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Orphan Sources and Fresh Fallout: Virtual Exercise in Mobile Measurement (ORPEX)

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Abstract

In recent years carborne gamma spectrometry has expanded from its role as a geological survey platform to serving as a useful asset in the field of emergency response to radiological and nuclear situations. Its two main applications are searching for orphan sources and for surveying in the aftermath of an accident involving the release of radioactive materials. Despite this expansion, the opportunities for gaining practical experience in the field are limited by cost considerations and practicability. These limitations are exacerbated by the fact that data generated and displayed in the field differ significantly from gamma spectral data generated in a laboratory environment. As a means of exercising existing emergency measuring/surveying capability and introducing carborne measurements to a larger group, a virtual exercise was devised. The exercise ORPEX (Orphan Sources and Fresh Fallout Virtual Exercise in Mobile Measurement) featured two typical emergency scenarios in which carborne measuring systems might be deployed: firstly a search for multiple orphan sources and secondly surveying to delineate patchy fallout from a local release point. In the first scenario, synthetic spectral data were generated for imaginary point sources and inserted into genuine carborne measurements from in the Trondheim area of Norway. Participants were presented with a typical software tool and data in a range of typical formats and asked to report the source locations and isotopes within a time limit. In the second scenario, synthetic spectral data representing fallout from a local fire involving radioactive material were added to real carborne data from the Trondheim area. Participants were asked to produce maps that identify and characterise the regions of contamination within the same time limit. Fourteen individual organisations from seven different countries supplied results. Results from participants indicate that for strong sources of isotopes with simple spectra featuring high energy peaks, location and identification is not a problem. Problems arise for isotopes with low energy signals or that present a weak signal even when visible for extended periods. Experienced analysts tended to perform better in identification of sources even if they were inexperienced in mobile measurements whereas those with experience in such measurements were more confident in providing more precise estimates of location. The results indicated the need for the inclusion of less frequently encountered sources in field exercise related to mobile measurements.

Key words

Mobile gamma spectrometry, orphan sources, exercise

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1.0 Introduction

Carborne gamma ray spectrometry is used for a number of purposes including the search for lost or orphan radioactive sources or confirmation of their abscence (Ulvsand et al, 2002), geological surveying, and radionuclide fallout mapping (Sandersson et al, 2003; IAEA, 2003). In recent years, carborne systems have begun to be marketed for applications in the areas of nuclear smuggling prevention and emergency preparedness for malevolent acts involving nuclear or radioactive materials. Such measuring systems most often consist of large volume NaI detectors in the range 4 to 16 l, acquiring spectra over intervals of 1 or 2 s. Carborne systems are usually operated over 256 or 512 channels. Usually some level of integration or interaction with a geographic information system exists whereby each spectrum is recorded together with GPS Latitude/Longitude coordinates and various other types of information (dose rate, activities etc.) and viewed in real time. The practical deployment of carborne systems is not without challenges. The short measurement time combined with the low resolution of NaI detectors, present the analyst with significant challenges on two fronts. The first is in relation to the identification of isotopes that may be encountered; a task that is not trivial for anything other than those with strong high energy emissions. Secondly, background and variation of background signals also constitute a challenge for the analyst in that weak signals may be superimposed upon a noisy highly variable background making identification of signals of interest difficult, and interaction of gamma rays with materials can produce significant amounts of scattering. Some systems employ high resolution detectors to improve identification e.g. HPGe or lanthanum halide detectors but these tend to be less common and may be employed in a secondary role to the large volume NaI system. The spectra generated in carborne systems are usually displayed in real time on a cascading ”waterfall” display or variant therof (see Fig. 1) with channel counts being respresented by a colour scale such that a continuous rapid visual assessment of the spectra may be conducted.

