detector. Total efficiency data was provided to facilitate coincidence corrections should participants want to apply them. A fuller table of the variation of efficiency with energy is Appendix 1.

3.3 True Coincidence Correction Factors

In order to determine if participants could realistically expect to derive appropriate TCC factors based on the data provided in the exercise, the efficiency data provided was used with the TRUECOINC code (Sudár, 2002) to determine factors for a number of isotopes that could be expected to be vulnerable to summation. The Monte Carlo derived values and the TRUECOINC values are in reasonable agreement. It is probable that deviations in the values such as they are due to the efficiency data in TRUECOINC being derived from interpolative functions applied to the raw data which may introduce some uncertainty. The extent to which this effects the results was untested as the factors calculated by both methods were deemed to be comparable.

3.4 Nuclear Data

All nuclear data for the modeled nuclides in the simulation was taken from the ENSDF data sheets downloaded in March 2008 from the National Nuclear Data Centre (<http://www.nndc.bnl.gov>)

Isotope	Energy keV	Monte Carlo TCC factor	TRUECOINC TCC factor
Cs-134	475.37	1.229	1.210
Cs-134	563.25	1.281	1.240
Cs-134	569.33	1.288	1.250
Cs-134	604.72	1.162	1.140
Cs-134	795.86	1.164	1.140
Cs-134	801.95	1.253	1.220
Cs-134	1167.97	0.917	0.880
Cs-134	1365.19	0.799	0.805
La-140	68.92	1.333	1.290
La-140	109.42	1.338	1.290
La-140	173.54	1.239	1.190
La-140	266.54	1.317	1.250
La-140	432.49	1.254	1.230
La-140	487.02	1.185	1.170
La-140	751.64	1.107	1.100
La-140	815.77	1.042	1.090
La-140	1596.21	1.164	1.145
La-140	2521.40	0.947	0.944
Sb-127	61.10	1.173	1.150
Sb-127	412.10	1.042	1.070
Sb-127	473.00	1.023	1.023
Sb-127	603.50	1.130	1.120
Sb-127	685.70	1.003	1.004
Sb-127	698.50	1.000	1.000
Sb-127	783.70	1.000	1.000

Table 3. Comparison of true coincidence summation factors derived from Monte Carlo simulation and values determined by the TRUECOINC code.

4. Test Analysis and Results

To check that the data in the test spectrum could be analyzed to produce meaningful results using off-the-shelf available software under time constraint, the test spectrum was analyzed (prior to being distributed) using Genie 2000 in a period of less than three hours. Efficiency data provided was used to construct an efficiency calibration within Genie and an energy/shape calibration based on the provided calibration spectrum was constructed prior to the test analysis. The spectrum was analyzed using a standard library driven routine and peak areas were derived by a least squares method. The parameters for determination of areas and which peaks were multiplets were optimized in advance using the information in the calibration spectrum. The library used was a custom library

containing no natural nuclides as the participants had been informed in advance that natural background nuclides were not included. All found peaks were fitted automatically with the minimum of interference from the operator. All found peaks were checked manually and identified multiplets deconvoluted using the routines built into the software itself. The results were then checked on a line by line basis and final activities calculated based primarily on peaks with the least interference and maximum emission probabilities. Coincidence correction factors had been determined in advance using the peak and total efficiency data supplied using the TRUECOINC code and these factors were applied to the results to produce the final activities. Once satisfied that the participants had a realistic chance of producing meaningful results and that no major faults were observed in the spectrum, the spectrum was deemed ready for distribution.

5. Results and Considerations for Individual Nuclides.

The following section discusses the situation regarding individual nuclide constituents of the test spectrum and the results obtained by the participants.

5.1. Strontium-91

Sr-91 has a wide range of gamma lines but only a limited number with appreciable intensity. Combined with the relatively low activity of the isotope compared to other constituents of the sample and the short count time, analyses of ^{91}Sr potentially poses some problems. Of the strongest lines, 620.1 keV is a minor contributor to a complex multiplet made up of this line and two others at 620.9 and 621.2 keV from ^{132}I , the ratios of gamma emissions for these two relative to the ^{91}Sr emission being 11 and 40 approx. which potentially poses severe problems for accurate area determination using default conditions on commercial software. The peak at 925.8 keV has better intensity but lies between two closely spaced peaks at 925.2 keV (^{140}La) and 927.4 keV (^{132}I) both of which have areas greater than the ^{91}Sr peak by factors of 5 posing difficulties for accurate determination of the area. The strongest peak of ^{91}Sr lies at 1024.3 keV although the strength of emission is offset by the lower efficiency at this energy. There is a small contribution from $^{131\text{m}}\text{Te}$ which may elevate the peak area slightly although it is relatively insignificant. There is insignificant coincidence correction for this peak. A strong peak is also exhibited at 749.8 keV (23.6%) and this peak is sufficiently well separated to be

useful. A triplet of peaks is present between 652 and 653 keV: 652.3 (2.97%), 652.9 (8.0%) and 653.0 (0.37%). Depending on how the users' library is setup, the analysis will probably either try to deal with them separately or as a triplet. The quickest correction would be to sum the probabilities (11.34%) and correct the activity by $(2.97/11.34)=0.26$. However the 652.3 keV peak exhibits coincidence losses of approx 7% and the probability should therefore be reduced to 2.76% in which case the final correction for the triplet would be 0.267.

^{91}Sr was identified by most participants in the preliminary results and some of those who missed the isotope in the first round identified it in the second. Activities provided were generally reasonable and even in cases where the activity was overestimated, the overestimation was not excessive. There did not appear to be any obvious candidate among the reported false positives which ^{91}Sr may have been mistaken for.

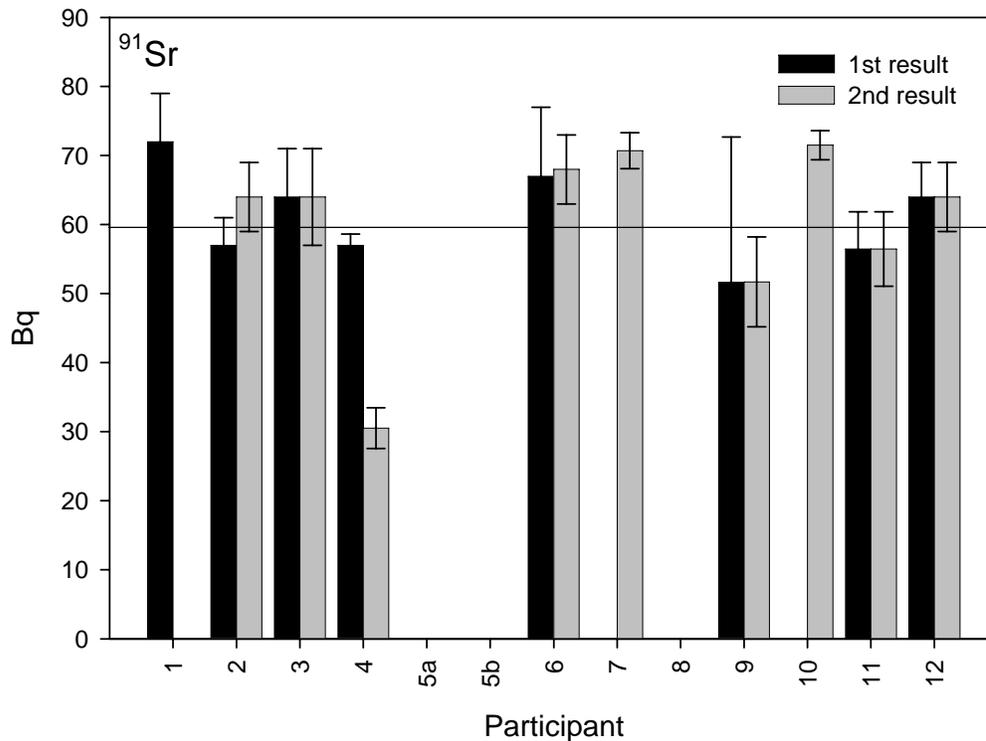


Figure 3. Participant results for ^{91}Sr .

5.2 Yttrium-91m

Y-91m has only one gamma emission at 555.57 keV and there are no other significant peaks in the vicinity. Given a reasonably accurate energy calibration there is no obvious reason the isotope would not be identified although the low activity relative to other isotopes and short count time may have complicated matters. There is no significant coincidence correction. Only two participants identified $^{91\text{m}}\text{Y}$ in the spectrum in the preliminary round. A number of the participants who missed $^{91\text{m}}\text{Y}$ had identified the presence of the parent ^{91}Sr and some participants who missed ^{91}Sr identified $^{91\text{m}}\text{Y}$. Given the length of the half lives of these isotopes and the period that had “passed” since the start of the accident, it had been thought that participants who had identified one of the pair would have checked for the second but there is no obvious pattern in the second results of participants checking for the partner isotope. Participant 2 produced an accurate measure of the activity of this isotope in the first round and improved upon this in the second. Participant 11 provided slightly elevated estimates in both rounds.

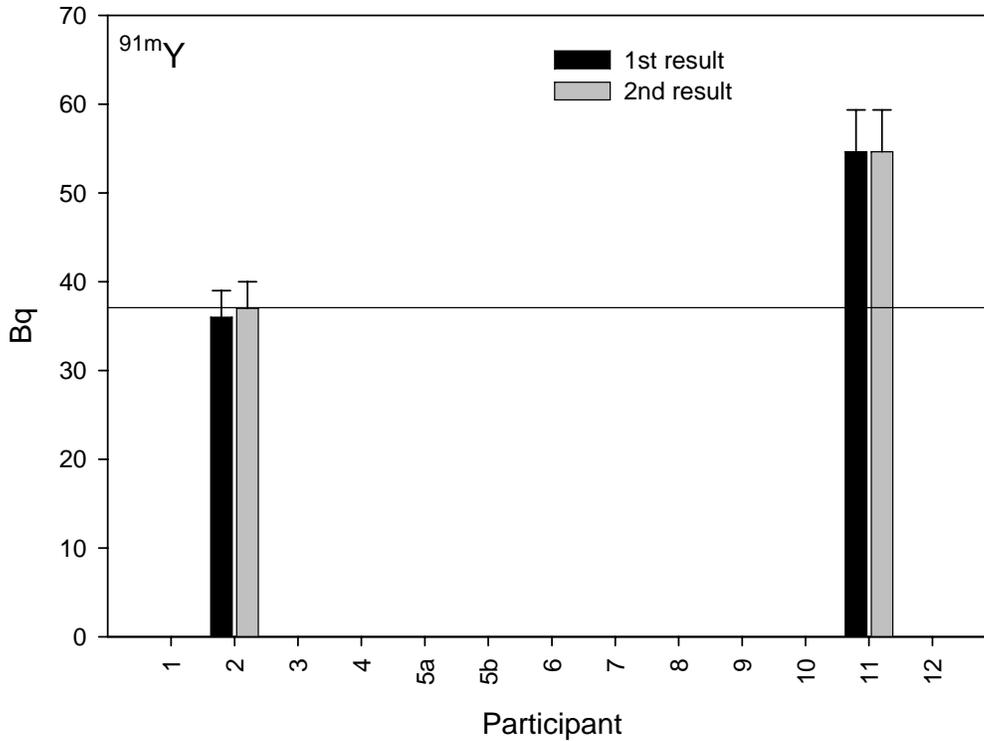


Figure 4. Participant results for $^{91\text{m}}\text{Y}$.

5.3 Niobium-95

Nb-95 has only one significant gamma line at 765.79 keV (100%) and identification and quantification of the nuclide should have been relatively simple for participants and this is reflected in the majority of participants reporting ^{95}Nb in the preliminary results with accurate estimates of activity. One deviant result was recorded in the first round for Participant 10 although this was improved significantly in the second.

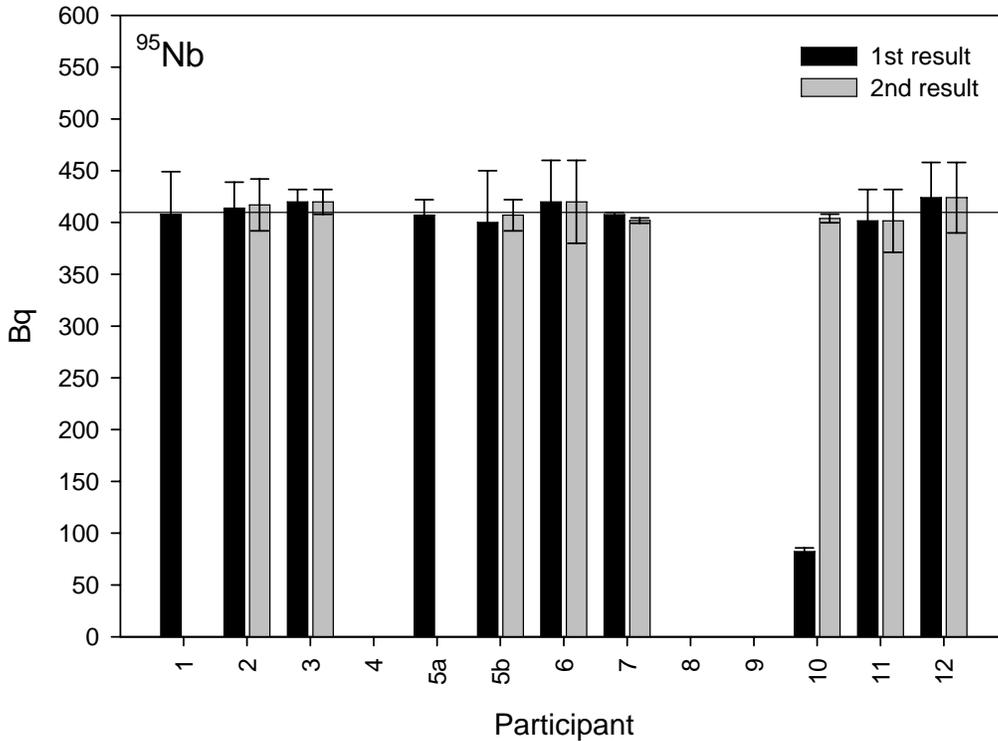


Figure 5. Participant results for ^{95}Nb .

5.4 Zirconium-95

Zr-95 has two strong lines at 724.2 keV (44.17%) and 756.73 keV (54 %) and should pose no problems in identification. All participants bar one reported the presence of the nuclide in the preliminary results although in the second round, a participant who had found ^{95}Zr in the preliminary phase chose to remove it from their result whilst retaining ^{95}Nb . Activity estimates for ^{95}Nb were quite acceptable for all participants. A deviant result in the first round for Participant 10 was improved upon in the second.

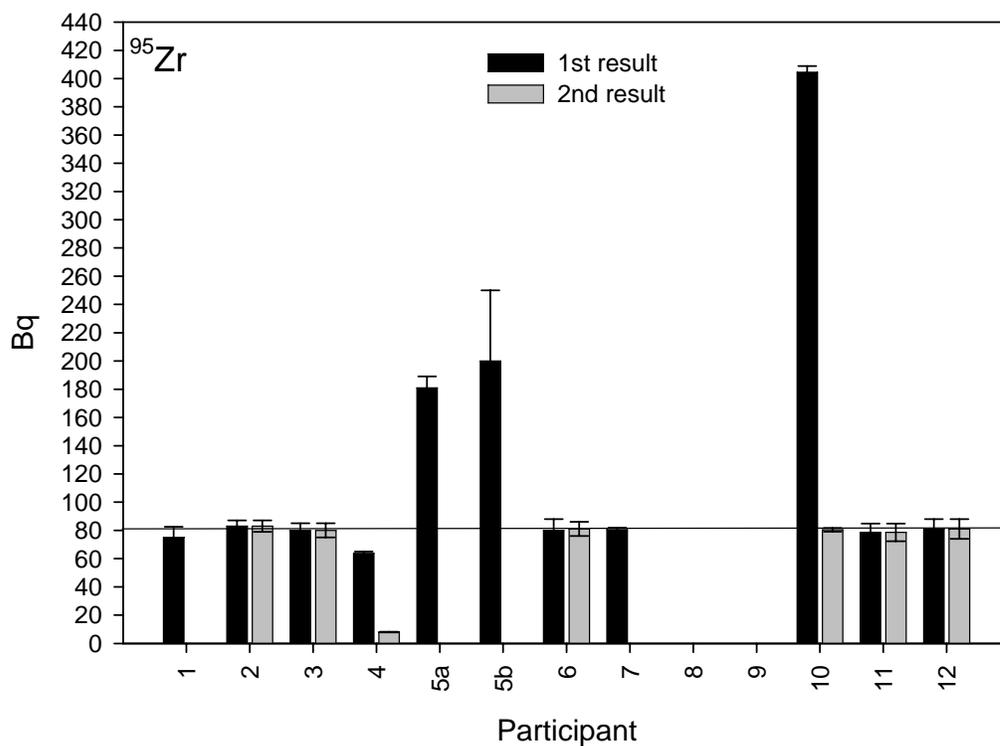


Figure 6. Participant results for ^{95}Zr .

5.5 Ruthenium-103

Ru-103 has a range of lines but the two most useable are the high probability (90.9%) line at 497.08 keV and 610.33 keV (5.73%) neither of which are interfered with to any major extent and serve as effective key identification lines. Activity values from those who identified the isotope were quite accurate (Figure 7.) and some participants managed to improve the accuracy of the estimate in the second round of reporting.

5.6 Antimony-127

Sb-127 poses a range of problems in the context of the test spectrum. The isotope possesses a range of lines that should facilitate relatively simple identification although some of them are involved with lines from other nuclides. The line at 252.4 keV is between the emissions of two other isotopes and may suffer with respect to area determination producing a lower result than actuality.

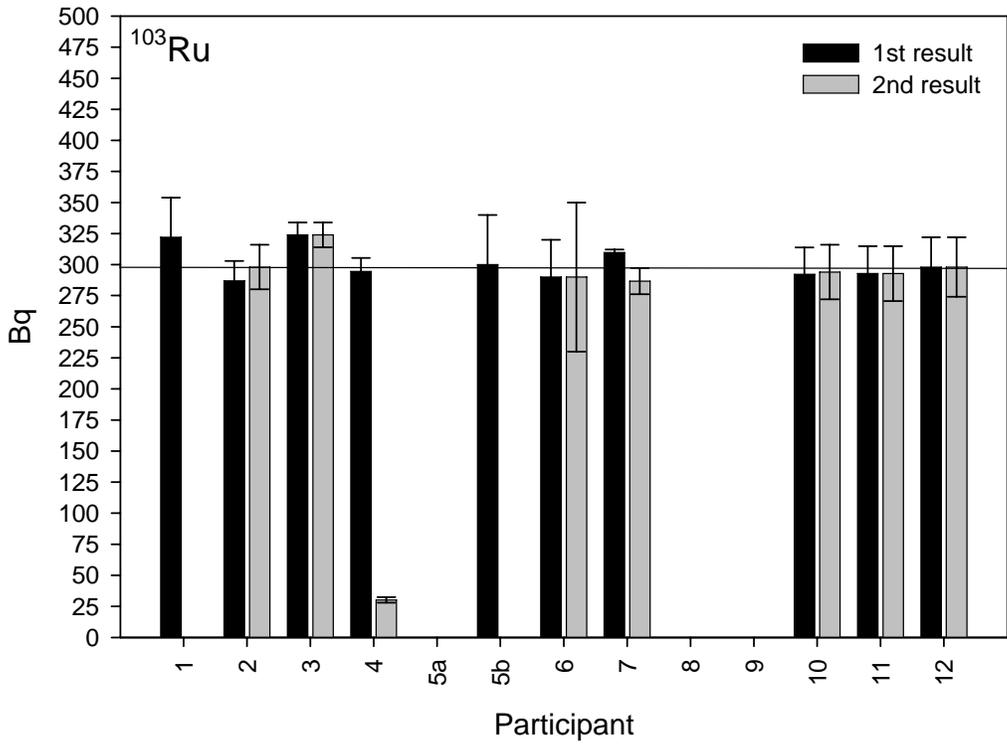


Figure 7. Participant results for ^{103}Ru .

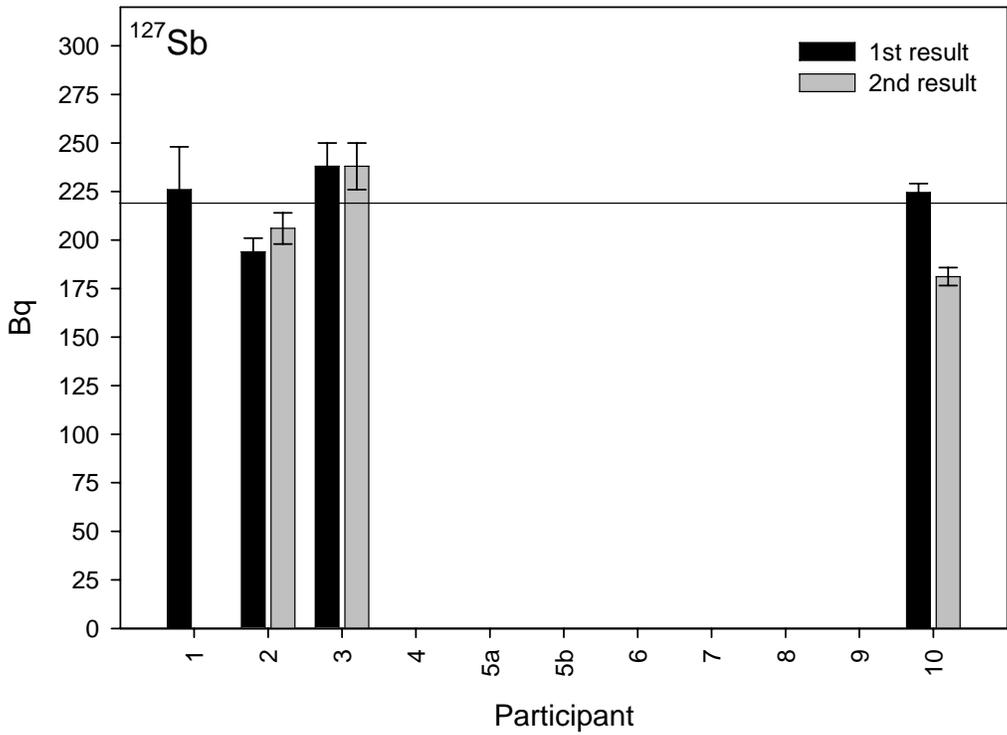


Figure 8. Participant results for ^{127}Sb .