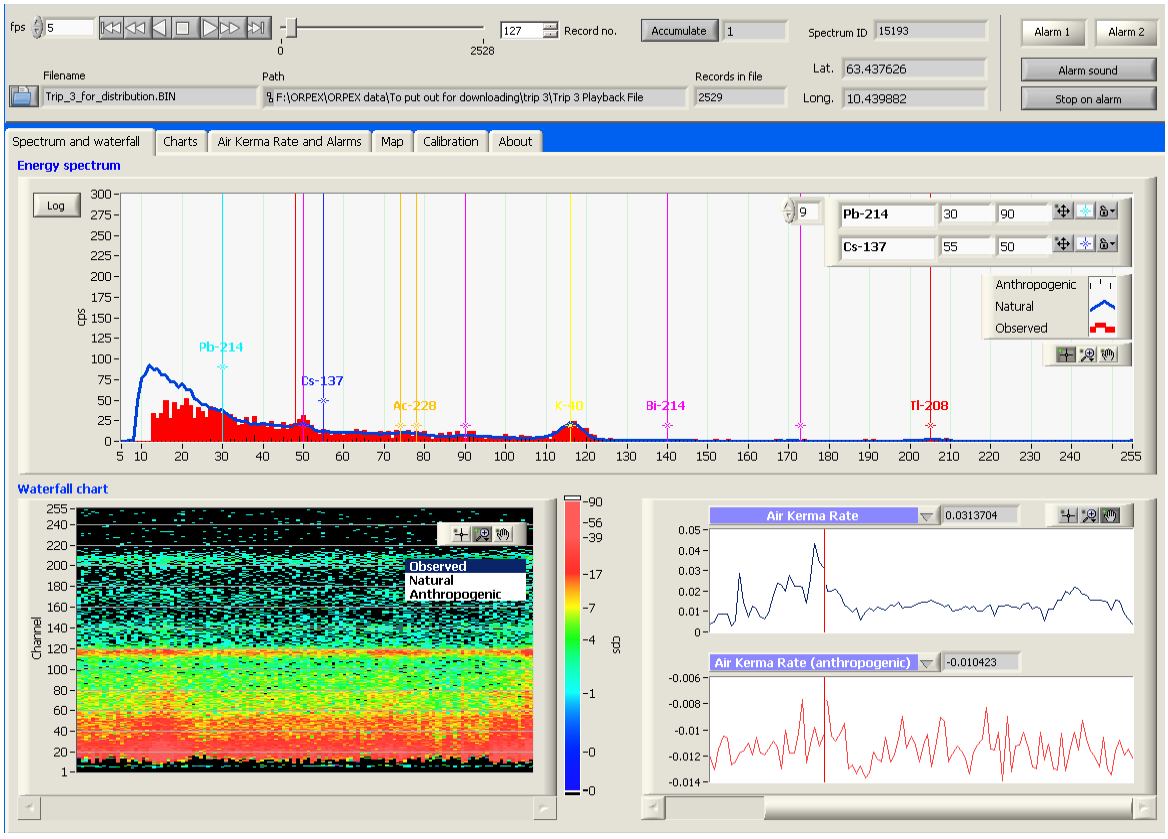


Figure 1. Typical display of the interface for a carborne spectrometry system. Waterfall display is on the lower left of the screen.

Systems usually feature some level of integration or interaction with a geographic information system whereby each spectrum is recorded together with GPS latitude/longitude coordinates and various other types of information (dose rate, activities etc.) and viewed in real time. The practical deployment of carborne systems is not without challenges. Large volume detectors typically found in carborne systems are usually operated over 256 or 512 channels and spectra are accrued over short time periods. Combined with the low resolution of NaI detectors, the analyst is presented with significant challenges on two fronts. The first is in relation to the identification of isotopes that may be encountered; a task that is not trivial for anything other than those with strong high energy emissions. Background and variation of background signals also constitute a challenge for the analyst in that weak signals may be superimposed upon a noisy highly variable background making identification of signals of interest difficult, and interaction of gamma rays with materials can produce significant amounts of scattering.

Although carborne systems are being marketed as solutions tailored to emergency response and security applications, there are limited opportunities available for in the field training. A number of field exercises have been conducted over the past ten years (see Mellander et al, 2002; Smethurst, 2000; Smethurst et al, 2001; Ulvsand et al, 2002) but the organisation of and participation in such exercises is predicated by a number of factors. For the purposes of practicability, the types of radioactive sources that can be deployed during field exercises are limited to the suite of isotopes that are available in the country hosting the exercise. The suite is therefore limited usually to ^{137}Cs, ^{241}Am, ^{60}Co, ^{131}I and perhaps natural isotopes. The environments in which the exercises are conducted tend to be, for the purposes of safety and practicability, military lands or similar and non-urban environments. Participation in such exercises is subject to the significant cost that can be entailed in moving equipment and personnel to the location for a period perhaps of up to a week and for countries distant from the exercise location, cost can be a prohibitive factor to active participation. Individual countries can of course organise internal exercise opportunities but these tend to be even more limited in scope than large scale exercises. Carborne systems are expensive solutions and the investment required to obtain and run such systems are significant. Despite this, the opportunities for an organisation to obtain hands-on experience or to evaluate the appropriateness of this measurement method for their intended purposes before purchase are very limited.

In order to attempt to address the above and other factors, an exercise *Orphan Sources and Fresh Fallout Virtual Exercise in Mobile Measurement* (ORPEX) was developed for carborne gamma spectrometry under the auspices of the Nordic Nuclear Safety Research organisation (NKS). The intention of this exercise was to provide participants with an opportunity and materials to practice with, or gain an introduction to, the type of data typically generated by such systems for isotopes that may realistically be encountered in an emergency situation in a typical urban environment. To achieve this, signals from hypothetical sources were simulated, existing analysis and display software was adapted for use by participants with all levels of experience, and the exercise materials were distributed electronically to keep costs to a minimum.

2.0 Description of the Exercise

Three data sets were developed for the exercise and were denoted Trip 1, Trip 2 and Trip 3. The data was a combination of real carborne measurements and synthetic data for sources that would be difficult to obtain in real life. The original background carborne data were acquired in year 2000 by Mark Smethurst and Les Beard using the Geological Survey of Norway's emergency measuring system GAMMALOG (Smethurst 2000, Smethurst et al, 2005). The full data set extends from Åre in Sweden to Trondheim in Norway. Data were acquired at 1 second interval using a 16 l NaI detector and a 256 channel spectrometer. Two segments of the full data sets were extracted for use in the current exercise. The first, used in Trip 1, was a ten minute recording (600 measurements) on the E14 starting at Åre and heading towards Trondheim. The second, used in Trips 2 and 3 was a forty minute recording taken in and around the largely urban environment of Trondheim. The original data were checked for any obvious problems or anomalies prior to artificial data being superimposed. It should be noted, however, that the measuring system was not fully warmed up upon leaving Åre and the natural photo-peaks in the spectra at the start of Trip 1 could be seen to migrate slowly into their correct energy positions as the automatic energy stabilisation of the measuring system took full effect. Also, there were distinct traces of ^{137}Cs in the original carborne measurements from Chernobyl fallout and possibly the former atmospheric testing of nuclear weapons.

Trip 1 was a short test data set including two easily identifiable anthropogenic sources (^{137}Cs and ^{60}Co) positioned out of range of each other along a straight road. The materials relating to Trip 1 were made available to the exercise participants two weeks before the formal start of the exercise so that participants could familiarise themselves with the data formats and software. The second trip, Trip 2, simulated a typical search for orphan sources in an urban environment. Ten different sources were simulated and placed along and beside a complex driving route (see Fig. 2) so that they would present different challenges to the participants. Some of the signals were weak, unusual source isoptopes were included in the data, and sources were placed close together or where they would be detected multiple times from different parts of the complex driving route. The underlying real carborne measurements included a varying background signal and typical town-driving pattern including driving in both directions on some roads.

The first source in Trip 2 was a strong ^{131}I source that was clearly visible on most of the data visualisations in the software provided. The second and third sources were placed in close succession: an ^{192}Ir source quickly followed by an industrial radiography ^{75}Se source. The sources were clearly visible but signals from them overlapped in the intervening stretch of road. The spectra for the two sources are similar when viewed using a low energy resolution measuring system so the potential was present for missing the second source (^{75}Se). The fourth source was a weak ^{67}Ga medical source placed in an open area. The signal from this source, being primarily low energy peaks and weak, was relatively difficult to detect against the varying natural background signal. The fifth source was a tightly collimated, strong ^{137}Cs source. This was visible at two locations in the route, one of which was passed twice. The intention was to check whether an appropriate link was made between the sequential spectral records and geographic locations. Source 6 was an ^{169}Yb industrial radiography source positioned such that, although the signal was weak and presented a difficult spectrum for identification, the signal was visible during an extended period when the vehicle was stopped in traffic. The opportunity was therefore present to sum spectra to obtain a better picture of the source. Source 7 consisted of a tightly collimated ^{60}Co source visible from two points in the route, widely separated in time. Source 8 simulated a large mass of 20 year old depleted uranium - also observed twice in the route. The two observations of this source were