This situation is also present for 445.1 keV whilst 543.3 keV is of quite low probability. The strongest two lines at 473.0 keV and 685.7 keV, whilst not totally separated from other lines are dominant in those multiplets and should not suffer greatly in deconvolution producing reasonable results. The line at 722.2 keV cannot be easily separated from a dominant ^{131}I line. Not all participants managed to locate ^{127}Sb in the first round, only 4 reporting the isotope as found and there was no indication of an improvement in that situation in the results provided in the second round. For those participants who identified the isotope activity estimates were in quite good agreement with the modeled value.

5.7 Iodine-131

I-131 exhibits a suite of strong lines the following of which provide robust identification and quantification possibilities: 284.3 (6.14%), 364.49 (81.7%), 636.97 (7.17%) and 722.9 keV (1.77%).

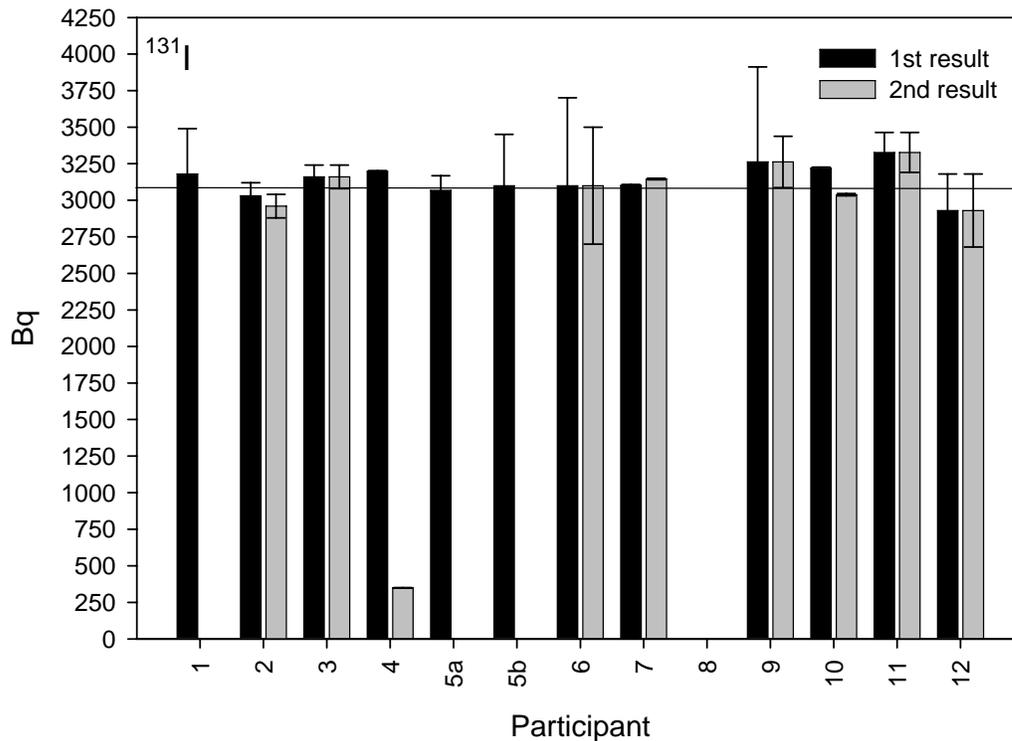


Figure 9. Participant results for ^{131}I .

The last of these presents some issues in that it is in close proximity to a strong line from ^{95}Zr and the activity result relative to the other lines may be deviant. The peak at 284 keV

is interfered with by a weaker contribution ($< 8\%$) from ^{132}I and is susceptible to slight summing-out but the correction is less than 3%. The peak at 364 keV has no significant contributions from any other isotope and the 636 keV is a well resolved singlet. All participants identified ^{131}I in the test spectrum during the first round and all activity estimates were reasonable.

5.8 Tellurium-131

Te-131 presents difficulties due to its low relative activity in the test spectrum and limited number of strong lines. The main line of 149.7 keV (68.9%) is in a difficult position due to $^{131\text{m}}\text{Te}$ (with a peak at the same energy) and the next strongest line at 452.32 keV is also affected.

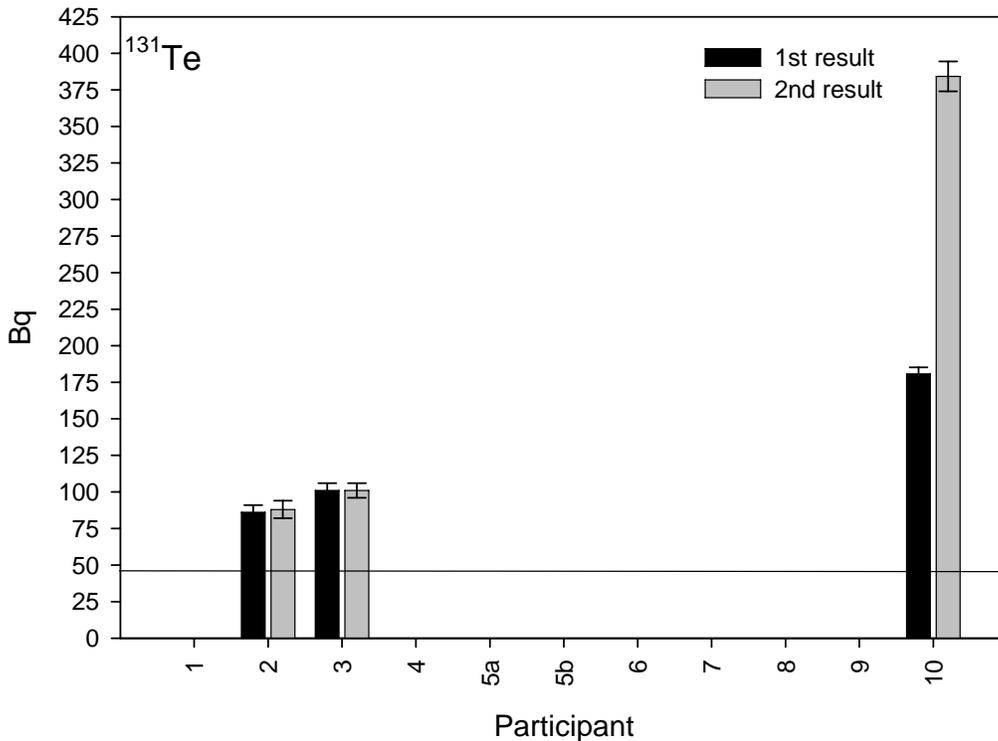


Figure 10. Participant results for ^{131}Te .

The best candidates after the primary lines are 492.66 keV, 654.26 keV and 1146.96 keV. The 1146.96 keV peak is interfered with by ^{132}I and 654.26 keV is hampered by poor statistics. On this basis, determination can only “easily” be by 492.66 keV which is a relatively low emission line. Te-131 was only identified in the first round by three

participants despite many participants reporting having found ^{131m}Te and ^{131}I the presence of which could reasonably be used to infer the potential for ^{131}Te being present. All results reported were higher than the modeled value.

5.9 Iodine-132

I-132 exhibits a range of lines that should contribute to effective quantitative and qualitative analysis. Of these the five strongest are 522.65 keV, 630.22 keV, 667.69 keV, 772.6 keV and 954.55 keV although all of these require significant corrections to be made for summation. The weak line at 262.9 keV is potentially useable due to the high activity but contains a contribution from ^{133}I .

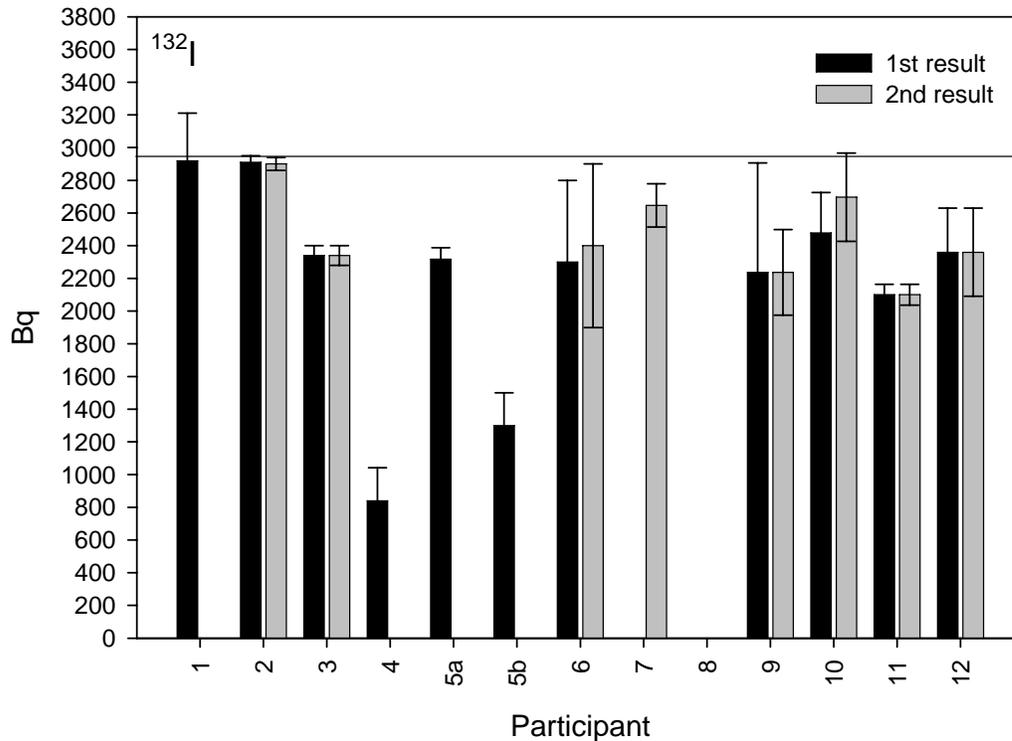


Figure 11. Participant results for ^{132}I .

The 387.9 keV peak is not strongly interfered with and 505.90 keV is a reasonably well separated sufficiently strong line for activity estimation. The line is susceptible to strong summation. Most other lines are either weak or interfered with. The majority of participants identified ^{132}I and one who did not pick it up in the second round. There is

some evidence within the results of participants either incorrectly or not applying correction factors for this isotope, the majority of results being significantly (and somewhat consistently) underestimated.

5.10 Iodine-133

I-133 has a limited range of useful gamma lines amongst its many emissions, the most useful of which would appear to 529.8 keV. This line stands well separated and has a high probability. Other lines such as 875.3 keV and 1298.2 keV are part of multiplets although these are such that separation of the contributions should be straightforward. For the participants that did not identify this isotope, a check was made of the reported false positives but none were found that would be suitable candidates for the misidentified 529.8 keV line. In general the activity estimations were reasonable.

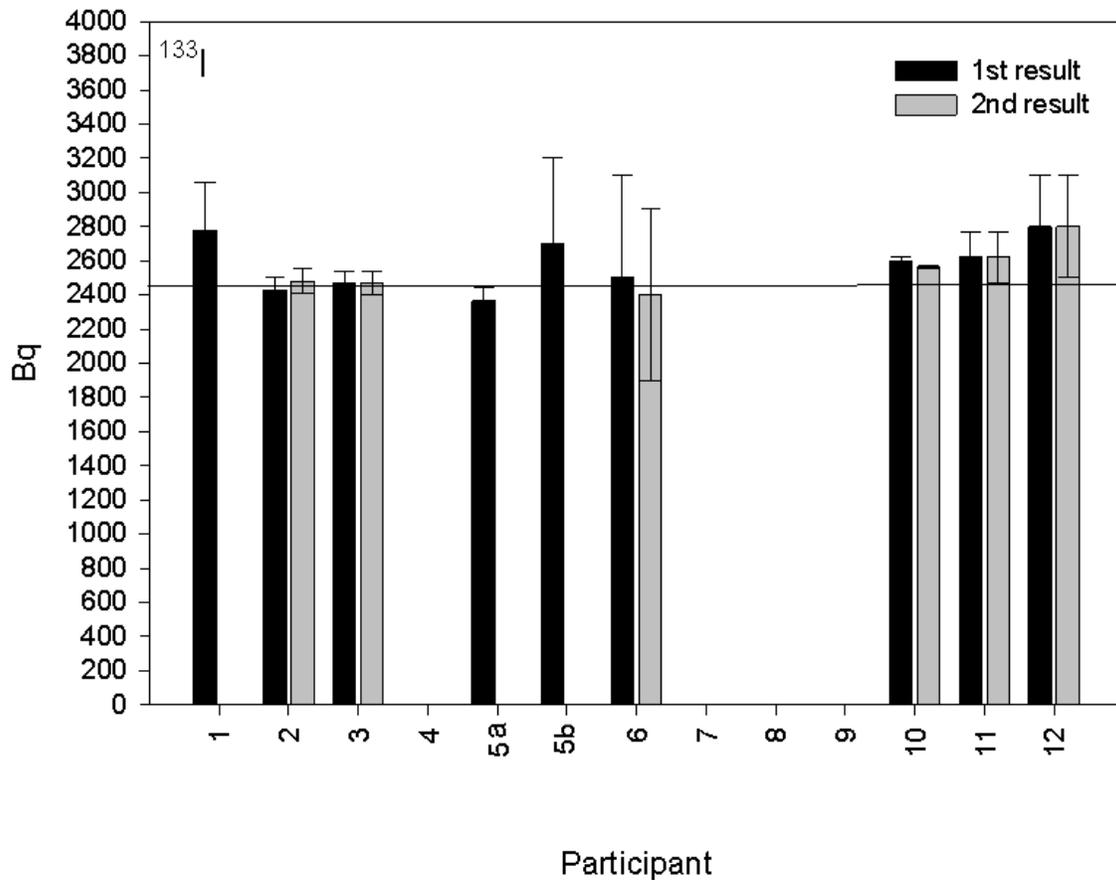


Figure 12. Participant results for ^{133}I .

5.11 Iodine-135

Of the numerous ^{135}I lines potentially of use, the most problematic are likely to be those of the weaker emissions. Of the most significant lines, 546.56 keV is part of an unresolved doublet with ^{132}I at 547.2 keV, a problem also occurring for the 417.63 keV peak. The majority of participants had no apparent trouble identifying the isotope and activity estimates were quite good in most cases.

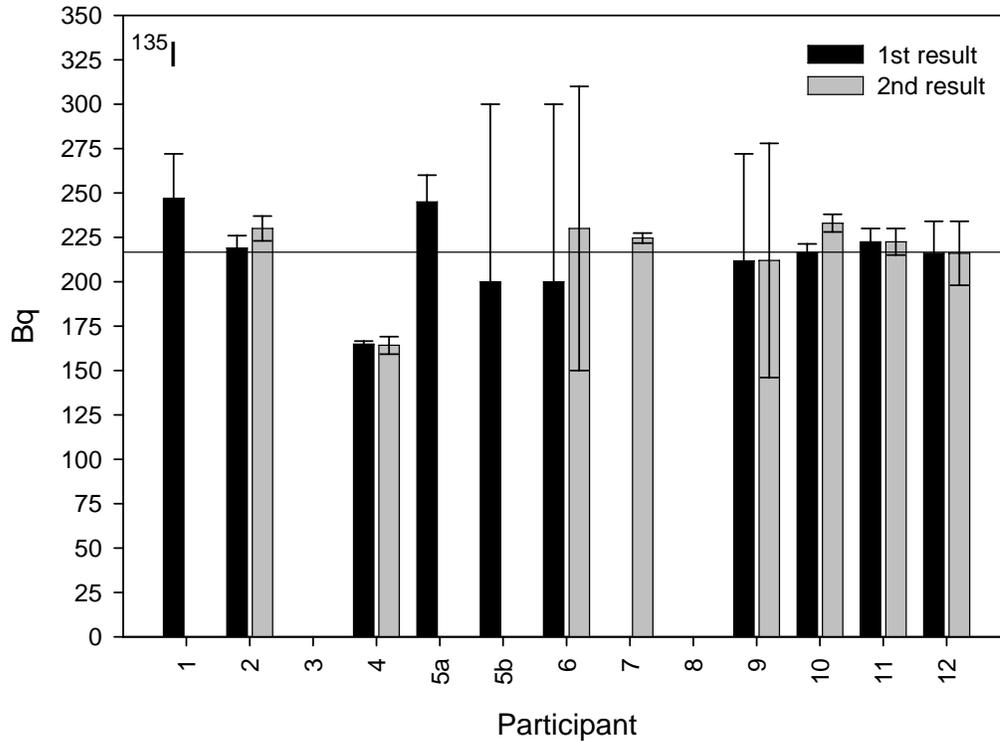


Figure 13. Participant results for ^{135}I .

5.12 Cesium-134

The two strongest lines at 604.7 keV and 795.84 keV should provide consistent results although require correction for summation. The weak 475.35 keV peak may be problematic due to the influence of the stronger ^{127}Sb peak nearby. Summation will also cause problems at 801.95 keV. Interferences from ^{135}I are most likely to impact upon the two energies over 1 MeV and there is a summing out correction of approximately 10% for the first peak and 20% for the second. Although no problems were evident in participants' identification of ^{134}Cs , the vast majority of results reported were under estimated. The consistency of this under estimation by participants is indicative of

probable errors in the application of coincidence corrections even though summation problems are probably well known for this isotope.

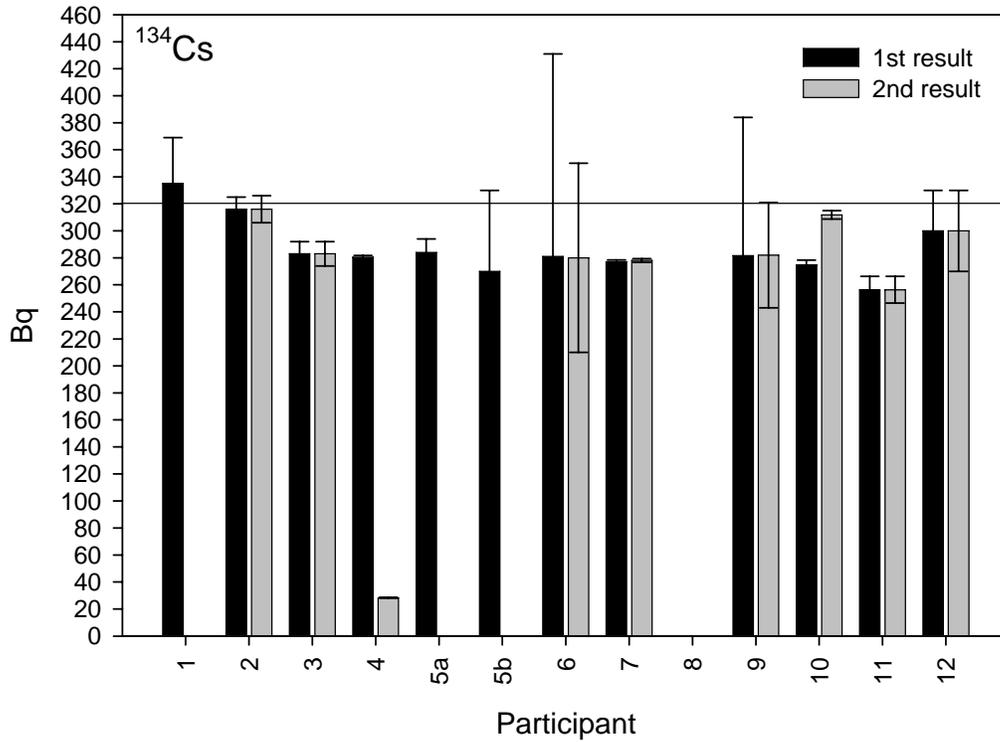


Figure14. Participant results for ^{134}Cs .

5.13 Cesium-136

The peak at 340.55 keV is subject to summation as are those at 818.51 keV and 1048.07 keV (which is potentially interfered with by a number of weak lines from other isotopes). 1235.36 keV is a less reliable line than the previous three due to interference from ^{133}I . Not all participants identified ^{136}Cs and in all cases activity was underestimated possibly as a result of summation problems.

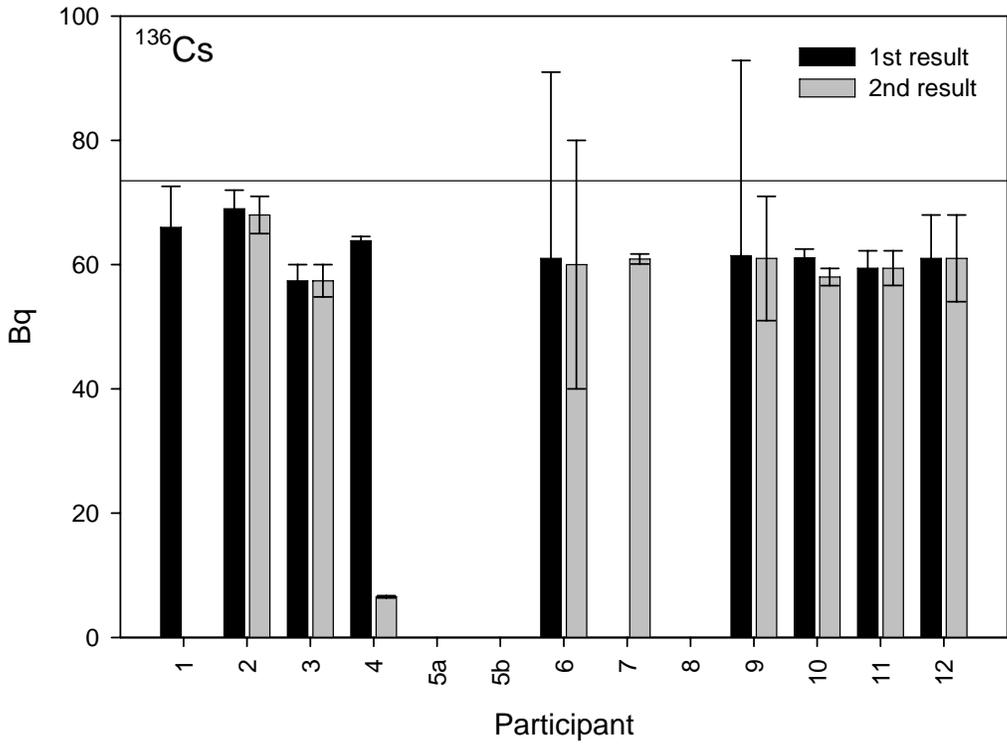


Figure 15. Participant results for ^{136}Cs .