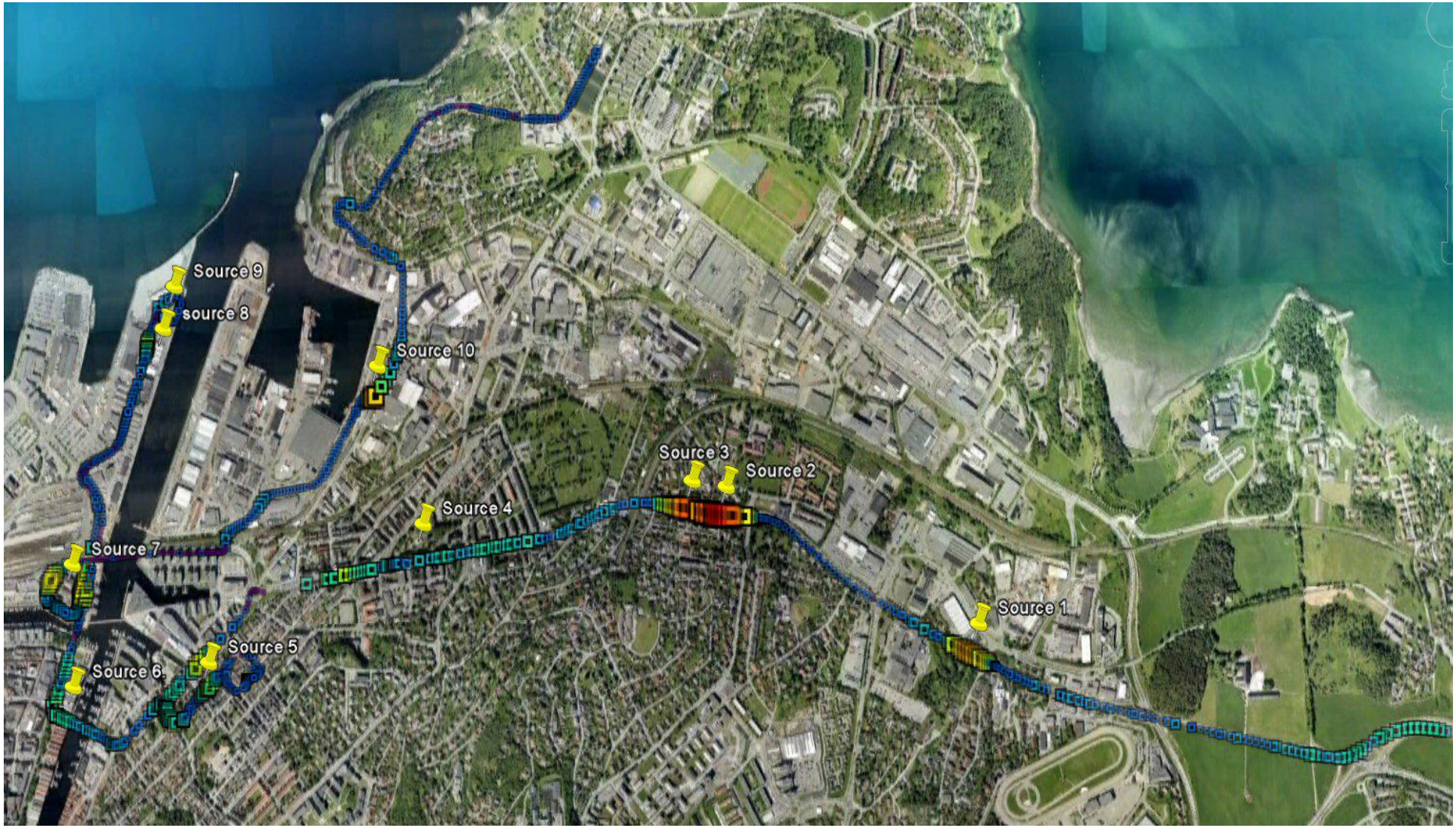


Figure 2. Route and positioning of sources for Trip 2.

separated by a weak ^{133}Ba souce, Source 9, which was visible only for a short period. The final source for Trip 2 was a strong ^{90}Sr thermoelectric generator presenting strong and highly visible Bremmstrahlung.

The third trip, Trip 3, utilised the same real carborne data as Trip 2 but in this case a fire resulting in the release of nuclear waste was simulated. The location of the fire was given to the participants at the start of the exercise.The participants were asked to map out possible contamination levels in the city landscape as a result of the fire. Two contamination plumes were simulated, originating at the point of the fire. One plume was larger and more significant than the second and spread in a different direction. The plumes were divided into zones based on relative levels of contamination present. Participants had 8 days to report the locations and identities of the sources in Trip 2 and the shapes and characteristics of the plumes of contamination in Trip 3.

2.1 Data Generation

Data for the sources in Trips 1 and 2 were generated in a number of different ways. Actual measurements of strong sources of ^{137}Cs and ^{60}Co were available for the actual measuring system (Smethurst et al. 2001, Ulvsand et al. 2001) against which simulated signals could be compared. Synthetic spectral data was generated using the codes described by Hensley et al (2005) and Plenteda (2002), via manual modification of real spectra or by the addition of actual and synthetic spectra. The ^{90}Sr source employed was a rebinned actual spectrum accrued with the kind assistance of David Mercer and Benjamin Sapp of the Los Alamos National Laboratory, United States. For each source, activities employed in the simulations were based on typical industrial/medical sources in common use, amounts of material that have been involved in previous incidents or estimates of amounts that could be considered reasonable within the context of the presented scenario. Information as to nuclear data (energies, probabilities etc) were retrieved from the online Table of Isotopes hosted on the website at Swedens Lund University (http://nucleardata.nuclear.lu.se/nucleardata/toi). Calculations of ingrowth and decay were based upon the US DOE's Radiological Toolbox (Eckerman and Sjoreen, 2006). Spectral conversions were conducted using either home made routines or SPECON 2000 (Hong, 2001).The distances of the carborne measurement points from each introduced source were determined and used in the simulations. The measurement "lag" usually associated with mobile measurement systems was not simulated. Shielding of sources, for example by the wall of a house, was simulated by introducing a realistic amount of appropriate material in the modelling. Environmental scattering was mimicked using extracts from genuine spectra. For sources such as depleted uranium, the appropriate level of daughter buildup was included. Statistical noise was added to all simulated spectra. The effects of coincidence summation were not included in the simulation because they are small/insignificant in the types of measurement being simulated. The original carborne measurements were not changed in any way.

2.2 The Playback Software

The software, by Robin Watson and Mark Smethurst, called GAMMALOG Playback (Watson and Smethurst, 2011), is based loosely on the Geological Survey of Norway's GAMMALOG emergency measuring system of Smethurst et al (2005) and provides the usual visualisations of incoming spectral data including spectrum plots, waterfall (or rainbow) plots and charts of data derivatives like estimated air kerma rate. Navigational data are in view at all times, and a primitive map visualisation is available. The software allows the user sequential and random access to the track data including play-forwards, play-backwards and rate-of-play controls. On startup the software reads calibration data appropriate to the detector

system used for data collection, and constructs a model geological/natural spectrum for each measured spectrum in a data set. It does this through the real-time application of traditional window stripping as described by Smethurst et al (2005). It then subtracts the presumed natural spectrum from the observed one to obtain a candidate for a spectrum for the anthropogenic nuclides present in the measured spectrum. The three forms of spectrum - observed, anthropogenic, and presumed natural - are visible simultaneously in real time; the waterfall display is user-configurable to display one of observed, anthropogenic, or presumed natural spectra.

The attempt to separate the natural and anthropogenic components of the measured spectra is useful when searching for contamination in the environment that might be camouflaged by a strong and varying natural signal. The window stripping for determination of the natural signal breaks down severely in the presence of signals which interfere with any of the three energy windows used for characterising the natural signal. One of the photopeaks of ^{60}Co, for example, impinges on the ^{40}K window, resulting in an overestimate of the natural background signal whenever significant amounts of ^{60}Co are present. However, even when this occurs, the software makes it clear that contamination is present.GAMMALOG Playback allows the user to accumulate an average spectrum over a specified series of 1 s data records. This can be used to improve the signal-noise ratio in the data, helping to better define low amplitude photo-peaks that persist across multiple records. GAMMALOG Playback can be configured to automatically stop playing a data set when one of two user-controlled alarm conditions is met: when the presumed natural total count rate deviates significantly from the observed total count rate, and when the energy weighted total count rate exceeds a critical value.

All co-ordinates were given in the geodetic co-ordinate system according to datum WGS-1984, as originally used by the Geological Survey of Norway in acquiring the carborne data set. In open terrain the GPS data are accurate to within a few metres, while in urban areas erroneous jumps can be detected in the navigational data due to the temporary concealment of satellites by taller buildings. Occasionally the navigation fell out completely in which case the last known latitude/longitude co-ordinates were repeated until a new fix was obtained, giving the illusion that the measuring system was standing still. These navigation issues are typical of real data and give the current exercise data a real feel. The carborne measurements were acquired following a normal driving pattern and are strongly influenced by the road conditions and topography.

2.3 Materials Provided.

Data were distributed to the participants in such a way that any participant had a reasonable chance of working with the data irrespective of the software resources available to them. Since many participants may not have access to commercial software, and because commercial softwares operate with a variety of proprietary data formats, data was delivered together with a customised software package that provides most of the typical functionality of a proprietary system in a small footprint, easy to operate package, “Playback”.

Each Trip was delivered in the form of a binary data file for use with the Playback software as provided. This data file contained spectral information, a unique spectrum identifier for each spectrum, geographical information and a number of other parameters based on the raw spectral data. This file was only playable in the software provided. Each Trip was also delivered in the form of a single standard tab-delimited spreadsheet including the unique identifier, geographical coordinates and the channel by channel raw spectral data. In addition,

individual 1 s spectra were provided individually in a number of a different standard formats each labelled with the unique spectrum identifier. These formats included Canberras .cnf format, Ortecs .chn format, channel-tab-counts text files and the IAEAs .spec format. For participants who could not or did not want to install the provided Playback software, a video was provided for each trip portraying the data being played through the Playback software. Each Trip was also provided in the form of a Google .kml file that could be opened in software of the participants' choice. The kml file contained positional information, the unique spectrum identifier and ancilliary information based on the spectral data. Measuring points were coloured according to a crude estimate of air kerma rate based on energy weighted total gamma count rate.