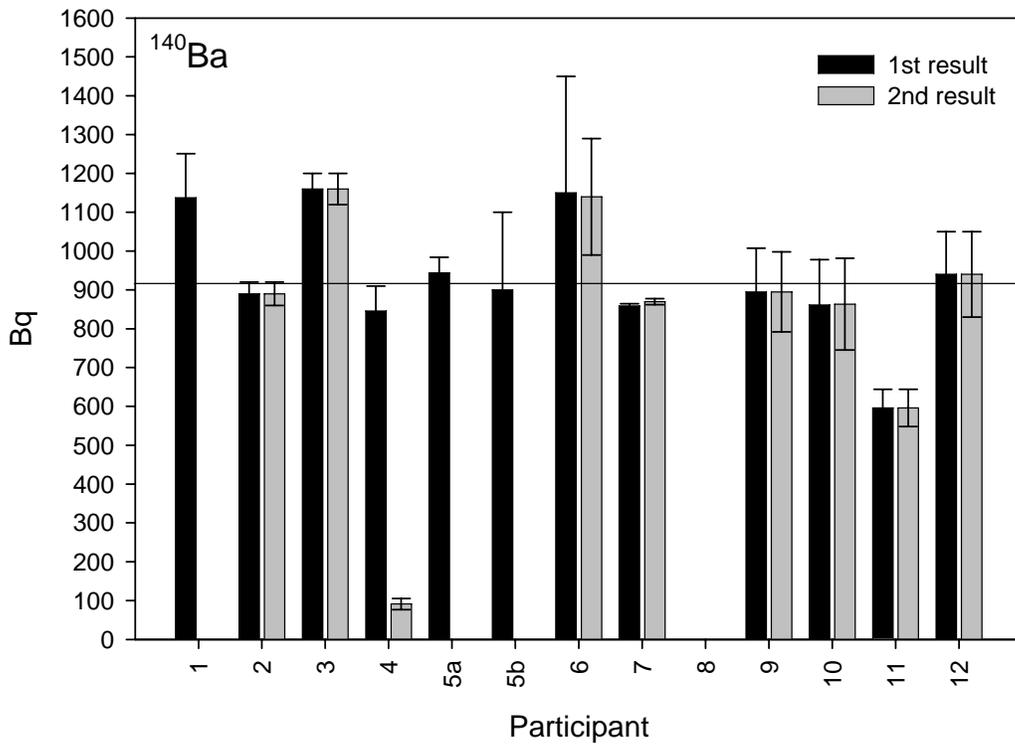


Figure 16. Participant results for ^{140}Ba .

5.14 Barium-140

Ba-140 should be relatively problem free for both identification and activity determination although the peak at 423.73 keV most likely contains interference from a nearby peak of ^{133}I . All participants identified ^{140}Ba and the majority provided reasonable to good estimates of activity.

5.15 Lanthanum-140

A number of the lines of ^{140}La are subject to significant interferences from other isotopes such that individual contributions to multiplets may not be resolved correctly. The four least impacted peaks also require summation corrections. All participants bar one identified ^{140}La and given the consistency of the under estimation it is most likely that coincidence summation problems account for the disparity.

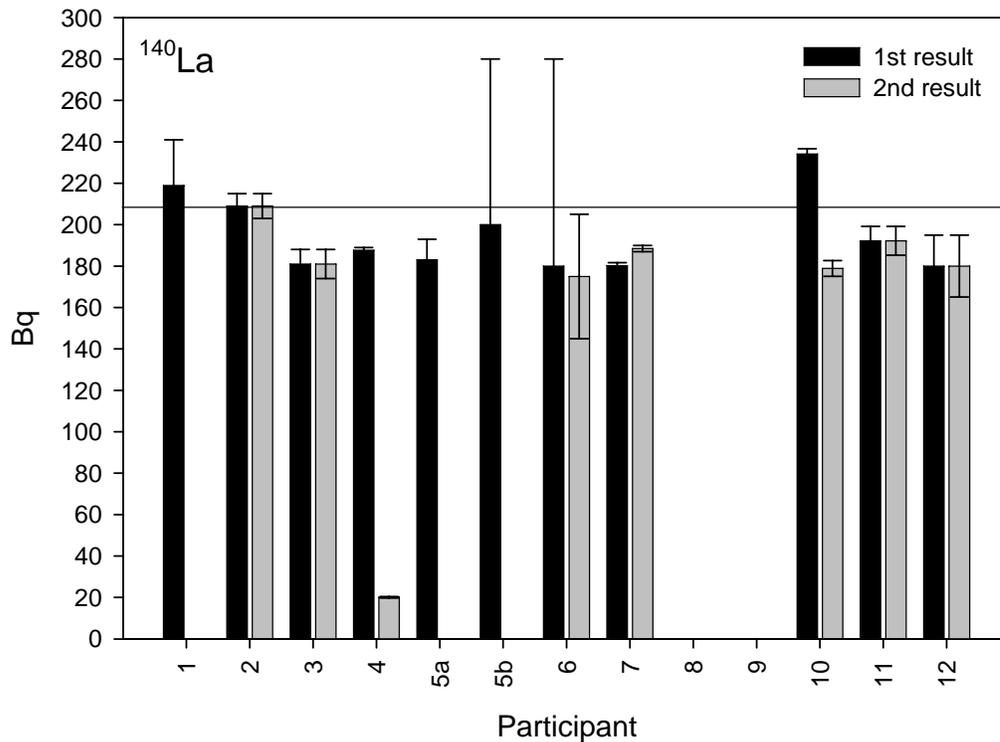


Figure 17. Participant results for ^{140}La .

5.16 Cesium-137

Cs-137 should have provided no problems in either identification or quantification and as was expected, all participants identified this isotope and produced acceptable results for activity.

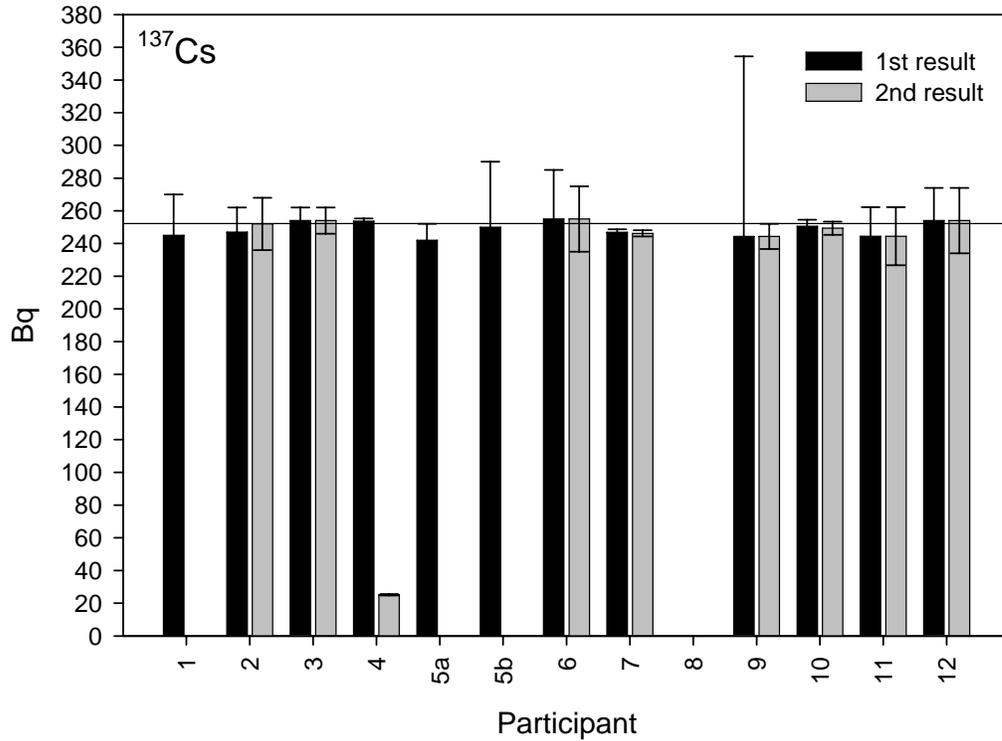


Figure 18. Participant results for ^{137}Cs .

5.17 Cerium-141

Ce-141 has only one gamma line at 145.4 keV with the potential for interference from a weak line of ^{132}I at 147 keV but this does not seem to have been a problem. All participants bar two identified ^{141}Ce and although some evidence of underestimation was present in the data, results were fairly consistent and not unreasonable especially in light of the fact that the isotope was one of the lower activity isotopes present relative to the other constituents of the spectrum.

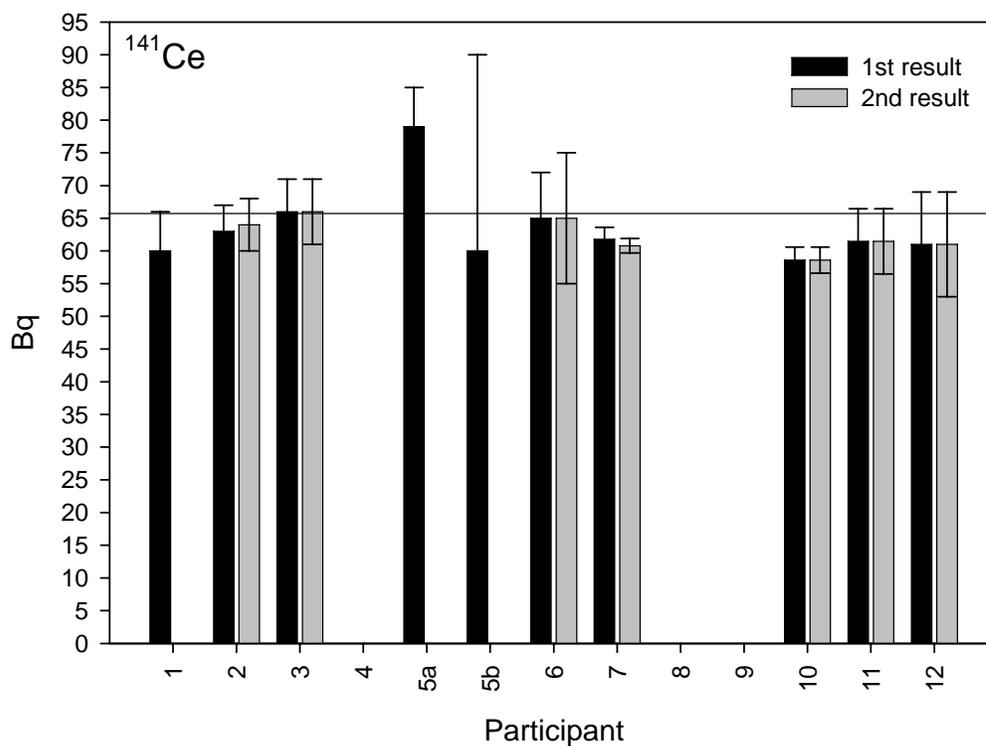


Figure 19. Participant results for ^{141}Ce .

5.18 Cerium-143

Ce-143 exhibits many gamma lines although only a limited number of them are of any real use in analysis. Those of potentially most use are the main line at 293.27 keV (with a probability of 42.8%) and the two weaker lines at 664.57 keV and 721.93 keV. The first of these is part of a large multiplet in which it plays a small role and may obviously suffer as part during deconvolution. The second line is a similarly awkward position. In contrast, the main line is reasonably well separated with no major summation problems and should provide a solid estimate of activity. It's a little difficult to account for the low number of participants who located this isotope, only 4 participants correctly identifying it. Given the location of the main line it is potentially possible that it was mistaken for a natural isotope despite participants being told that no background had been modelled. Activity determinations however were quite good with respect to the true value.

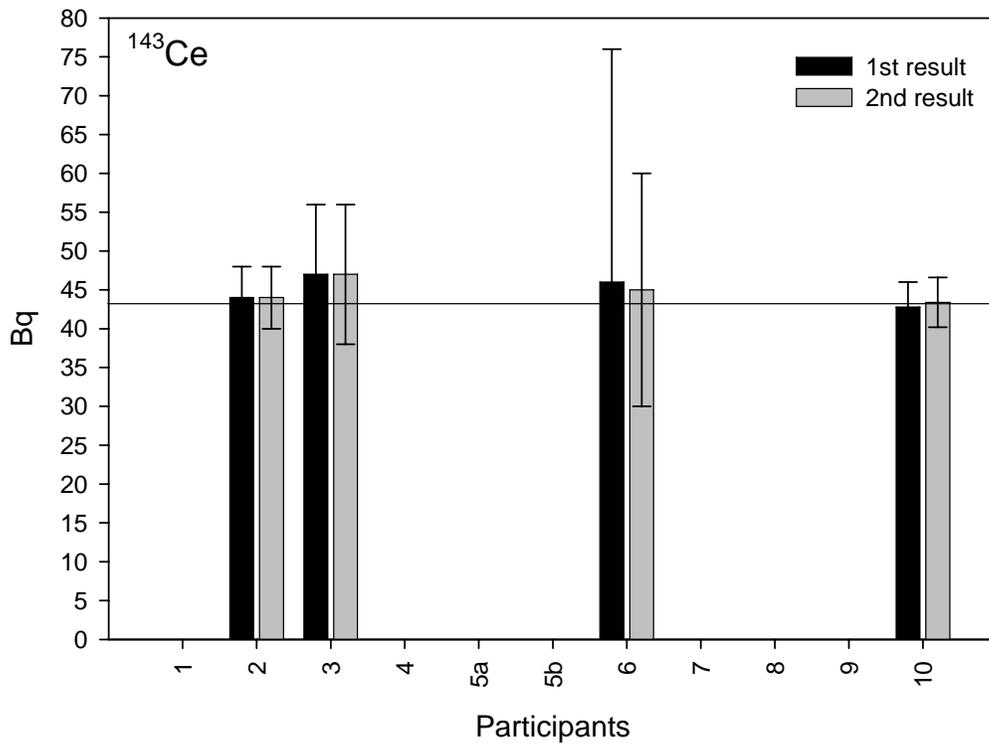


Figure 20. Participant results for ^{143}Ce .

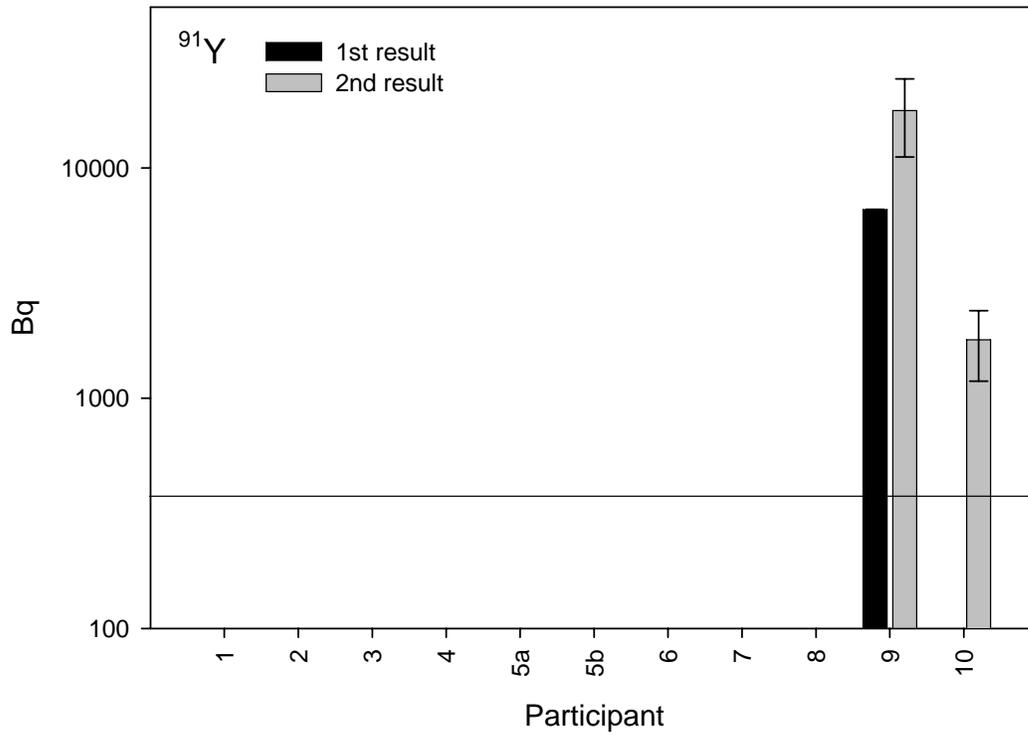


Figure 21. Participant results for ^{91}Y .

5.19 Yttrium-91

Y-91 has one weak line and was present in the spectrum at an activity that could be considered relatively low – 376 Bq. The combination of these factors therefore meant that the isotope would present a significant challenge in identification and quantitation and was probably the most difficult isotope in the spectrum. The single line also occurs as part of a multiplet with a larger peak from ^{131m}Te . Two participants managed to identify the isotope but activity determination was poor due largely it must be assumed to problems with the separation of the ^{131m}Te contribution.

5.20 Tellurium-131m

This tellurium isotope has a very large suite of lines although many of them are so weak as to be insignificant. Based on the above, ^{131m}Te would constitute a difficult isotope to quantify although perhaps not identify within the spectrum. Less than half of the participants reported the isotope and only one of these produced an activity estimate close to the actual value.

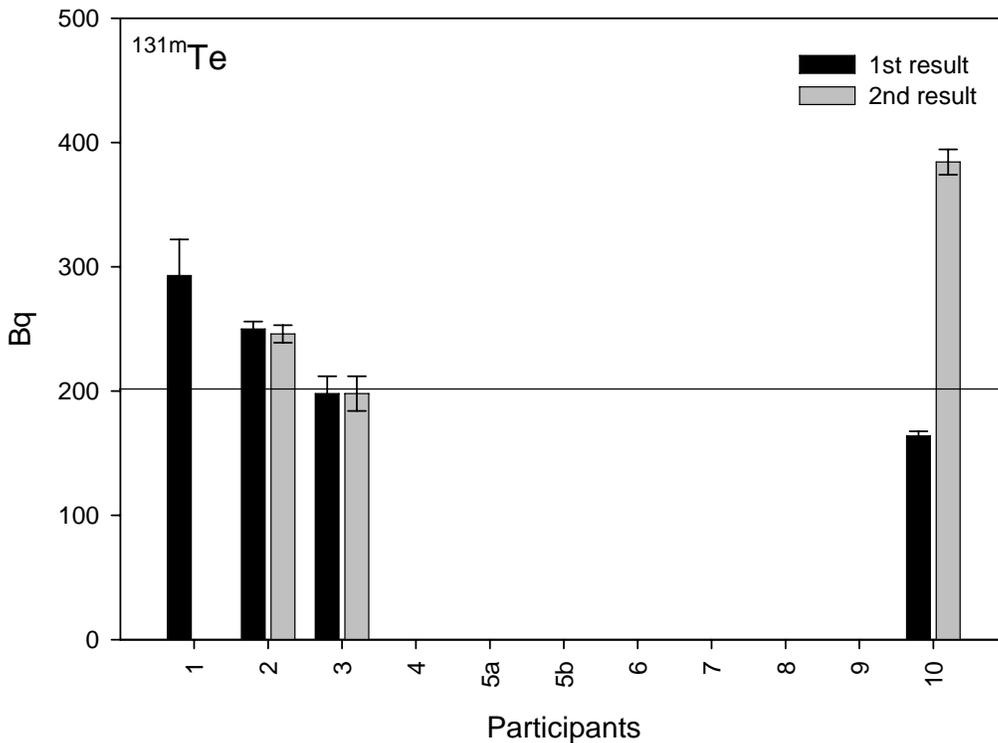


Figure 22. Participant results for ^{131m}Te .

5.21 Tellurium-132

Te-132 exhibits only 4 lines with 2 relatively being relatively strong and none of these lines are interfered with to any large extent. The first line at 49 keV exhibits some summing out (to a stronger degree than the other lines). The majority of participants identified the isotope and activity estimates were consistently good.

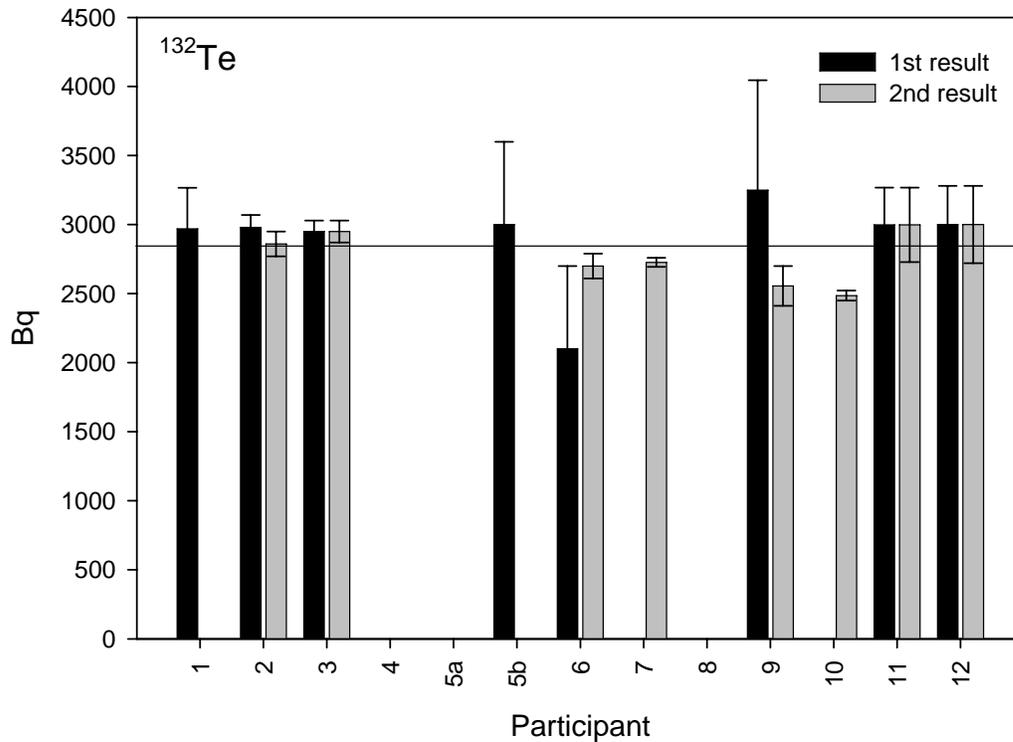


Figure 23. Participant results for ^{132}Te

5.22 Xenon-135

With a number of lines, ^{135}Xe has two emissions that should facilitate effective analysis: 249.7 keV (90%) and 608.15 Kev (2.9%). The first of these is well separated with no summation. The second is not so well defined and may be interfered with by the presence of some stronger neighbours. More than half of the participants identified the isotope, two of these managing it one the second round. One participant identified the isotope on the second round but declined to estimate the activity. Activity determinations were consistent and in good agreement with the true value.