2.4 Energy Calibration.

Spectral data presented throughout the exercise was based upon channels as opposed to energy – necessitating participants conducting an energy calibration prior to engaging in analysis of the materials. To facilitate this, a spectrum was provided of ^{134}Cs and ^{60}Co such that a basic energy-channel graph could be constructed. The actual energy – channel relationship used in the synthesis of the spectra was a zero of -70 and a gain of 13.19986 such that:

$$\text{Energy (kev)} = -70 + 13.19986*\text{Ch}$$

Using this relationship, ^{40}K had a peak at channel 116 and ^{137}Cs had a peak at channel 55.5. To test that the energy calibration spectrum provided could replicate this, the spectrum was used to calibrate an off-the-shelf installation of a commercial software and produced a relationship of:

$$\text{Energy (keV)} = -75.68 + 13.121*\text{Ch}$$

yielding useable results (channel 56 for 661 keV).

2.5 Data Transmission

Data was transmitted to participants in the following formats, as discussed previously, for all three trips:

1. The Playback file
2. The trip as a Google Earth file
3. The individual spectra for all points of the relevant trip in Canberra .cnf format, Ortec .chn format, IAEA format and as channel tab counts text files.
4. The entire trip as a spreadsheet with spectral identifier, gps coordinates and channel counts.
5. A video file of the trip being played on the Playback software for those who didnt want to install the Playback software.

Two weeks before the actual exercise the energy calibration data, the Playback installer and the relevant data for the practice Trip 1 was distributed. Two weeks later the data for Trips 2 and 3 were distributed. Participants had 8 days in which to report. Data was transmitted by email or via provision by email of links to a server where the material could be downloaded.

3.0 Detailed Description of Routes and Sources.

3.1 Trip 1

Trip 1 consisted of a short distance on a straight road along which two easily identifiable and clearly visible sources (^{137}Cs and ^{60}Co) had been placed (see Fig. 3). The route for Trip 1 had a relatively steady background signal with no confounding factors against a successful location and identification of the sources. The sources themselves were of sufficient strength to facilitate identification. The first source of Trip 1, a ^{137}Cs source, was located at 63.405652°, 13.053439° in a small building. The nearest point to the source was 1020. The second source (^{60}Co) was located at 63.403647°, 13.019515° in a small car to the south of point 1097. Both sources were clearly visible using Spectral Dose Index values and the spectra of both sources were sufficiently clear to allow easy identification (see Fig. 4).

Figure 3. Locations of Sources 1 and 2 for Trip 1.

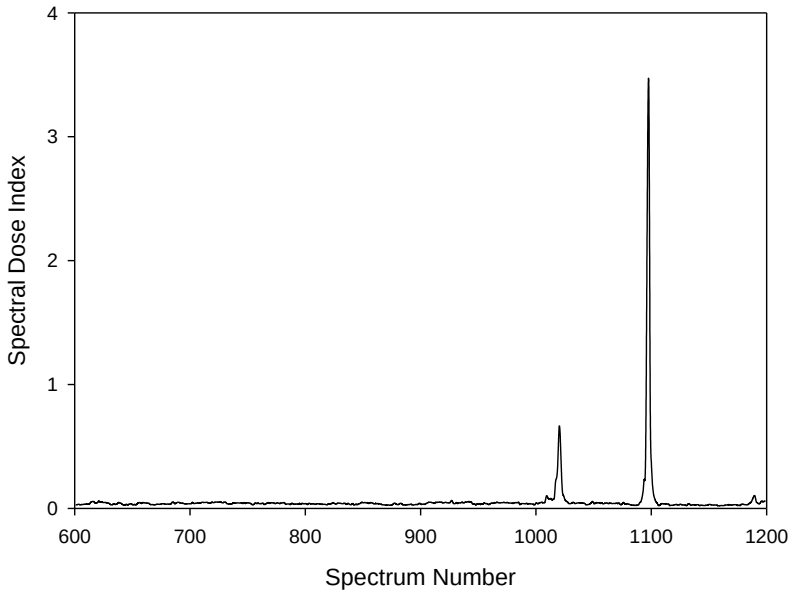


Figure 4. Spectral Dose Index over the whole of Trip 1 with both sources clearly visible.

3.2 Trip 2

Trip 2 was a longer route through a mainly built up area. Along this route were placed a number of point sources in various configurations which the participants were asked to locate and identify. Background was more variable than that for Trip 1 (see Fig. 5).