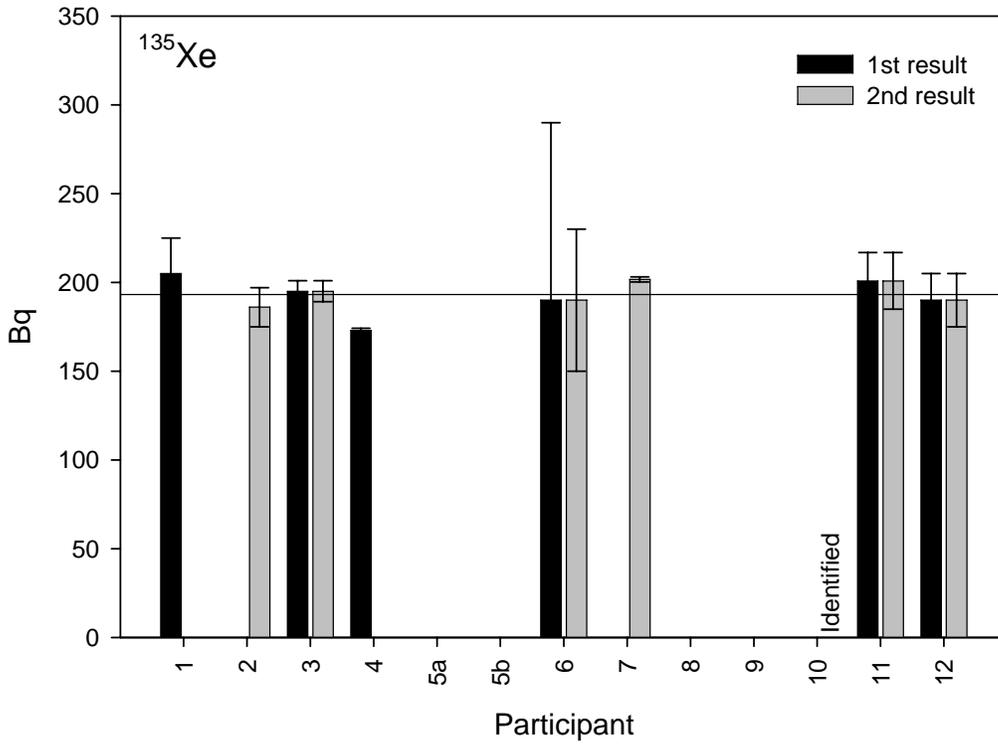


Figure 24. Participant results for ^{135}Xe

5.23 Xenon-133

This isotope was potentially the most difficult of the spectrum along with ^{91}Y due to it having the lowest activity of all and it's having but one line of any use at 80.9 keV (30%) which happens to occur in what is normally a difficult part of the spectrum due to Pb x-rays and its position on the efficiency curve. In addition, this line is dominated to some extent by a strong line from ^{131}I although the distance between them should be sufficient for software to recognise the existence of two peaks. The difficulty is reflected in the response of the participants, less than half identifying it and only two producing activity estimates of any accuracy.

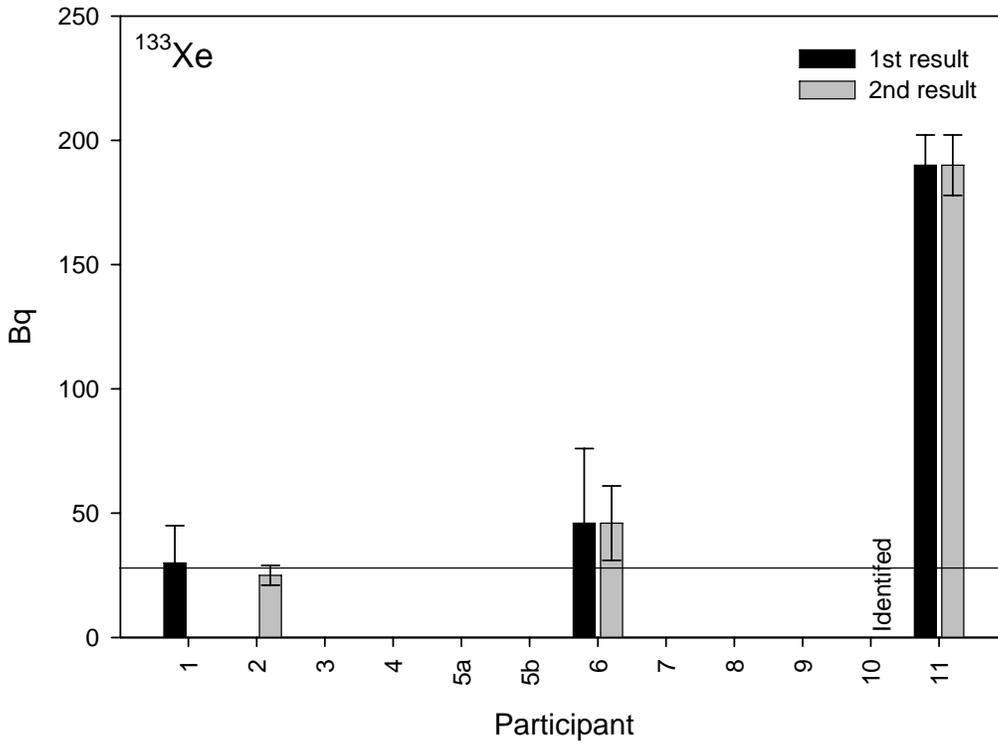


Figure 25. Participant results for ^{133}Xe

6. False Positives

A wide range of false positives were reported by participants in both stages of the exercise. The only participant who did not report any at all was Participant 2. Although participants had been informed that background lines of the uranium and thorium series had not been simulated, some reported these. Of the anthropogenic nuclides reported, the vast majority were reported at quite low activities (< 100 Bq). Given the number of nuclides present and the wide range of false positives it is impossible to assign reasons for all the isotopes.

A selection of isotopes reported as false positives are given in Table 4.

⁷ Be	¹³³ Ba	¹⁷⁷ Yb	⁵⁷ Co
²³⁹ Np	²² Na	²¹² Bi	⁸⁹ Zr
¹³⁸ Cs	⁴¹ Ar	²¹⁴ Pb	¹²⁶ Sb
¹⁸⁷ W	⁵⁶ Mn	²³³ U	¹³⁰ I
²¹⁰ Tl	⁵⁸ Co	¹²⁶ I	^{131m} Xe
²²³ Fr	^{69m} Zn	⁶⁰ Co	¹¹³ Sn
²²⁴ Ra	⁷⁵ Se	^{85m} Kr	²⁰³ Hg
¹⁰⁹ Cd	²³⁷ Np	⁹⁷ Zr	¹⁰⁶ Rh

Table 4. Reported false positives.

7. Follow-up

After the exercise was complete, a range of ancillary spectra were made available to the participants. These spectra were intended to allow for further investigation by participants and facilitate further analysis should they so desire. The spectra provided were as follows (only for the test spectrum NKSPEK1).

The test spectrum with coincidence summation switched off (NKSPEK2).

The test spectrum with high resolution where 1 FWHM was equivalent to 1 channel (NKSPEK3).

The test spectrum with high resolution and no coincidence summation (NKSPEK4).

The test spectrum with just the photopeaks (NKSPEK5).

The test spectrum with just photopeaks and no coincidence summation (NKSPEK6).

The test spectrum with just the photopeaks and high resolution (NKSPEK7).

The test spectrum with just photopeaks, no coincidence summation and high resolution (NKSPEK8).

The test spectrum minus the photopeaks (NKSPEK9).

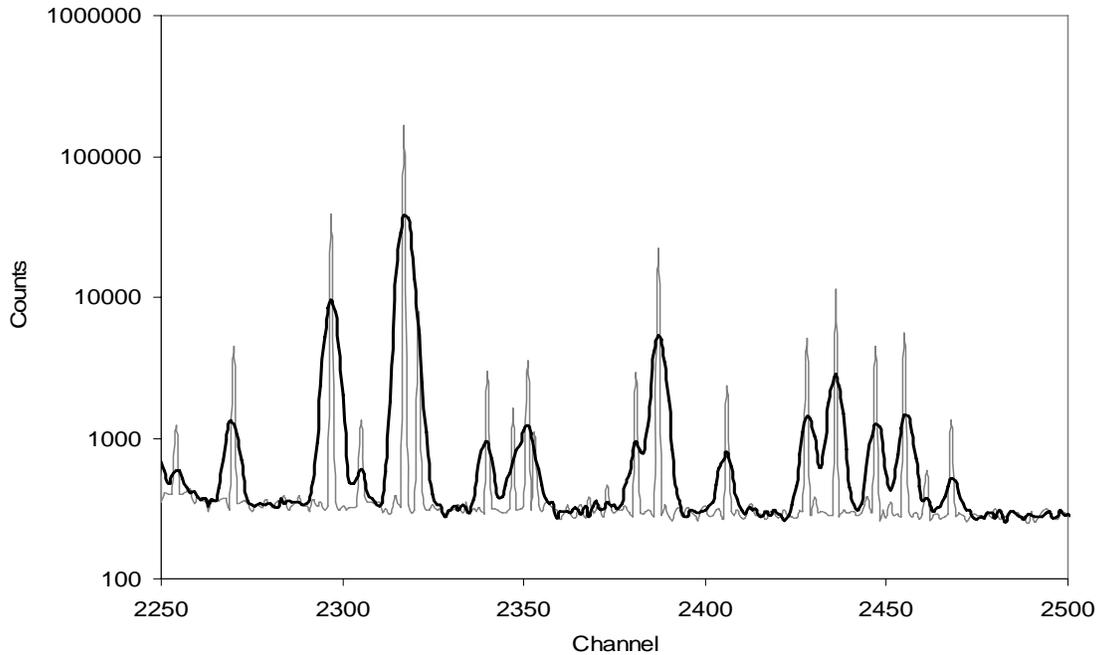


Figure 26. Comparison between a section of NKSPEK 1 (black line) and the high resolution NKSPEK 3 (grey line).

8. Discussion

8.1. Spectral File Formats

The spectra were initially generated in the form of .RMS files as described in Appendix 1. The RMS format (and others) carries information in addition to raw counts and time data and it was explained to the participants that the extra information included in the transmitted file was not correct, hopefully forcing them to apply the efficiency data sent and to energy/shape calibrate their systems. These .RMS files were then converted to IEC format as described in Nuclear instrumentation - MCA histogram data interchange format for nuclear spectroscopy (IEEE, 1993). This format is similar in structure to the RMS format. Once the spectra were in IEC format they were opened in Genie 2000 and saved as Canberra's proprietary CNF format. These files were then converted to CHN and other formats using CAMBIO and SPECON (Hong, 2000). Spectra were opened in a range of popular software packages to ensure that participants would have a reasonable chance of successfully opening and analysing the data. The energy/shape spectra were also converted in exactly the same way and by this process it was intended that any problems

arising out of spectral conversion and different formats being analysed according to one generic energy calibration function would be avoided. Any likely problems and other conditions were communicated to the participants in the calibration stages of the exercise and prior to transmitting the test data. No significant problems were encountered during the exercise regarding the formats apart from some difficulties transmitting the Canberra format by email. The extension corresponds to a Microsoft system file and was stopped by some virus checkers.

Communication between the organiser and participants indicated that there remains a certain uncertainty for some labs regarding their abilities to handle spectral file formats for software packages that they do not use. These concerns appear to relate primarily to certain proprietary file formats from specific manufacturers and reflect the situation as reported by Nikkinen (2001). It is appreciated that smaller laboratories may not have access to the programming skill base necessary to write their own conversion routines. However third party conversion codes do exist which can open and convert even proprietary formats that have caused problems in the past (see Lasche, 2007). Although the acquisition of codes and utilities for the conversion of spectra to a variety of formats is one solution to the problem of reading different spectra types, a more obvious solution is that one standard format is adopted or devised and that this is used for data transfer particularly during emergencies. While a number of suggested formats exist and a number of initiatives have resulted in various suggestions, it does not appear that there has been a widespread adoption of any particular standard spectrum file format nor is it certain that any suggested standard type suggested so far can accommodate the information necessary to conduct thorough analyses. This aspect as it relates to technical assistance between institutions and states in emergency situations is a matter of some import and worthy of effort towards its resolution.

8.2 True Coincidence Summation

True coincidence summing correction methods have been described in the literature for a number of decades (see for example Debertin and Schotzig, 1979; Morel et al., 1983, Sinkko and Aaltonen, 1985; De Felice et al, 2000), a number of utilities, both free and commercial, are available for conducting such corrections (see Lepy et al., 2006, Arnold

and Sima, 2004; Sudár, 2002) and the major software manufacturers have begun to include such corrections in their packages. It appears however that penetration of summation correction into the user base such as was represented in this exercise has some way to go. An oft mentioned reason for the lack of implementation of such corrections is the necessity to conduct efficiency calibrations for both total and peak efficiency. The total efficiency curve necessitates (usually) the use of monoenergetic isotopes which can be both hard to find for the typical energy range and expensive to purchase. To counter this however, the exercise provided total efficiency data and enough of it such that peak to total ratio calculation should not have been a problem. Despite this it seems that the level of implementation of the correction remained low.

It is reasonable to assume that many laboratories do not feel under pressure to apply such corrections given that the majority of the isotopes they measure daily are not prone to any significant extent. While that may be the case for normal environmental measurements, the situation in an emergency situation may not be so straightforward. A number of isotopes are well known as being prone to coincidence summing (^{22}Na , ^{60}Co , ^{134}Cs etc.). However any isotope with a wide range of gamma emissions may be prone and many of the nuclides that may occur in an emergency situation may be vulnerable to greater or lesser extents.

8.3 Uncertainties

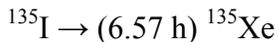
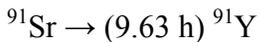
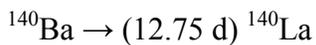
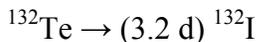
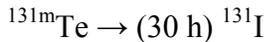
A notable aspect of the exercise was the wide range of uncertainties reported for nuclides between participants. All participants were asked to report at the 1 sigma level and all participants were provided with the same efficiency data and spectrum. Even allowing for some participants having reported at 2 sigma, its difficult to establish why the uncertainties are so variable. Fitting of an interpolative curve to the provided data may result in variations in the efficiency uncertainty but the efficiency data provided was more extensive than would normally be generated and uncertainties in curve fitting should not have been any higher than approximately 3%. Uncertainties in all other parameters should have been quite small. Depending on which peak was selected for any particular isotope, uncertainties may have varied between participants but for isotopes with one line such as ^{137}Cs or ^{141}Ce the uncertainties between participants should have been somewhat similar.

8.4 False Positives

The exercise resulted in the generation of a large number and range of false positives in the reported results. No participant provided estimates of the confidence with which any individual isotope was identified. Related to the matter of false positives is the subject of coincidence correction, an effect of which can be the generation of sum peaks. Comparison of NKSPEK1 and NKSPEK 2 without summation should indicate which peaks may be due to coincidence summation and may have resulted in false positives. This aspect of not correcting for this summation is less often mentioned than the underestimation of activities in certain isotopes however constitutes an additional layer of complexity in the matter of post event spectra.

8.5 Mother-daughter pairs

A number of mother-daughter pairs were present in the isotope suite. Given that the participants were instructed that the sample had been measured immediately after being taken and that both the sampling and measurement times were short, there should have been no need for corrections for ingrowth/decay to have been performed. The following pairs were present:



While the participants were not required to perform any corrections nor could the time scales involved lead to any assumptions about equilibrium having been established between members of any pair, it was hoped that the presence of one isotope would have led participants to infer the possible presence of the other, especially for the pairs where the half life was such that an expectation of presence would be reasonable.

Participant	1	2	3	4	5a	5b	6	7	8	9	10	11	12
^{131m}Te													
^{131}I													
^{132}Te													
^{132}I													
^{140}Ba													
^{140}La													
^{91}Sr													
^{91}Y													
^{95}Zr													
^{95}Nb													
^{133}I													
^{133}Xe													
^{135}I													
^{135}Xe													

Figure . Identification of mother-daughter nuclides by participant. Grey shading – isotope found in first round. Red shading – isotope not found in first round but found in second. Blue shading – isotope found in first round and removed in second.

For most of the isotope pairs, both members were found. This pattern was not evident however for $^{91}\text{Sr}/^{91}\text{Y}$ where the majority located the parent but not the daughter. Given the short half-life of the parent and the fact that some participants managed to locate ^{91}Y , it could theoretically be argued that more participants could have been expected to have located ^{91}Y , at least in the second round although identification of the isotope is predicated by the factors discussed earlier.

8.6 Software performances

Given the small sample number and the fact that some participants took the opportunity to test new software it would be unwise to attempt to draw conclusions as to the effect of either operator or software on analysis results. Although information was sought regarding the specificities of peak fitting etc, it was impossible to establish any patterns. In general, participants who performed well, performed well in all aspects of the exercise. Participants who identified most also tended to produce the most accurate results, have applied coincidence correction and had the least false positives.

8.7 General observations

Two aspects of such an exercise as was conducted are of obvious interest – the use of synthetic spectra for such exercises and the performance of participants. In relation to the former, attempts were made to draw upon the experience gained and the recommendations made within the last NKS exercise of this type (Nikkinen). The first of those recommendations was that the purpose of such exercises should be explicitly defined beforehand. For the REMSPEC exercise, the emphasis was very much upon the production of the best results possible by the participants within a short period of time. The participants had been instructed to provide results within what was a very short time period indeed in order to try and reproduce the conditions and demands that might be expected after an accident. It was also intended that the exercise would replicate what might happen should a lab be asked to analyse data they had not accrued themselves. In balancing these two objectives, it was decided that calibration data would be disseminated first. Although this is unrealistic for the latter circumstance, it was felt by the organiser that most labs, when presented with a tabulated list of efficiency data, would find the entering of such data in their own systems to be a trivial task. Somewhat surprisingly, this was not the case for all and reflects the difficulties reported in the previous NKS exercise by some participants. It would appear that laboratories are used to calibrating their systems one particular way, presumably using calibration sources, and perhaps have not explored how efficiency data may be entered in other ways. The majority of commercial analysis packages facilitate the entry of efficiency data manually and the majority of homemade programs utilise efficiency files that are essentially text files yet it seems to be the case that some labs only use the more typical efficiency calibration routines involving the analysis of a calibration spectrum. This was clearly evident in some participants requesting accurate data as to the calibrations spectrums activities. It was clearly stated in the instructions however that the calibration spectrum was obtained using “approximate” activities. This had been done as, in an emergency, one lab may transmit efficiency data either as stand alone data or as part of an .RMS or IEC file (which in effect reduces to the same problem). They may also be in a position to transmit a typical point source calibration spectrum which is unlikely to be accurate enough for efficiency calibration. Therefore, for an emergency assistance scenario, labs

should perhaps be fully aware of the different methods for entering calibration data aside from the normal ways of deriving such data from spectra. Irrespective of what is or what is not likely to be sent by one lab to another in an emergency, the sending of a spectra from which an assisting lab is expected to derive efficiency data presents significant problems in that such a spectrum will not allow for the derivation of the total efficiency data necessary to conduct accurate estimates of corrections required for summation.

The second conclusion from the previous exercise had been that a set of spectra could be derived to serve as a training data set for further use by participants. In the spirit of that suggestion, a full set of spectra were provided after the exercise of varying versions of the test spectrum. These included high resolution versions and versions without continuum. It was hoped that this would allow participants to conduct further analysis as they saw fit. The no-continuum high resolution version for example allows reasonably accurate measures to be made of “true” peak areas or to check for deconvolution quality. The organiser is not suggesting that such spectra are fully quality checked reference spectra but they may nonetheless constitute a useful exercise material in laboratory training programs or such in-house activities.

The third conclusion of the previous exercise pertained to what may happen should we not conduct this type of exercise regularly. This exercise cannot address what may happen or may not but hopefully goes some way towards preventing us ever having to find out - something that could happen at the worst possible time.

The organiser has not attempted to conduct the sort of analysis typically performed after intercomparisons such as those run by international organisations. This was because the organiser felt that in an emergency, a lower level of accuracy is quite acceptable. Therefore the words “realistic” and “acceptable” appear in this text and phrases such as “u-test” or “Z-score” do not. The usefulness of such measures in an exercise such as this are debateable and, in any case participants, are free to conduct such analyses in so far as they see fit for their own results.

In general it is quite apparent that some labs performed better on the exercise day in terms of identification and quantitation than others. There is a reasonably apparent pattern that labs that identified most also tended to produce better estimates of activity in many cases and the least false positives. The organisers do not intend to infer anything as to a lab's ability based on results tendered as a number of participants clearly stated that were taking this opportunity to test new software, to test "new recruits" or to test themselves with non-optimised versions of their own software in circumstances they felt they could potentially come across in an accident situation.