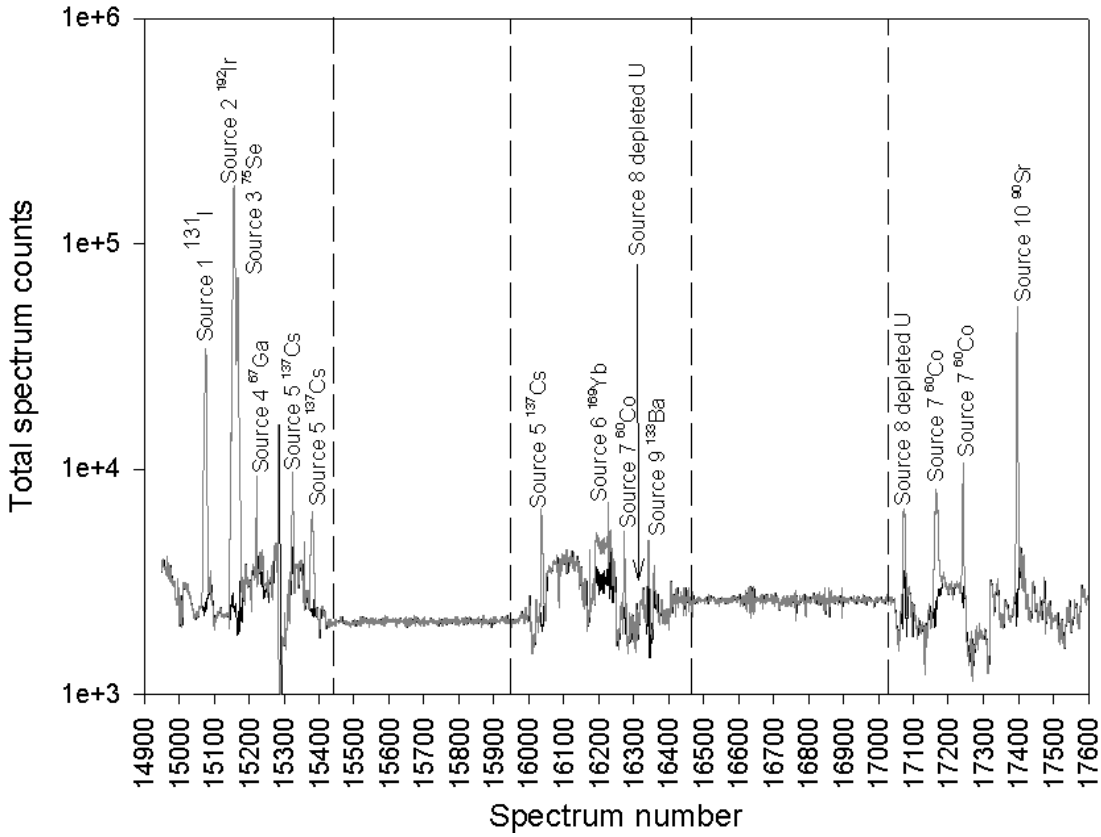


Figure 5. Variation in spectral information along Trip with and without added sources.

Along the route a number of factors may have posed challanges albeit typical of those encountered when making measurmeents of this type. The vehicle paused a number of times at traffic lights and for a longer period at one point in the journey. Data was missing for a short period at one stage in the journey. To the extent that was possible, these features were included in the exercise as it is possible that a vehicle may stop to obtain a more information upon locating a suspicious signal and in addition it allowed the participants to obtain more data for difficult sources such that they could employ various techniques in their analysis. An unexpected occurrence was the identification by a number of participants of sources that had not been inserted artificially. The majority of these were ^{137}Cs and appeared to arise due to the presence of Chernobyl or other fallout at various stages of the journey. This is discussed in full in the relevant section of this report.

3.2.1 Trip 2: Source 1.

The first source of Trip 2 was an ^{131}I source positioned at 63.434060°, 10.462924° in a car park between two buildings (Fig. 6) being representative of a typical medical source. The nearest point was probably 15076 or 15077. The source should have presented no difficulties in location or identification occurring as it did in an area of relatively stable background. The source was clearly visible on the waterfall plot of the playback software and on the charts of

various parameters any of which should have served to indicate the presence of a source (see Fig.'s 7,8 and 9).

Figure 6. Location of the first source of Trip 2.