A problem that was evident in the previous exercise related to converting spectra such that commercial software would be in a position to open the files. This problem was circumvented in REMSPEC by sending a range of spectral file types such that anyone had a reasonable chance of opening them. No evidence has therefore been provided that the original problem has been solved or addressed to any extent. However judging by some participants requests prior to the exercise that they could only participate if a specific file type was provided, it is the tentative conclusion of the organiser that many labs still lack confidence in their abilities working with file types that they do not use day to day. In light of that fact it would appear that some work should be performed on this matter: either by increasing competence in manipulating spectral files or deciding upon one standard type which would be transmitted in emergencies and which many countries have a reasonable chance of working with, either in its native format or by converting to the lab's format. Such work could perhaps best be conducted within the framework of international assistance agreements.

Regarding the use of synthetic spectra as an exercise medium for complex spectra, some conclusions can be drawn. There is no doubt that actual samples displaying complex isotope mixtures drawn from a reactor are a useful means of testing and improving laboratory competence. Finland for example has long conducted a national program involving samples drawn from a reactor and distributed rapidly to Finnish participants (see Klemola, 2008). However conducting exercises or activities using actual samples involving international participants is fraught with difficulties regarding transport, decay

and cost. In this respect synthetic spectra are a cost effective way of exercising with complex spectra with a relatively small sacrifice in realism or quality of the data.

The organisers requested feedback from the participants as to their feeling on the exercise and in the main these were positive. Based on experience from the exercise and feedback, the following suggestions are being made as to future potential progress, either within the NKS programmes or as part of international work on emergency preparedness:

- The establishment of a regular exercise programme similar to the REMSPEC exercise,
- Conducting slightly more complex exercises incorporating the full range of possible complexities (density correction, summation, geometry corrections, low signal – high background, decay – ingrowth situations etc),
- Exercises involving less typical situations or less typical instrumentation/contexts,
- Exercise related to data conversion etc.

10. Recommendations as to further activities.

- *Conduct a similar follow-up exercise with the same type of scenario but with a more challenging analysis.*

The spectrum of the REMSPEC exercise was, aside from the complexity of the spectrum itself, relatively simple with respect to its analysis. A more challenging exercise of a similar type would involve the full range of corrections such as background, decay, density/matrix etc. and possibly extending to some standard efficiency corrections for situations where the calibration data provided was for a related but not identical geometry.

- *Conduct additional similar type of exercises to improve our analysis capabilities and experience regarding other "scenarios" .*

The scenario of the REMSPEC exercise was relatively standard in that it represented a situation and a suite of nuclides well recognised by the majority of participants. An exercise involving a less typical but no less relevant alternative scenario type may provide a useful exercise for participants.

- *Activities related to improvement of "nuclear forensics" and related capabilities in general – determination of what kind of radioactive material is present, the shielding material, origin, age etc.*

Recent years have seen international developments such that the demands on organisations involved in radiological emergency preparedness have increased in scope from the more traditional activities typical of the years up to the turn of the century. As recognised by international bodies such as the IAEA, the type of information that responders may be required to deliver during a radiological situation necessitates analyses with which many responders may not be familiar or have little experience of. In this regard, activities such as exercises or workshops may go some way towards identifying and addressing the needs and requirements of response agencies in this regard.

- *Establish the necessary procedures for efficient international (and hence inter laboratory) assistance so that we effectively can make use of the capacity and capability of others in the analysis.*

Recent years have seen significant efforts regarding international assistance in radiological situations (Ugletveit and Molhoek, 2004). To date however, there has not been as much activity on the practical side of the problem despite the fact that technical/analytical assistance is likely to feature in any situation requiring international efforts. To this end, efforts may be required towards the establishment of procedures for efficient technical assistance. In this regard, similar exercises as to that conducted as part of REMSPEC may provide a useful means of both demonstrating and addressing requirements in this area.

Acknowledgments.

The organisers found the REMSPEC exercise to be a very rewarding experience and relatively stress free for most of the time. This was largely due to the willingness of participants to be flexible and to participate fully and the organiser duly acknowledges the efforts of the participants and their organisations. The organiser acknowledges the generous assistance of the NKS in conducting this exercise and a number of people and organisations who, while not specifically mentioned, contributed in a number of ways. The organisers also extend their gratitude to the staff of the CTBTO organisation and Øyvind Selnæs of the NRPA for his help with various programming activities and Finn Ugletveit of the same organisation for his valued opinions.

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Appendix 1.

Full efficiency data for the simulated spectra. Absolute values.

Energy keV	Peak Efficiency	Total Efficiency	Energy keV	Peak Efficiency	Total Efficiency
40	0.0042851	0.0048728	260	0.066337	0.12448
50	0.021382	0.025446	360	0.049032	0.11725
60	0.045309	0.055006	460	0.04079	0.11279
70	0.066747	0.082023	560	0.034108	0.10959
80	0.081261	0.10146	660	0.029235	0.10558
90	0.091632	0.1157	760	0.026523	0.10312
100	0.096717	0.12397	860	0.02435	0.10128
110	0.099771	0.12997	960	0.021961	0.096955
120	0.099382	0.13223	1060	0.020216	0.09631
130	0.09917	0.13421	1160	0.019313	0.091812
140	0.098147	0.1362	1260	0.017831	0.090634
150	0.095071	0.13454	1360	0.016825	0.088379
160	0.094255	0.1346	1460	0.016199	0.087685
170	0.09006	0.13245	1560	0.015443	0.087689
180	0.087641	0.13164	1660	0.014307	0.085386
190	0.084078	0.12983	1760	0.013952	0.083728
200	0.081214	0.12846	1860	0.013279	0.083541
210	0.0786	0.12754	1960	0.012622	0.081255
220	0.075996	0.12669	2060	0.012125	0.081019
230	0.073023	0.12537	2160	0.011456	0.078912
240	0.071127	0.12555	2260	0.011192	0.079335
250	0.067948	0.12368	2360	0.010562	0.077289
			2460	0.010073	0.078917

Appendix 2.

The IMS 1.0 File Format

RMS 2.0 (or IMS 1.0) ASCII file format, all calibrations and spectrum in a single file

The data is stored ordered according to keywords, the following keywords are specified:

#Collection

On single line:

- Start of air sampling date and time
- End of air sampling date and time
- Quantity of the air (in m³)

#Acquisition

On single line:

- Start of acquisition date and time
- Real measurement time (s)
- Live measurement time (s)

#Energy

On each line after the keyword

- energy (in keV)
- channel
- error (energy)

#Resolution

On each line after the keyword

- energy (in keV)
- FWHM (in keV)
- error (FWHM)

#Efficiency

On each line after the keyword

- energy (in keV)
- efficiency
- error (efficiency)

#Spectrum

First line: number of channels and optional energy calibration

On each line after the keyword until the end of file or STOP

- Channel number
- The contents of next 5 channels

An example of the RMS format is provided below:

```
BEGIN IMS2.0
MSG_TYPE DATA
MSG_ID 21032
DATA_TYPE SAMPLEPHD
#Header 3
VGL00 w1_20 P w1_20-nksc FULL
10200107101011
w1_20-2008/04/17-08:57:28.0 w1_20-2007/04/18-08:57:28.0 0
2008/04/18 08:57:28.0
#Collection
2008/04/15 08:57:28.0 2008/04/16 08:57:28.0 21028.23
#Acquisition
2008/04/17 08:57:28.0 41577.90 37797.00
#Calibration
2008/02/17 08:57:28.0
#g_Energy
59.540      175.567      0.009
88.040      261.382      0.006
122.070     363.835      0.007
391.710     1175.233     0.013
661.620     1987.058     0.031
898.020     2698.139     0.009
1173.230    3526.440     0.013
1332.510    4006.245     0.034
1836.010    5526.222     0.065
#g_Resolution
59.540      1.649        0.007
88.040      1.998        0.004
122.070     2.348        0.005
391.710     4.191        0.009
661.620     5.444        0.023
898.020     6.340        0.006
1173.230    7.246        0.009
1332.510    7.721        0.027
1836.010    9.062        0.045
#g_Efficiency
46.520      0.015        0.002
59.540      0.044        0.004
```

```

88.040      0.090      0.004
122.070     0.099     0.004
391.710     0.046     0.003
661.620     0.029     0.001
898.020     0.023     0.002
1173.230    0.019     0.002
1332.510    0.017     0.002
1836.010    0.013     0.001
#g_Spectrum
8192 2705
0  0  0  0  0  0
5  613  618  622  630  638
10 615  692  651  631  670
15 651  673  704  632  667
20 694  714  697  702  729.
.....5 channels per line to the end.....
8160 0  1  1  2  0
8165 0  0  0  0  1
8170 1  0  0  0  1
8175 1  0  1  0  0
8180 1  5  1  0  0
8185 0  0  0  0  1
8190 0  0
STOP

```

The IEC File Format

The IEC file format is an ASCII data exchange format for the transfer and distribution of multichannel pulse height data between laboratories and is fully described in IEC (1995). Each record starts with a value of A004 which is followed by 64 bytes of data and ending with 2 bytes containing a carriage return and line feed characters. All unused bytes in are filled with ASCII spaces. File records are as described below.

Record number 1: System identifier, sub-system identifier, analog-to-digital converter identifier, segment number, digital offset

Record number 2: Live time, real time, number of channels

Record number 3: Acquisition start time, sample collection time

Record number 4: Energy calibration information

Record number 5: FWHM calibration information

Record number 6: Sample information — 1

Record number 7: Sample information — 2

Record number 8: Sample information — 3

Record number 9: Sample information — 4

Record number 10: Spare

Record number 11 — 22: Energy and channel pairs

Record number 23 — 34: Energy and resolution pairs

Record number 35 — 46: Energy and efficiency pairs

Record number 47 — 58: User defined

Record number 59 — End: Spectral data

Example of the IEC spectral file format:

```
A004      T3 1 1 0
A004 37797.000000 41577.900000 8192
A00401/01/08 03:45:31 01/01/08 06:00:00
A004 1.87518 0.331972 0 0
A004 1.40997 0.00143341 -1.65848e-007 1.02387e-011 1
A004      Air filter
A004
A004
A004
A004SPARE
A004 661.65 1987.67 898.021 2698.7
A004 1460.81 4393.56 1836.01 5526.9
A004 0 0 0 0
A004 0 0 0 0
```


Appendix 3.

Modelled values used in the test spectrum. Uncertainties are an arbitrary 3% as no uncertainties in the input activities are included in the simulation process.

Isotope	Activity Bq	Uncertainty Bq
¹³¹ I	3046.5	60.9
¹³² I	2937.00	58.7
¹³³ I	2443.6	48.9
¹³⁵ I	217.6	4.4
¹³⁴ Cs	321.9	6.4
¹³⁶ Cs	73.4	1.5
¹³⁷ Cs	251.8	5.0
¹⁰³ Ru	297.8	6.0
¹²⁷ Sb	218	4.4
¹⁴⁰ Ba	914.1	18.3
¹⁴⁰ La	209.1	4.2
¹⁴¹ Ce	66.4	1.3
¹⁴³ Ce	43	0.9
⁹¹ Y	376	7.5
⁹¹ Sr	58.9	1.2
⁹⁵ Zr	80.6	1.6
⁹⁵ Nb	409.3	8.2
^{131m} Te	202	4.0
¹³² Te	2850	57.0
¹³¹ Te	45.6	0.9
^{91m} Y	36.9	0.7
¹³⁵ Xe	193	3.9
¹³⁵ Xe	27.6	0.6

Participant 1.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3180	310	¹¹³ Sn			
¹³² I	2919	292	²⁰³ Hg			
¹³³ I	2780	278				
¹³⁵ I	247	25				
¹³⁴ Cs	335	34				
¹³⁶ Cs	66	6.6				
¹³⁷ Cs	245	25				
¹⁰³ Ru	322	32				
¹²⁷ Sb	226	22				
¹⁴⁰ Ba	1137	114				
¹⁴⁰ La	219	22				
¹⁴¹ Ce	60	6				
¹⁴³ Ce						
⁹¹ Y						
⁹¹ Sr	72	7				
⁹⁵ Zr	75	7.5				
⁹⁵ Nb	408	41				
^{131m} Te	293	29				
¹³² Te	2970	297				
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe	205	20				
¹³³ Xe	30	15				

No secondary results reported within time.

Participant 2.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3030	90		2960.00	80.00	
¹³² I	2910	40		2900	40	
¹³³ I	2430	70		2480.00	70.00	
¹³⁵ I	219	7		230.00	7.00	
¹³⁴ Cs	316	9		316.00	10.00	
¹³⁶ Cs	69	3		68.00	3.00	
¹³⁷ Cs	247	15		252.00	16.00	
¹⁰³ Ru	287	16		298.00	18.00	
¹²⁷ Sb	194	7		206.00	8.00	
¹⁴⁰ Ba	890	30		890.00	30.00	
¹⁴⁰ La	209	6		209.00	6.00	
¹⁴¹ Ce	63	4		64.00	4.00	
¹⁴³ Ce	44	4		43.00	4.00	
⁹¹ Y						
⁹¹ Sr	57	4		64.00	5.00	
⁹⁵ Zr	83	4		83.00	4.00	
⁹⁵ Nb	414	25		417.00	25.00	
^{131m} Te	250	6		246.00	7.00	
¹³² Te	2980	90		2860.00	90.00	
¹³¹ Te	86	5		88	6.00	
^{91m} Y	36	3		37.00	3.00	
¹³⁵ Xe				186.00	11.00	
¹³³ Xe				25.00	4.00	

Participant 3.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3160	80	¹⁰⁶ Rh	3160.00	80.00	¹⁰⁶ Rh
¹³² I	2340	60		2340.00	60.00	
¹³³ I	2470	70		2470.00	70.00	
¹³⁵ I						
¹³⁴ Cs	283	9		283.00	9.00	
¹³⁶ Cs	57.4	2.6		57.40	2.60	
¹³⁷ Cs	254	8		254.00	8.00	
¹⁰³ Ru	324	10		324.00	10.00	
¹²⁷ Sb	238	12		238.00	12.00	
¹⁴⁰ Ba	1160	40		1160.00	40.00	
¹⁴⁰ La	181	7		181.00	7.00	
¹⁴¹ Ce	66	5		66.00	5.00	
¹⁴³ Ce	47	9		47.00	9.00	
⁹¹ Y						
⁹¹ Sr	64	7		64.00	7.00	
⁹⁵ Zr	80	5		80.00	5.00	
⁹⁵ Nb	420	12		420.00	12.00	
^{131m} Te	198	14		198.00	14.00	
¹³² Te	2950	80		2950.00	80.00	
¹³¹ Te	101	5		101.00	5.00	
^{91m} Y						
¹³⁵ Xe	195	6		195.00	6.00	
¹³³ Xe						

Participant 4.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3197.90	5.02	¹⁰⁹ Cd	348.58	1.17	²¹⁴ Pb
¹³² I	839.38	202.48	¹⁷⁷ Yb			²³⁹ Pu
¹³³ I			²¹² Bi			
¹³⁵ I	164.84	1.75	²¹⁴ Pb	164.12	4.97	
¹³⁴ Cs	280.41	1.28	²³³ U	28.30	0.27	
¹³⁶ Cs	63.84	0.68	²³⁹ Pu	6.53	0.16	
¹³⁷ Cs	253.67	1.68		25.13	0.40	
¹⁰³ Ru	294.56	10.83		30.08	2.21	
¹²⁷ Sb						
¹⁴⁰ Ba	845.34	64.54		91.01	14.44	
¹⁴⁰ La	187.66	1.27		20.11	0.33	
¹⁴¹ Ce						
¹⁴³ Ce						
⁹¹ Y						
⁹¹ Sr	57.00	1.63		30.52	2.96	
⁹⁵ Zr	63.80	1.31		7.97	0.29	
⁹⁵ Nb						
^{131m} Te						
¹³² Te						
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe	172.97	1.14				
¹³³ Xe						

Participant 5a

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3100	350	⁷ Be			
¹³² I	1300	200	²⁰³ Hg			
¹³³ I	2700	500	¹⁰⁶ Ru			
¹³⁵ I	200	100	¹²⁶ I			
¹³⁴ Cs	270	60	¹³⁰ I			
¹³⁶ Cs			^{131m} Xe			
¹³⁷ Cs	250	40				
¹⁰³ Ru	300	40				
¹²⁷ Sb						
¹⁴⁰ Ba	900	200				
¹⁴⁰ La	200	80				
¹⁴¹ Ce	60	30				
¹⁴³ Ce						
⁹¹ Y						
⁹¹ Sr						
⁹⁵ Zr	200	50				
⁹⁵ Nb	400	50				
^{131m} Te						
¹³² Te	3000	600				
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe						
¹³³ Xe						

Participant 5 reported twice in the preliminary phase using two different analysis systems. No secondary results were returned.

Participant 5b

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3068	100	²⁰³ Hg			
¹³² I	2318	70				
¹³³ I	2366	80				
¹³⁵ I	245	15				
¹³⁴ Cs	284	10				
¹³⁶ Cs						
¹³⁷ Cs	242	10				
¹⁰³ Ru						
¹²⁷ Sb						
¹⁴⁰ Ba	944	40				
¹⁴⁰ La	183	10				
¹⁴¹ Ce	79	6				
¹⁴³ Ce						
⁹¹ Y						
⁹¹ Sr						
⁹⁵ Zr	181	8				
⁹⁵ Nb	407	15				
^{131m} Te						
¹³² Te						
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe						
¹³³ Xe						

Participant 5 reported twice in the preliminary phase using two different analysis systems. No secondary results were returned.

Participant 6.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3100	600	¹⁸⁷ W	3100	400	⁵⁸ Fe
¹³² I	2300	500	²¹² Bi	2400	500	⁶⁰ Co
¹³³ I	2500	600	²¹⁴ Pb	2400	500	¹⁸⁷ W
¹³⁵ I	200	100	²³⁹ Np	230	80	
¹³⁴ Cs	281	150	¹³⁸ Cs	280	70	
¹³⁶ Cs	61	30	^{131m} Xe	60	20	
¹³⁷ Cs	255	30	¹⁰⁶ Rh	255	20	
¹⁰³ Ru	290	30	⁶⁰ Co	290	60	
¹²⁷ Sb			⁸⁸ Kr			
¹⁴⁰ Ba	1150	300	^{85m} Kr	1140	150	
¹⁴⁰ La	180	100	⁹⁷ Zr	175	30	
¹⁴¹ Ce	65	7		65	10	
¹⁴³ Ce	46	30		45	15	
⁹¹ Y						
⁹¹ Sr	67	10		68	5	
⁹⁵ Zr	80	8		81	5	
⁹⁵ Nb	420	40		420	40	
^{131m} Te						
¹³² Te	2100	600		2700	90	
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe	190	100		190	40	
¹³³ Xe	46	30		46	15	

Participant 7.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3102.4	4.96	⁵⁷ Co	3145.50	4.80	⁵⁷ Co
¹³² I			⁸⁹ Zr	2646.10	132.40	⁸⁹ Zr
¹³³ I			¹⁰⁶ Ru	2503.90	12.50	¹⁰⁶ Ru
¹³⁵ I			¹³³ Ba	224.60	2.80	¹³³ Ba
¹³⁴ Cs	277.1	1.3		278.00	1.30	
¹³⁶ Cs				60.90	0.80	
¹³⁷ Cs	246.8	1.9		246.20	1.90	
¹⁰³ Ru	309.6	2.45		286.70	10.50	
¹²⁷ Sb						
¹⁴⁰ Ba	858.9	5.5		869.70	7.80	
¹⁴⁰ La	180.2	1.5		188.50	1.50	
¹⁴¹ Ce	61.8	1.8		60.80	1.10	
¹⁴³ Ce						
⁹¹ Y						
⁹¹ Sr				70.70	2.60	
⁹⁵ Zr	80.5	1.4				
⁹⁵ Nb	407.65	2.2		401.90	2.50	
^{131m} Te						
¹³² Te				2726.80	33.20	
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe				201.70	1.40	
¹³³ Xe						

Participant 8.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I						
¹³² I						
¹³³ I						
¹³⁵ I						
¹³⁴ Cs						
¹³⁶ Cs						
¹³⁷ Cs						
¹⁰³ Ru						
¹²⁷ Sb						
¹⁴⁰ Ba						
¹⁴⁰ La						
¹⁴¹ Ce						
¹⁴³ Ce						
⁹¹ Y						
⁹¹ Sr						
⁹⁵ Zr						
⁹⁵ Nb						
^{131m} Te						
¹³² Te						
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe						
¹³³ Xe						

Participant 8 withdrew.

Participant 9.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3262.15	649.33	⁸⁹ Kr	3262	176	⁸⁹ Kr
¹³² I	2237	669.37	²¹² Bi	2237	262	²¹² Bi
¹³³ I			²¹⁴ Pb			²¹⁴ Pb
¹³⁵ I	211.63	60.31	²³⁷ Np	212	66	²³⁷ Np
¹³⁴ Cs	281.59	102.37	²³⁹ Np	282	39	²³⁹ Np
¹³⁸ Cs	61.41	31.42		61	10	
¹³⁷ Cs	244.35	110.1		244.3	7.7	
¹⁰³ Ru						
¹²⁷ Sb						
¹⁴⁰ Ba	894.79	112.45		895	103	
¹⁴⁰ La						
¹⁴¹ Ce						
¹⁴³ Ce						
⁹¹ Y	6590	20.23		17770	6604	
⁹¹ Sr	51.66	21.03		51.7	6.5	
⁹⁵ Zr						
⁹⁵ Nb						
^{131m} Te						
¹³² Te	3250.19	795.66		2556	144	
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe						
¹³³ Xe						

Participant 10.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3217.9	9.5	¹⁰⁶ Ru	3038	8	²⁴ Na
¹³² I	2478.1	248	¹²⁷ Te	2697	270	
¹³³ I	2598.7	25.6		2562	10	
¹³⁵ I	216.5	4.8		233	5	
¹³⁴ Cs	274.6	3.7		311.8	3.2	
¹³⁸ Cs	61.1	1.4		58	1.4	
¹³⁷ Cs	250.5	4		249.3	4	
¹⁰³ Ru	292.2	21.6		294	22	
¹²⁷ Sb	224.5	4.6		181.2	4.6	
¹⁴⁰ Ba	861	117		863.5	118.2	
¹⁴⁰ La	234.1	2.6		178.9	3.8	
¹⁴¹ Ce	58.6	2.0		58.6	2	
¹⁴³ Ce	42.8	3.2		43.4	3.2	
⁹¹ Y				1792	606	
⁹¹ Sr				71.5	2.1	
⁹⁵ Zr	404.5	4.4		80.4	1.3	
⁹⁵ Nb	82.2	3.6		403.9	4.2	
^{131m} Te	163.9	3.7		384.3	10.2	
¹³² Te				2486	36	
¹³¹ Te	180.7	4.6		384.3	10.2	
^{91m} Y						
¹³⁵ Xe				identified		
¹³³ Xe				identified		

Participant 11.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	3326.93	136.257	²² Na	3326.93	136.257	²² Na
¹³² I	2100.52	64.388	⁴¹ Ar	2100.52	64.388	⁴¹ Ar
¹³³ I	2619.77	151.521	⁵⁶ Mn	2619.77	151.521	⁵⁸ Co
¹³⁵ I	222.45	7.544	⁵⁸ Co	222.45	7.544	^{69m} Zn
¹³⁴ Cs	256.4	9.904	^{69m} Zn	256.4	9.904	^{85m} Kr
¹³⁶ Cs	59.42	2.787	⁷⁵ Se	59.42	2.787	⁸⁹ Kr
¹³⁷ Cs	244.48	17.747	^{85m} Kr	244.48	17.747	⁸⁹ Zr
¹⁰³ Ru	292.77	22.085	⁸⁹ Kr	292.77	22.085	⁹⁴ Y
¹²⁷ Sb			⁸⁹ Zr			⁹⁰ Mo
¹⁴⁰ Ba	595.92	47.74	⁹⁷ Zr	595.92	47.74	⁹⁷ Zr
¹⁴⁰ La	192.22	6.927	¹⁰⁶ Ru	192.22	6.927	¹⁰⁶ Ru
¹⁴¹ Ce	61.47	4.997	¹⁰⁹ Cd	61.47	4.997	¹⁰⁹ Cd
¹⁴³ Ce			¹²⁶ I			^{131m} Xe
⁹¹ Y			¹²⁶ Sb			²⁰³ Hg
⁹¹ Sr	56.46	5.408	¹³⁰ I	56.46	5.408	²¹² Bi
⁹⁵ Zr	78.6	6.224	^{131m} Xe	78.6	6.224	²¹⁴ Pb
⁹⁵ Nb	401.58	30.394	¹⁵⁵ Eu	401.58	30.394	²²⁴ Ra
^{131m} Te			¹⁸⁷ W			
¹³² Te	2998.2	269.548	²⁰³ Hg	2998.2	269.548	
¹³¹ Te			²¹⁰ Tl			
^{91m} Y	54.63	4.714	²¹² Bi	54.63	4.714	
¹³⁵ Xe	200.79	15.966	²¹⁴ Pb	200.79	15.966	
¹³³ Xe	189.99	12.179	²²³ Fr	189.99	12.179	
			²²⁴ Ra			
			⁹⁰ Mo			
			⁹⁴ Y			

Participant 12.

Isotope	Preliminary Results			Second Results		
	Activity Bq	Uncertainty Bq	False Positives	Activity Bq	Uncertainty Bq	False Positives
¹³¹ I	2930	250	⁵⁸ Co	2930	250	⁵⁸ Co
¹³² I	2360	270	⁷⁵ Se	2360	270	⁷⁵ Se
¹³³ I	2800	300	¹⁸⁷ W	2800	300	¹⁸⁷ W
¹³⁵ I	216	18	⁹⁷ Zr	216	18	⁹⁷ Zr
¹³⁴ Cs	300	30	¹⁰⁶ Ru	300	30	¹⁰⁶ Ru
¹³⁶ Cs	61	7	¹²⁶ I	61	7	¹²⁶ I
¹³⁷ Cs	254	20		254	20	
¹⁰³ Ru	298	24		298	24	
¹²⁷ Sb						
¹⁴⁰ Ba	940	110		940	110	
¹⁴⁰ La	180	15		180	15	
¹⁴¹ Ce	61	8		61	8	
¹⁴³ Ce						
⁹¹ Y						
⁹¹ Sr	64	5		64	5	
⁹⁵ Zr	81	7		81	7	
⁹⁵ Nb	424	34		424	34	
^{131m} Te						
¹³² Te	3000	280		3000	280	
¹³¹ Te						
^{91m} Y						
¹³⁵ Xe	190	15		190	15	
¹³³ Xe				2930	250	

Appendix 4.

List of participants and contact details. The following order is not indicative of a participant number in the exercise.

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Riia 142,

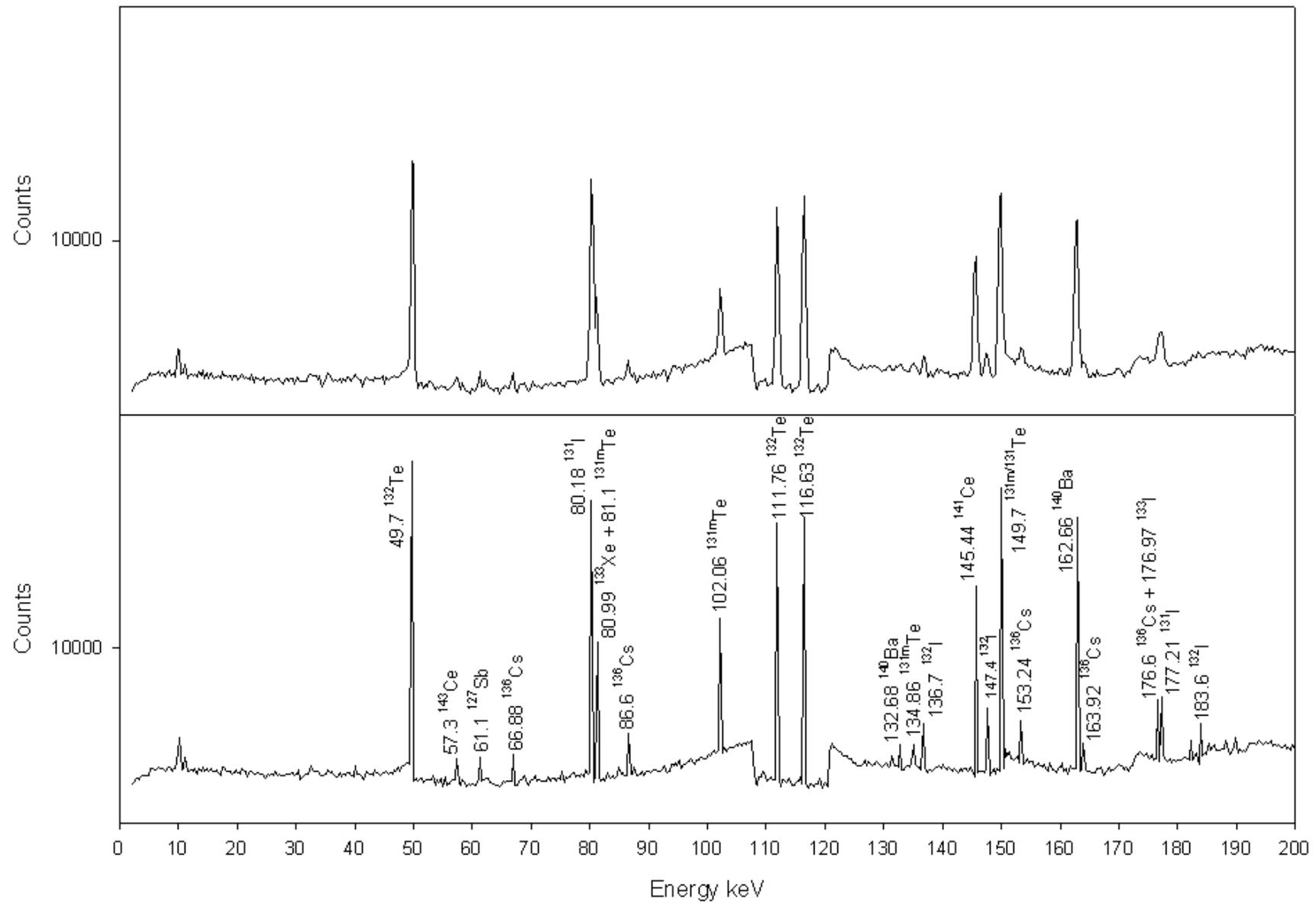
51014 Tartu,

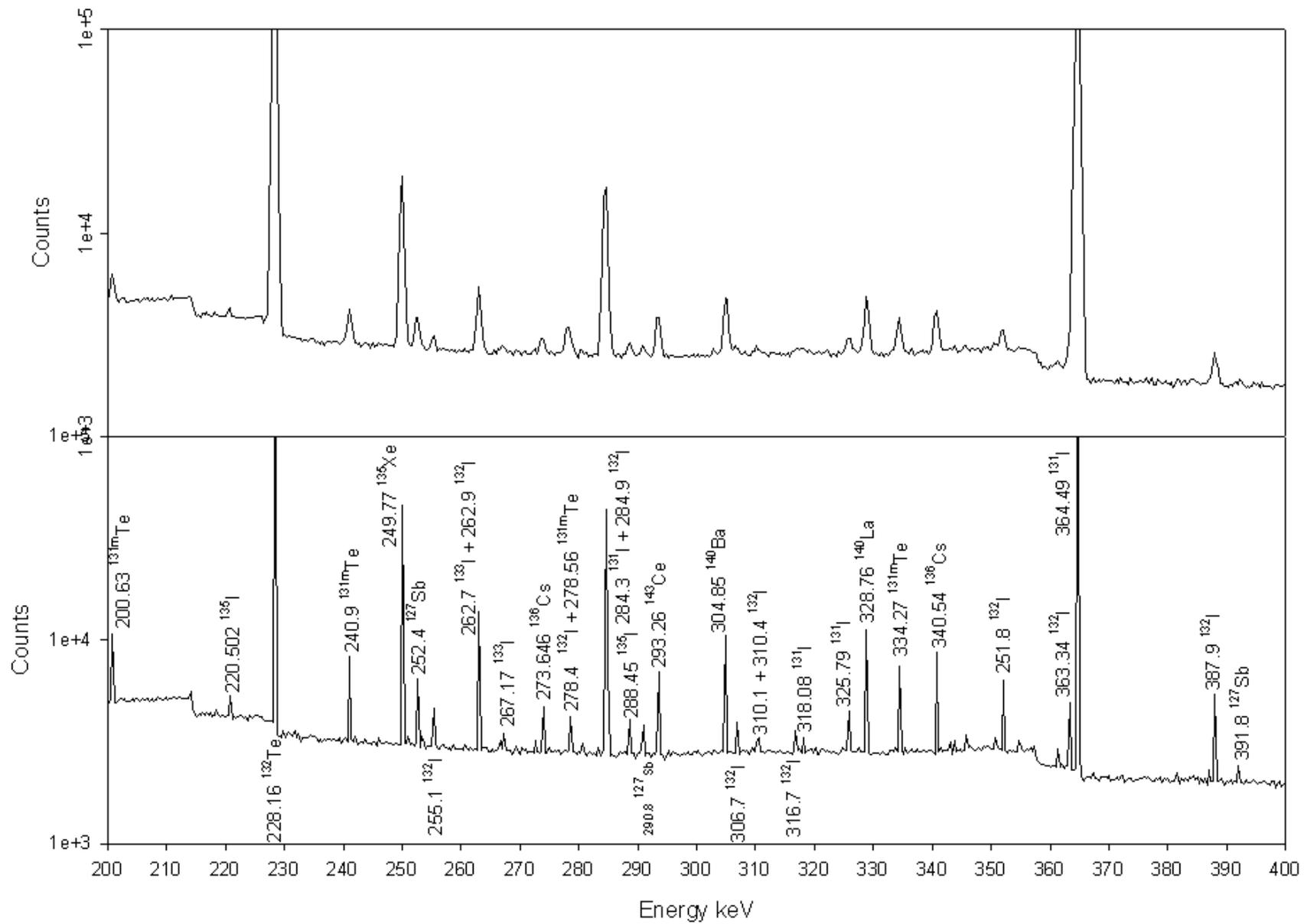
Estonia.

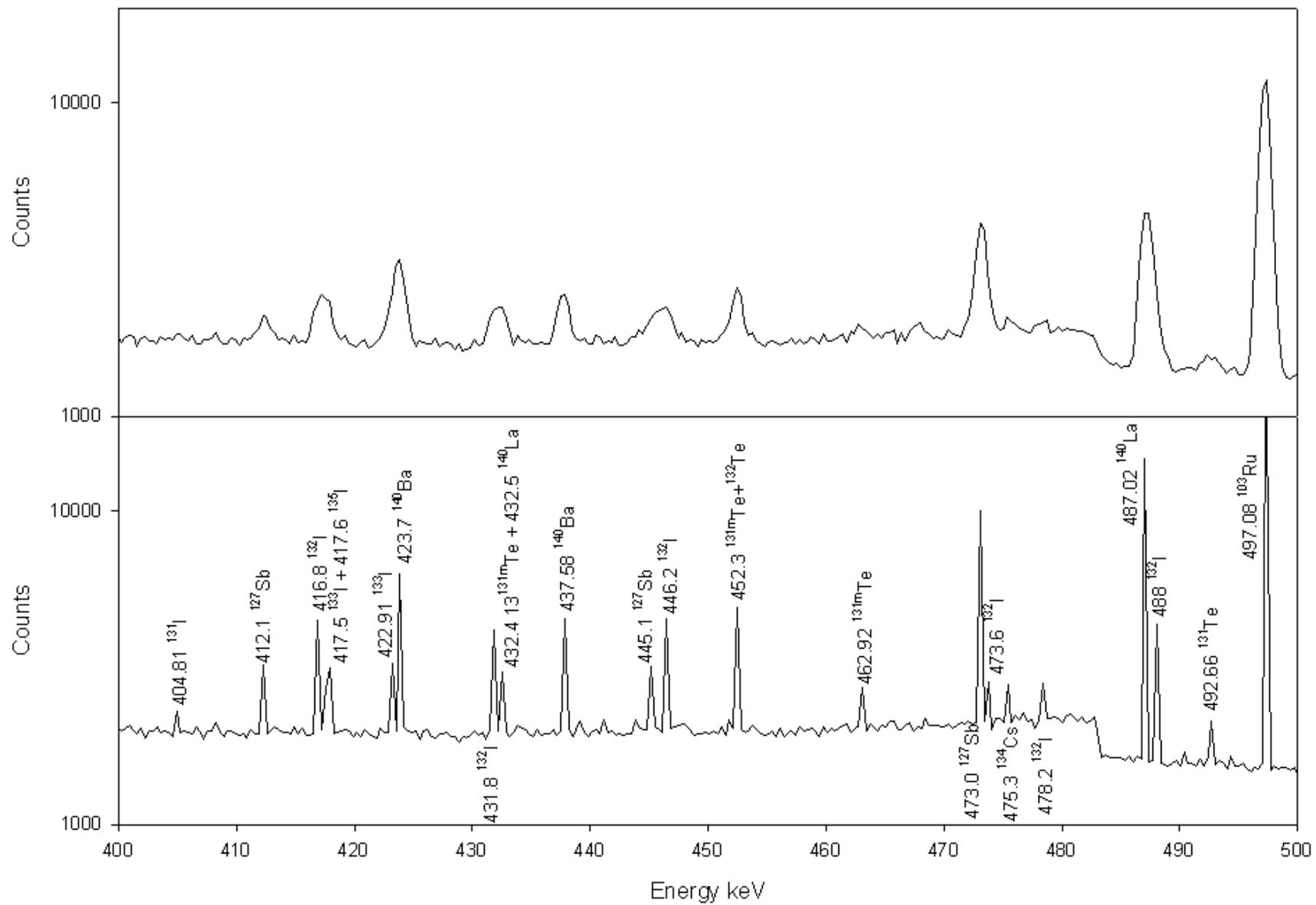
Kadri Isakar kadri.isakar@kiiruskeskus.ee

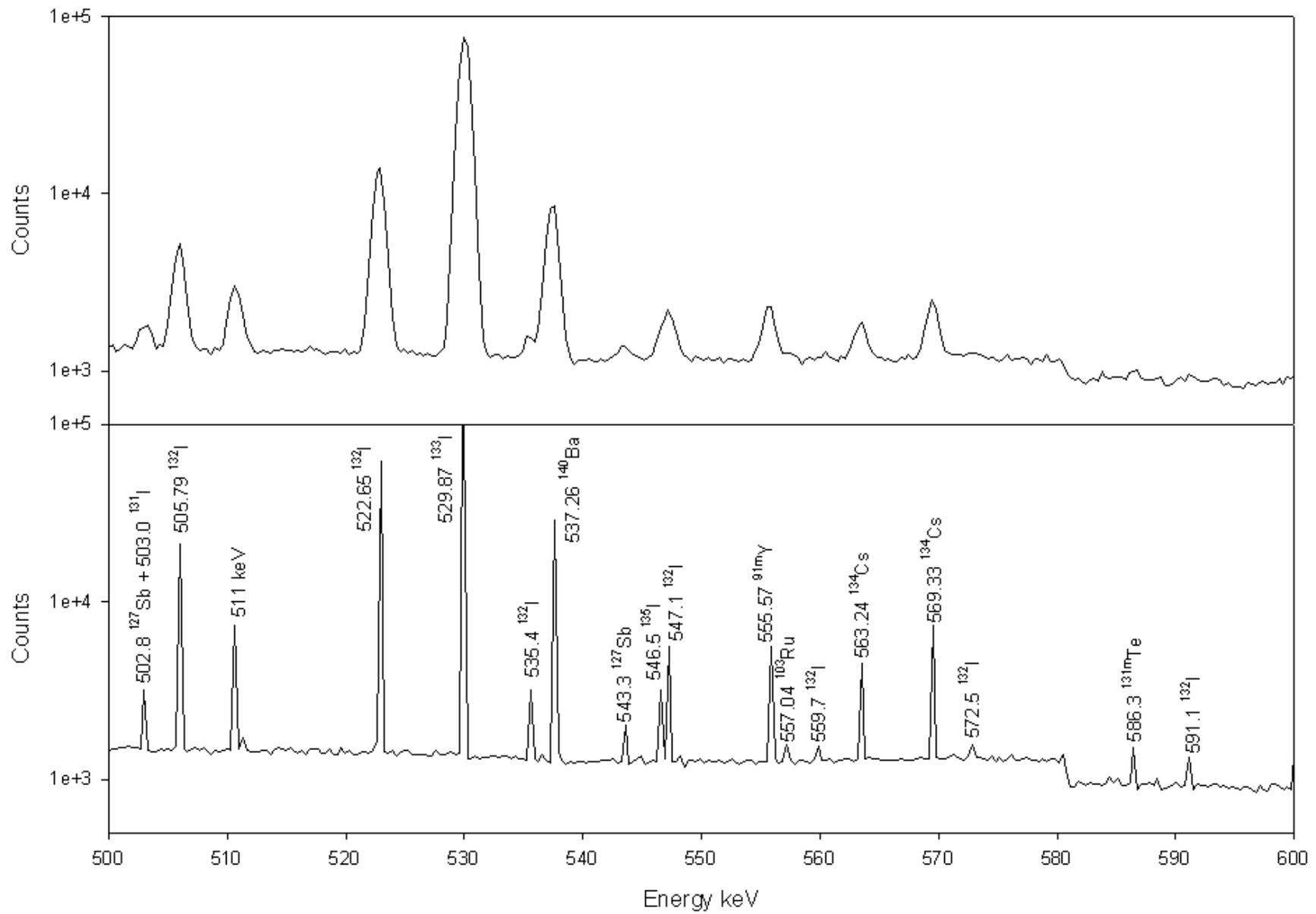
Appendix 5.

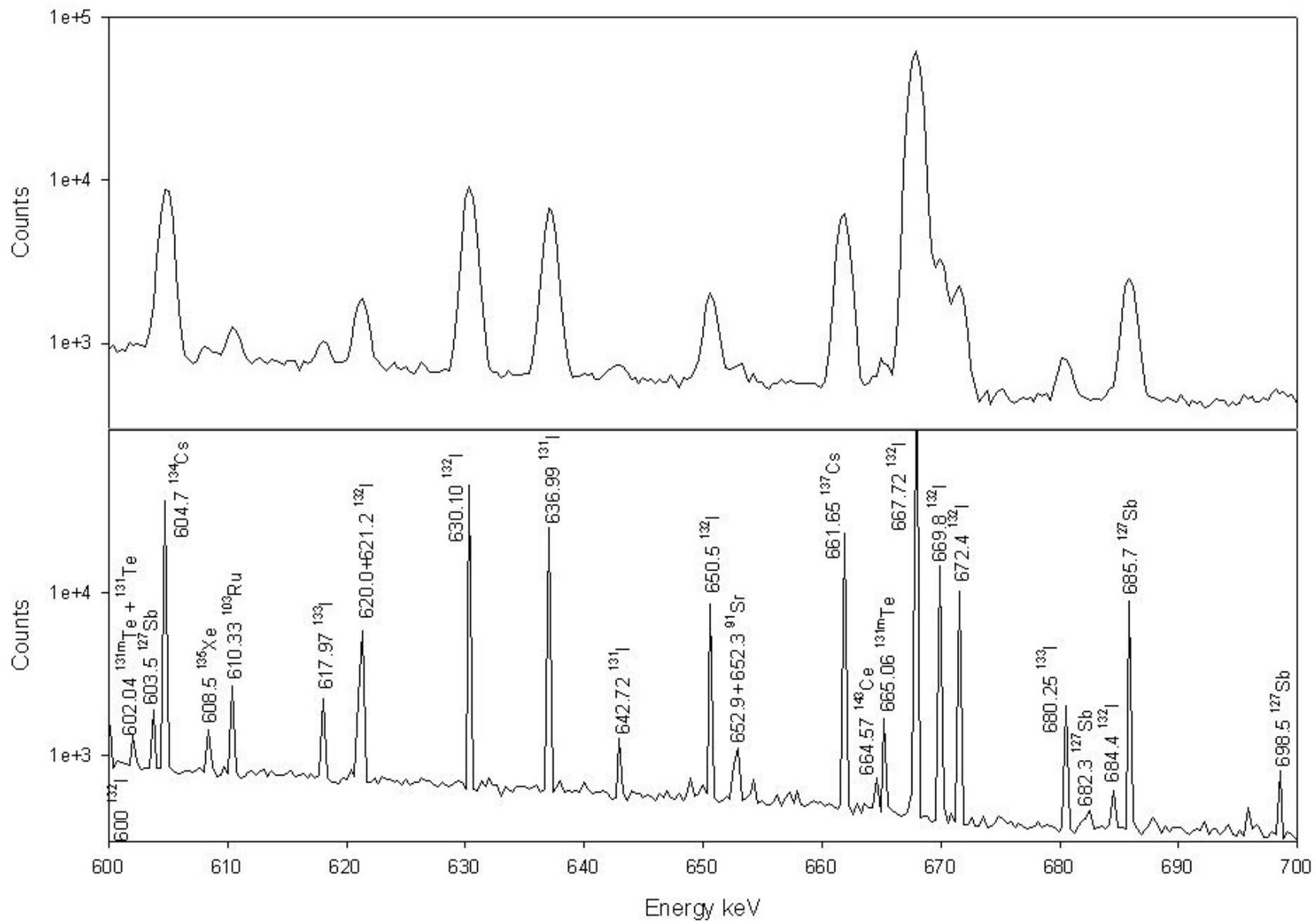
The test spectrum (NKSPEK 1) with the test spectrum in high resolution (NKSPEK 3) below. Major peaks have been tentatively identified.

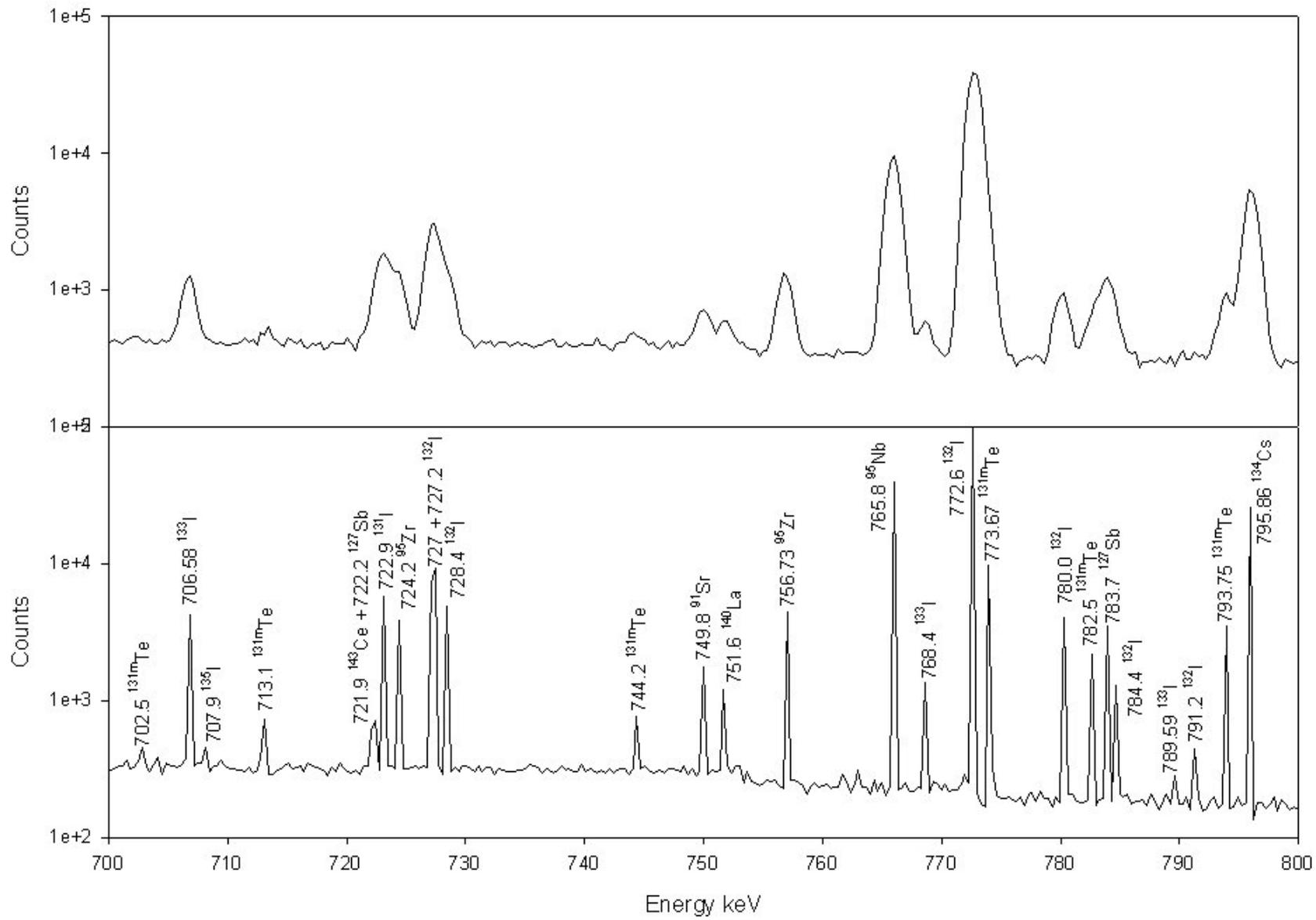


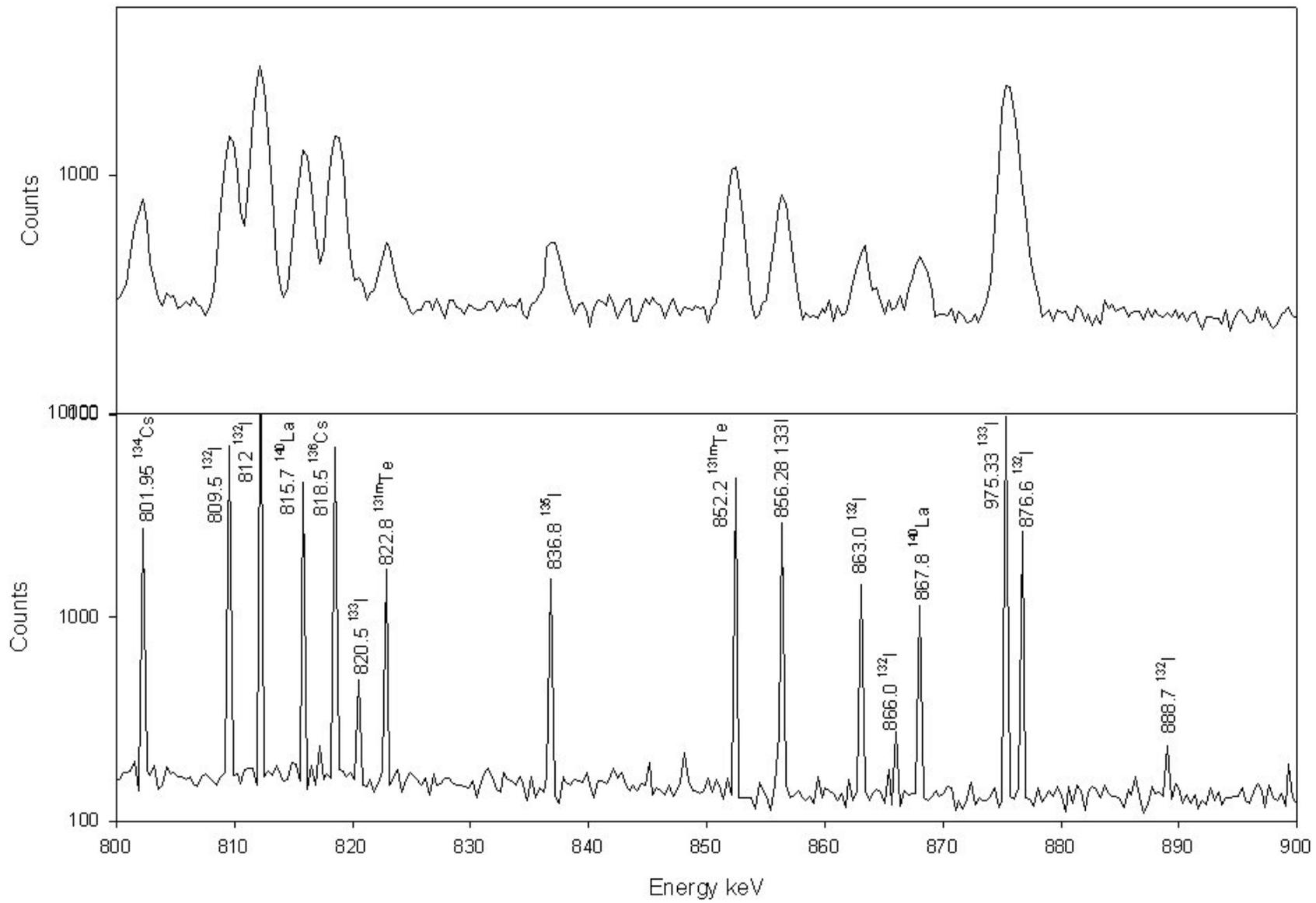


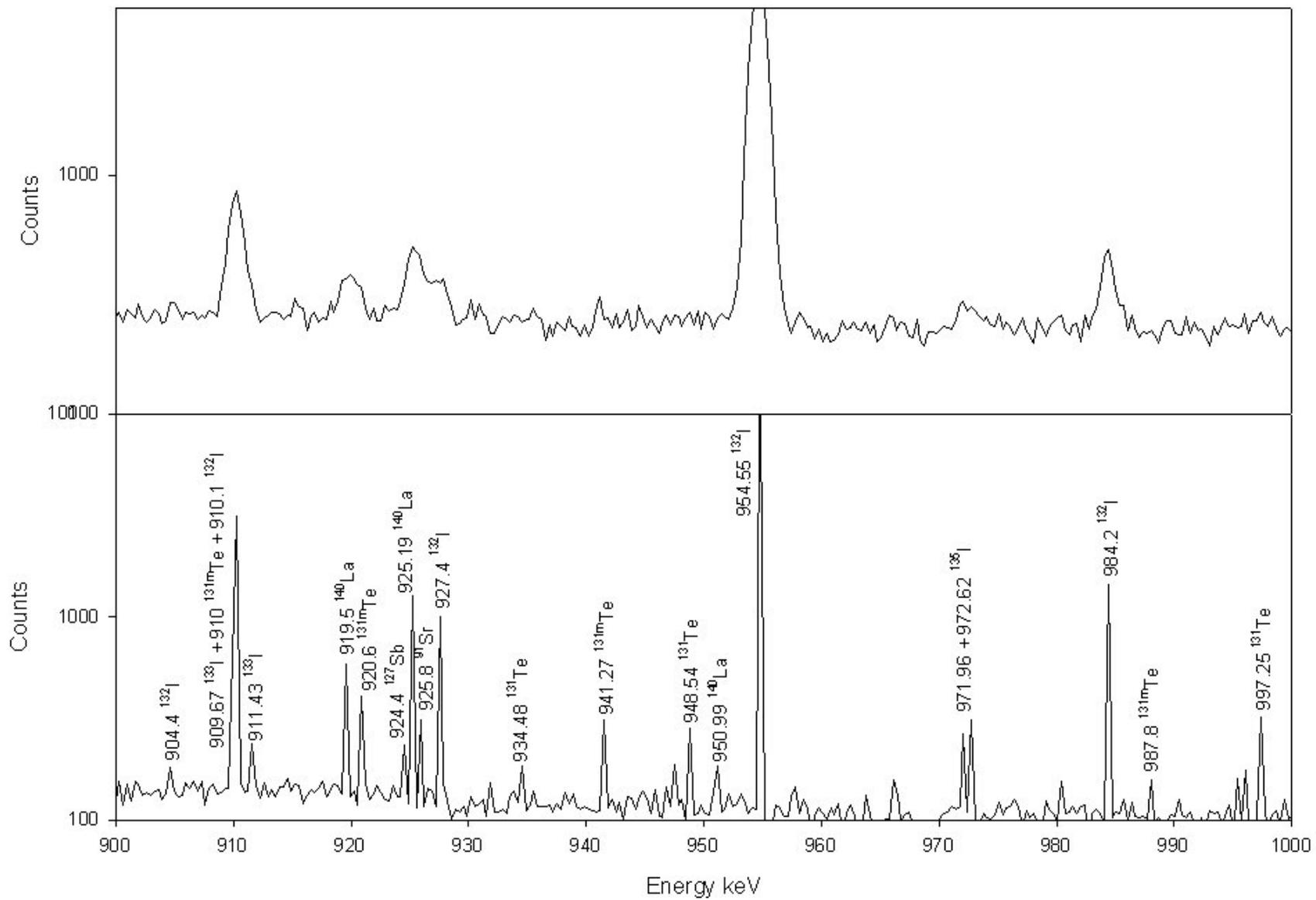


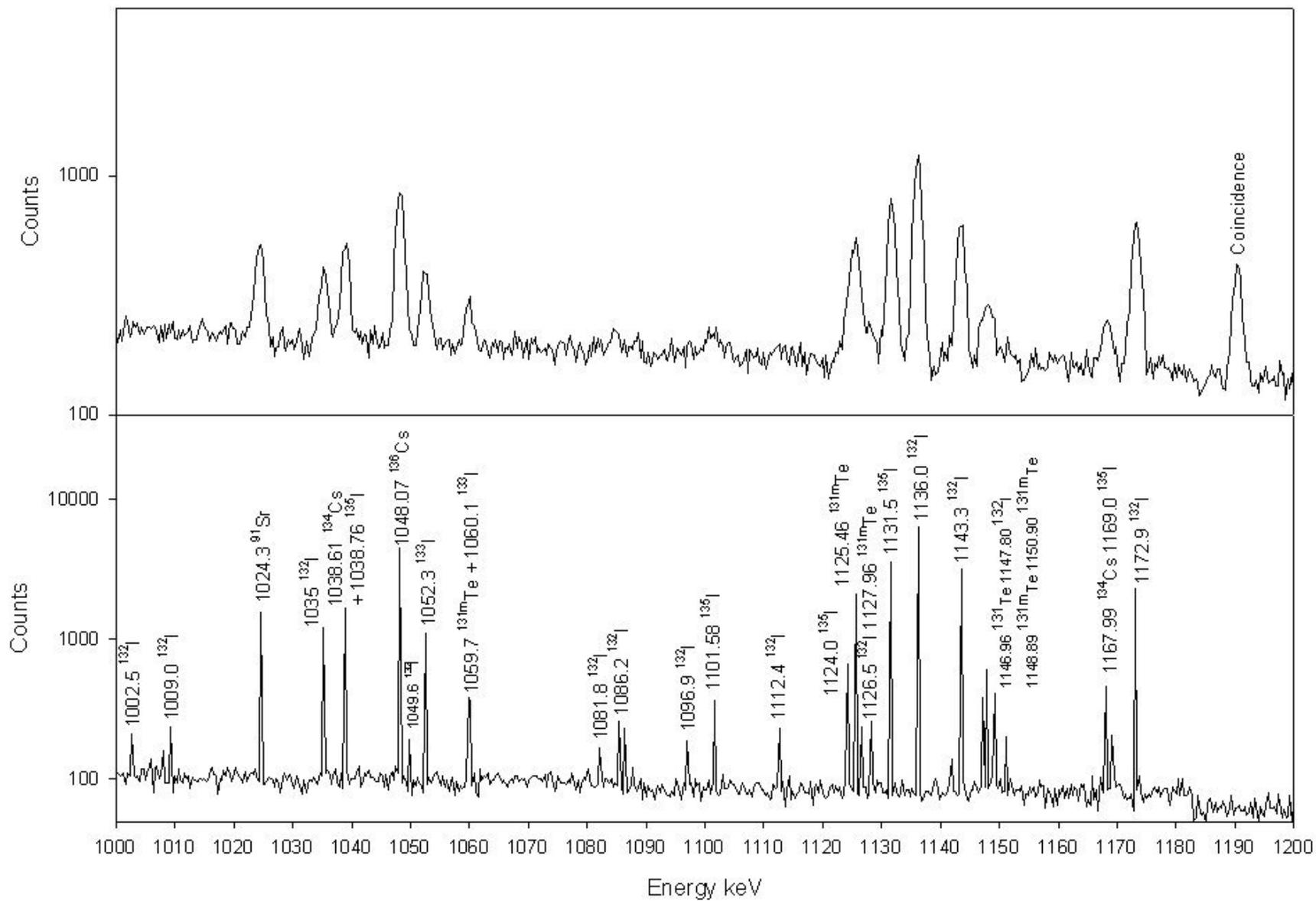


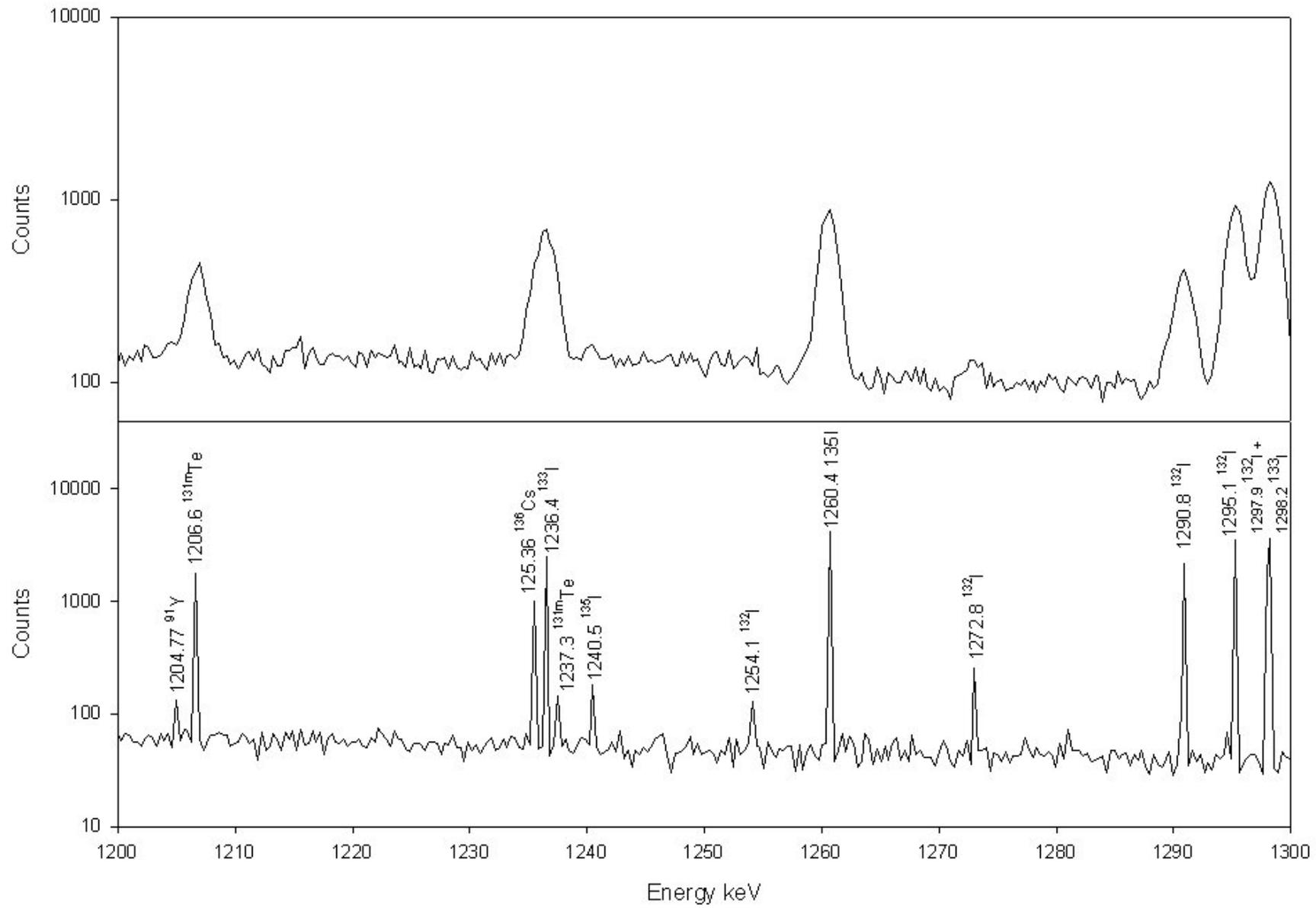


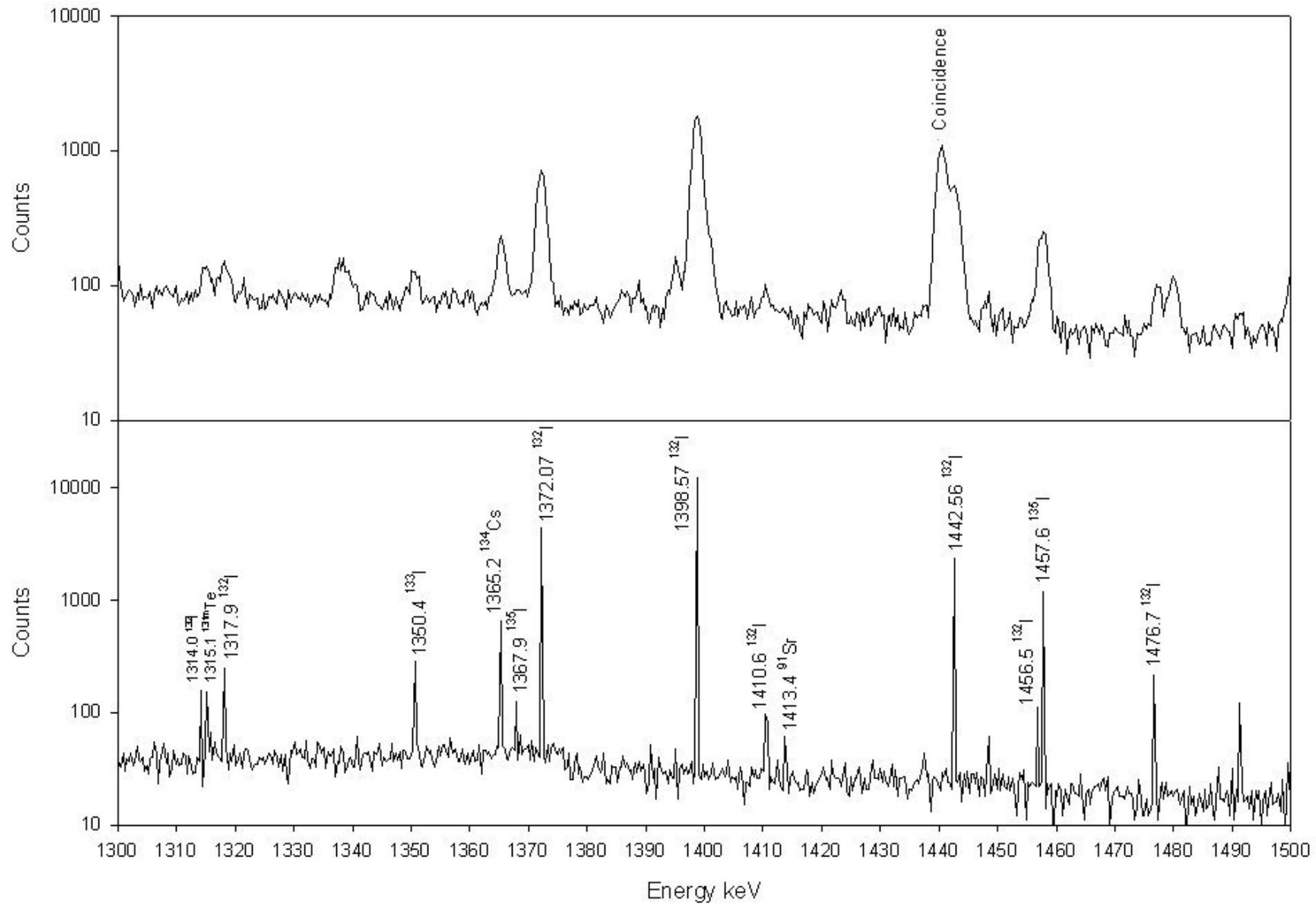


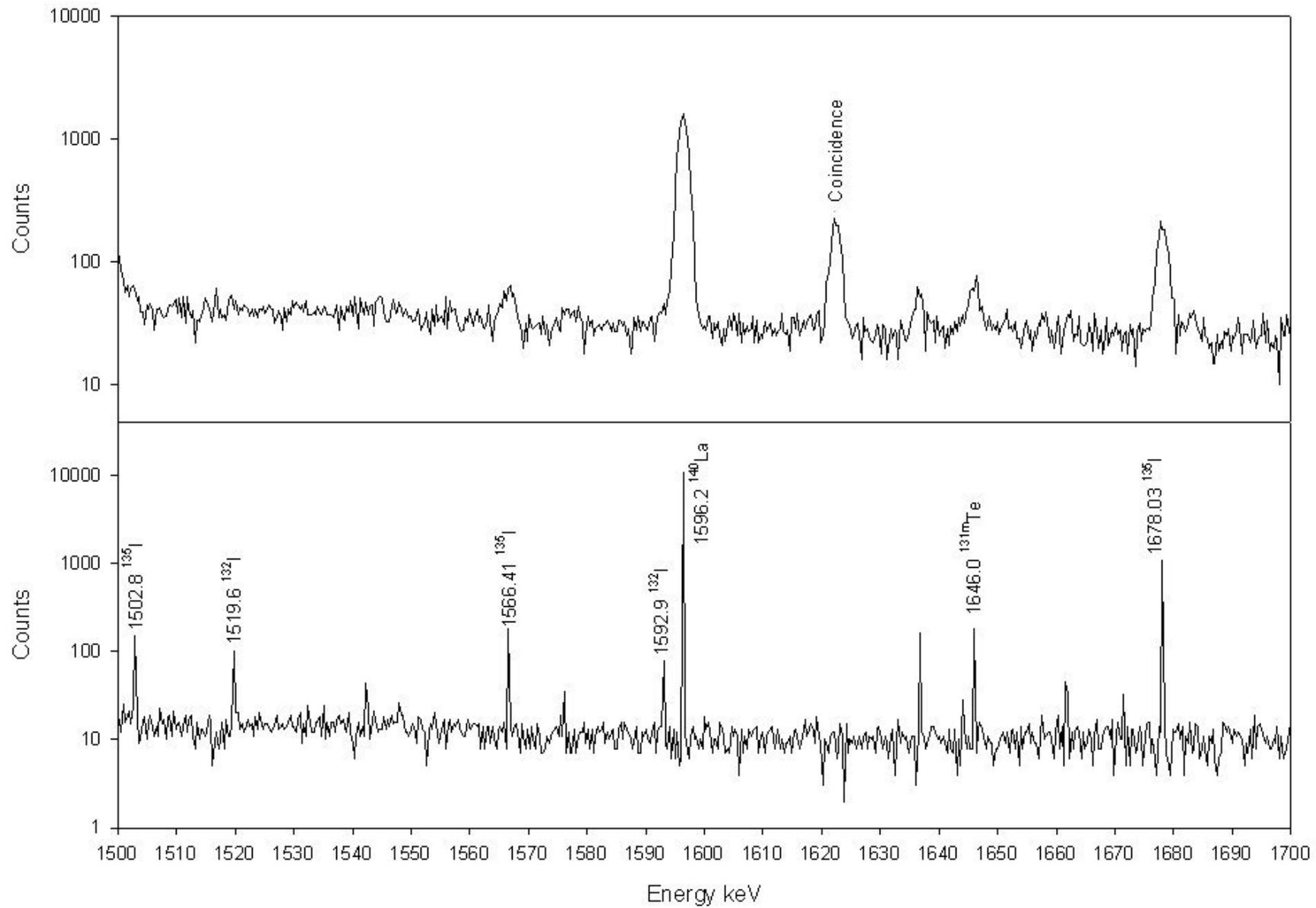


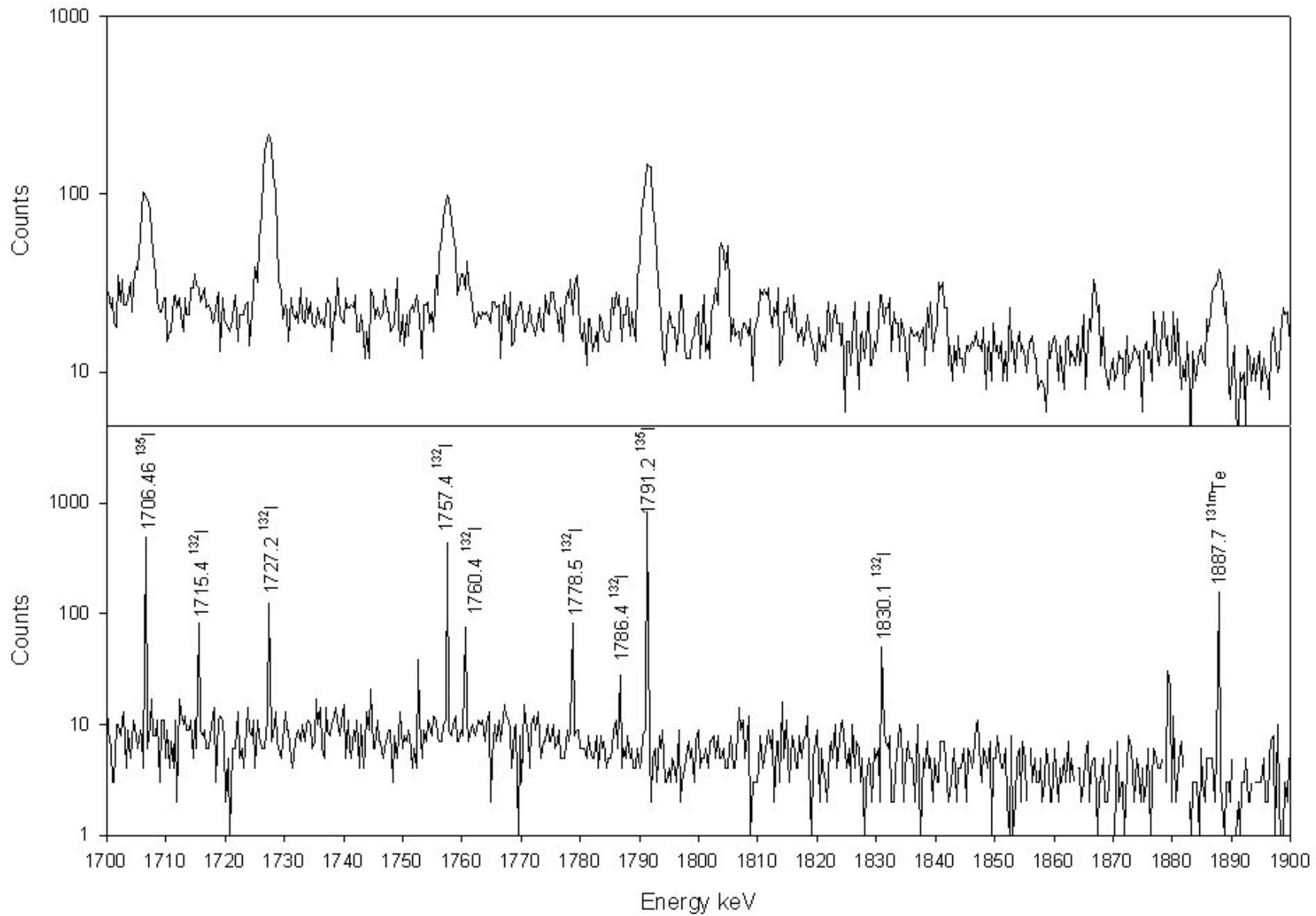


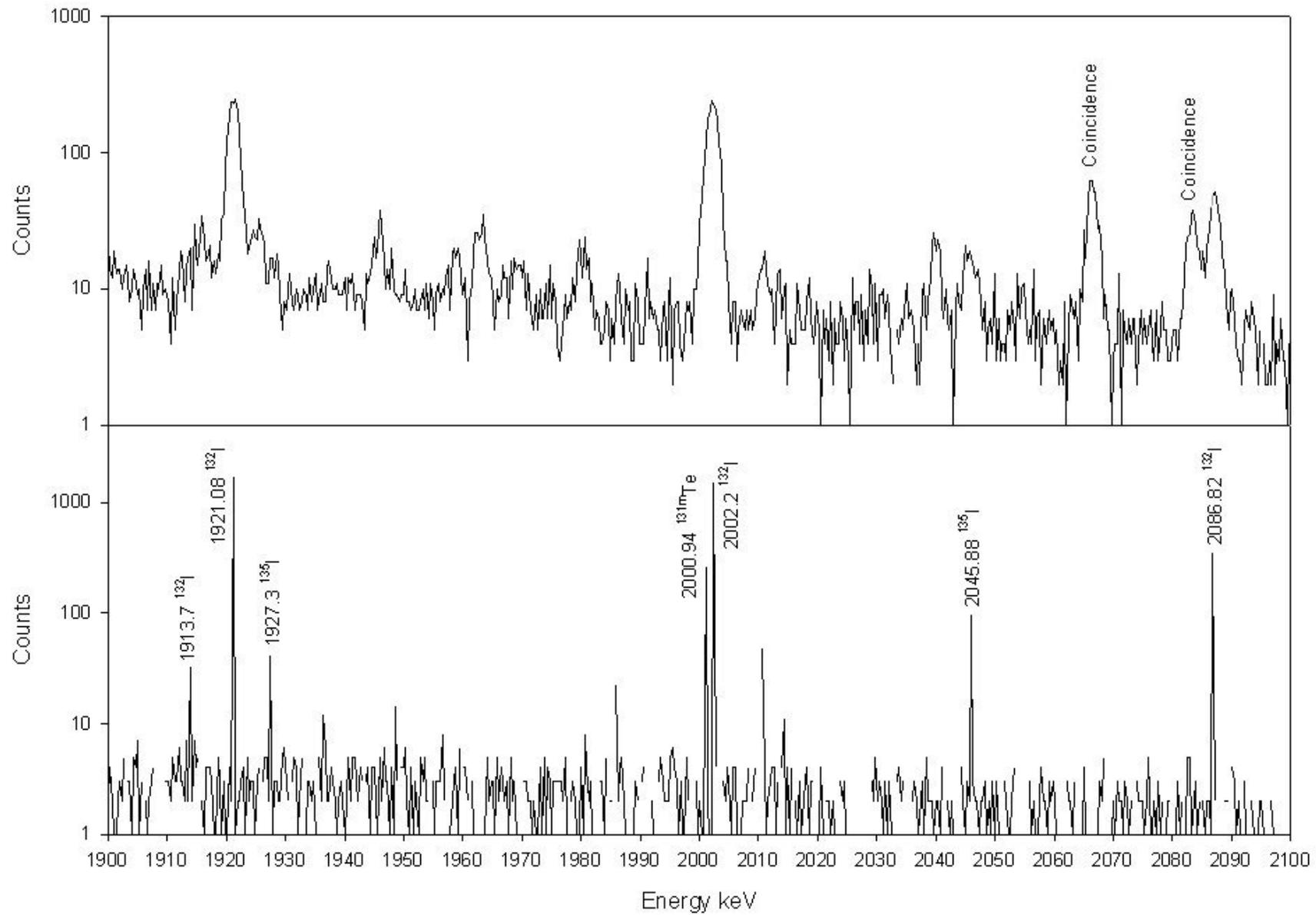


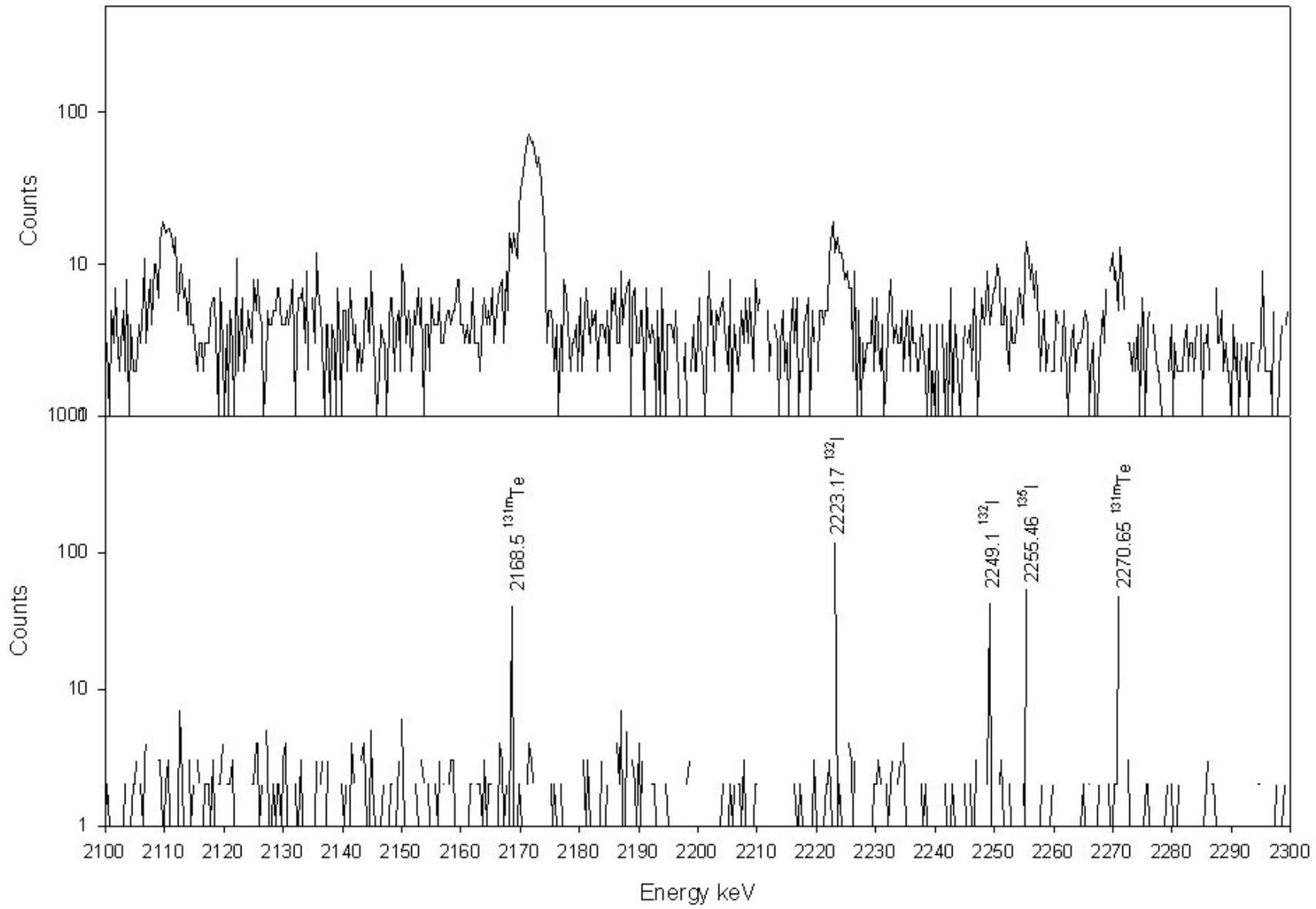


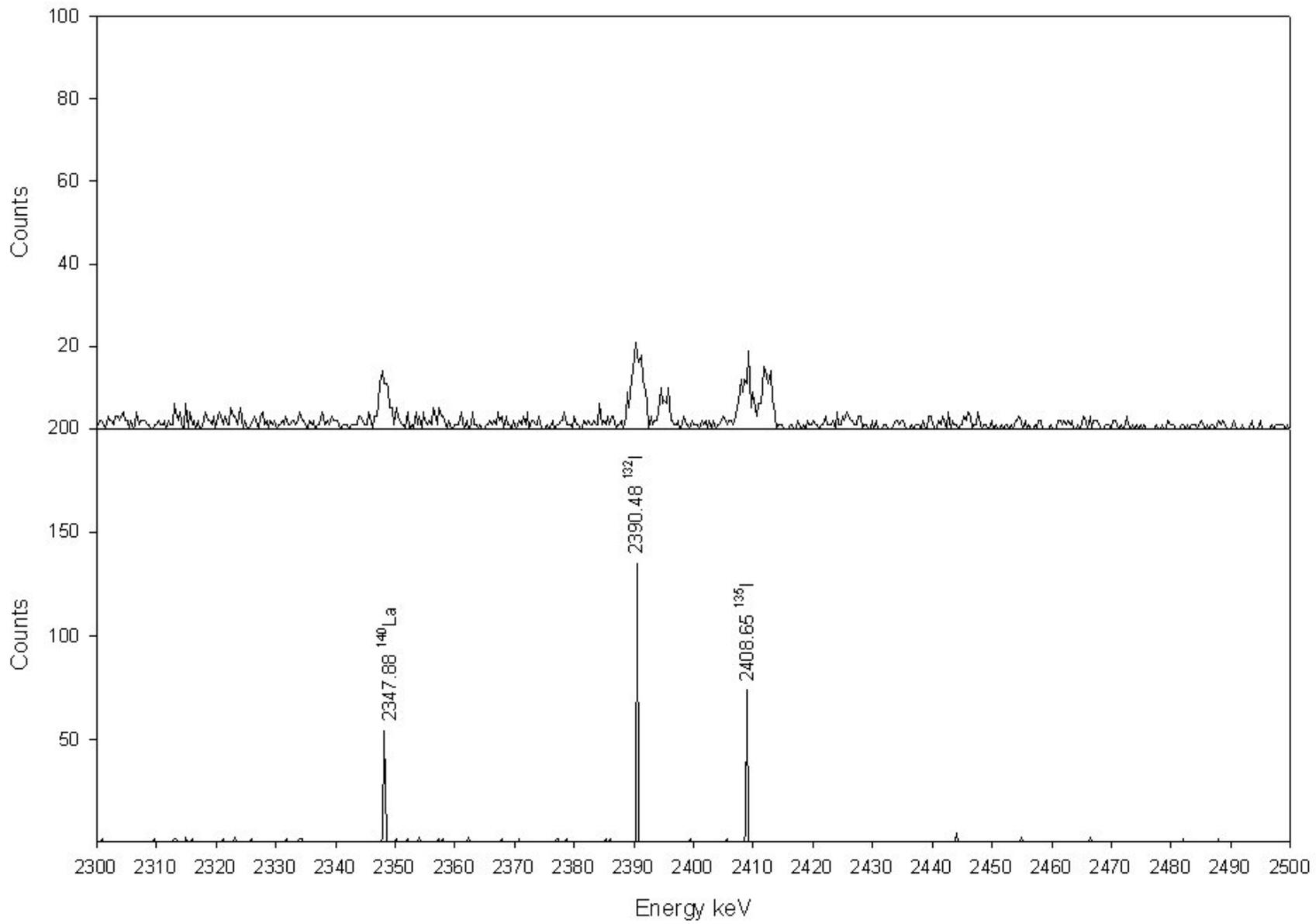












Title	Analysis of remotely accrued complex gamma ray spectra – proficiency test
Author(s)	Mark Dowdall
Affiliation(s)	Norwegian Radiation Protection Authority, Norway
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No. of pages	85
No. of tables	5
No. of illustrations	26
No. of references	22
Abstract	<p>This report presents details pertaining to an exercise conducted as part of the NKS-B programme using synthetic gamma ray spectra to simulate the type of data that may be encountered in the early phase of a nuclear accident. The aim of the exercise was to provide participants with an opportunity to exercise in the type of situation and with the type of data that may result after a nuclear accident. Attempting to conduct such exercise internationally using actual samples presents practical and logistical difficulties and a synthetic spectrum was employed to negate some of these problems. A HPGe spectrum was synthesized containing a range of typical fallout isotopes and distributed, along with calibration information, to the participant laboratories. The participants were required to submit results within three hours of receipt and with the option of submitting further results within one week. The results provided by the laboratories indicate that all laboratories were able to identify and quantify some of the isotopes but only some labs were in a position to identify and quantify virtually all the constituents of the spectrum. Results indicate that there remain some problems with aspects such as true coincidence summation and using file formats with which labs may not be familiar with. The exercise provided a useful opportunity in exploring the possibilities of using synthetic spectra for exercise purposes and offered participants the chance to practice with the sort of scenario that may result after an accident.</p>
Key words	Gamma spectrum, HPGe, coincidence summing, nuclear accident, synthetic spectrum