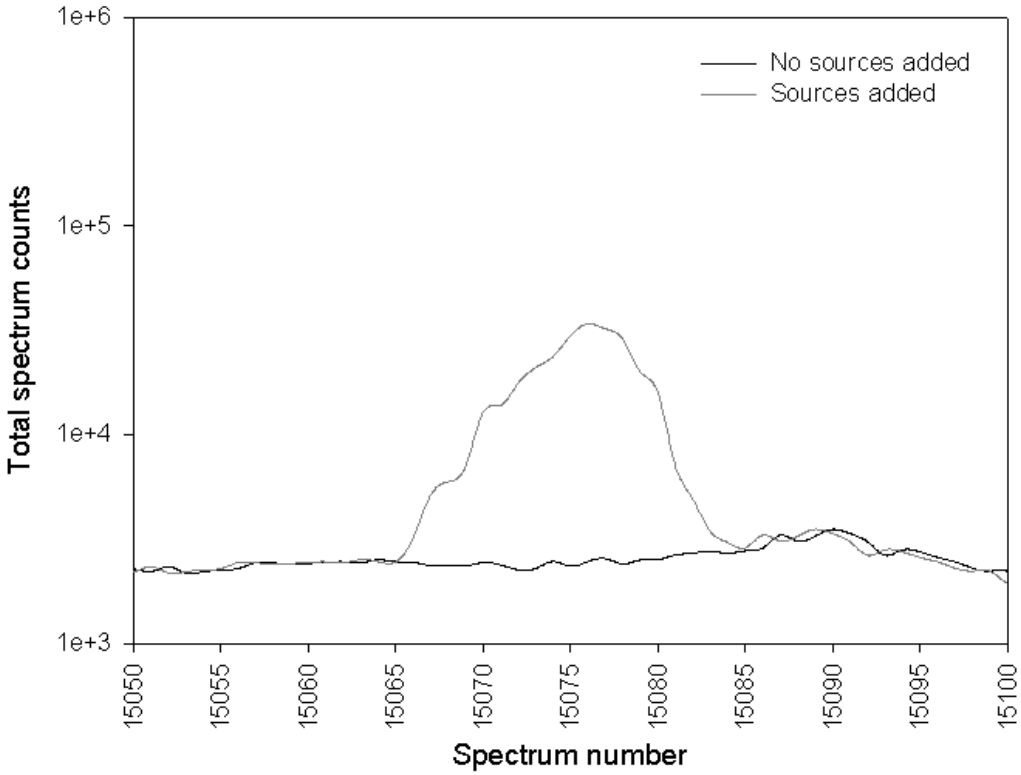


Figure 7. Total spectrum counts over the part of Trip 2 for which Source 1 was visible.

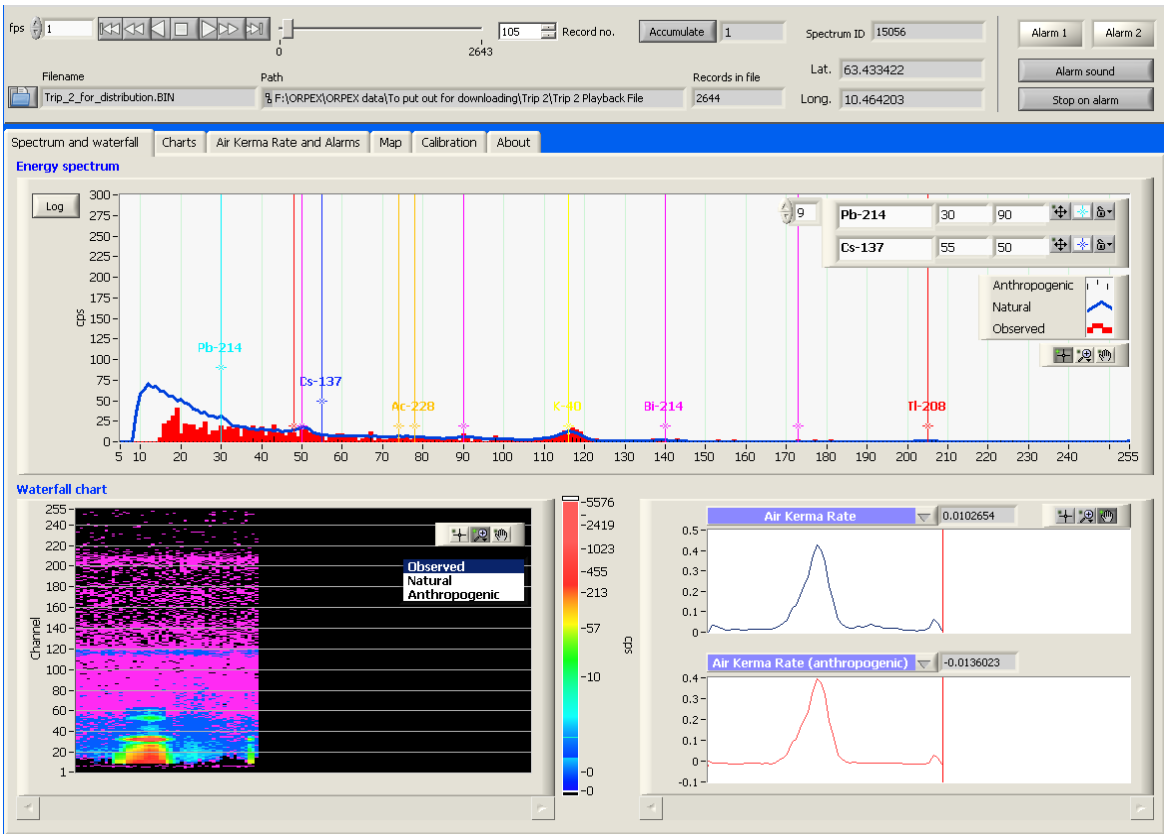


Figure 8. Playback screenshot for Trip 2 Source 1.

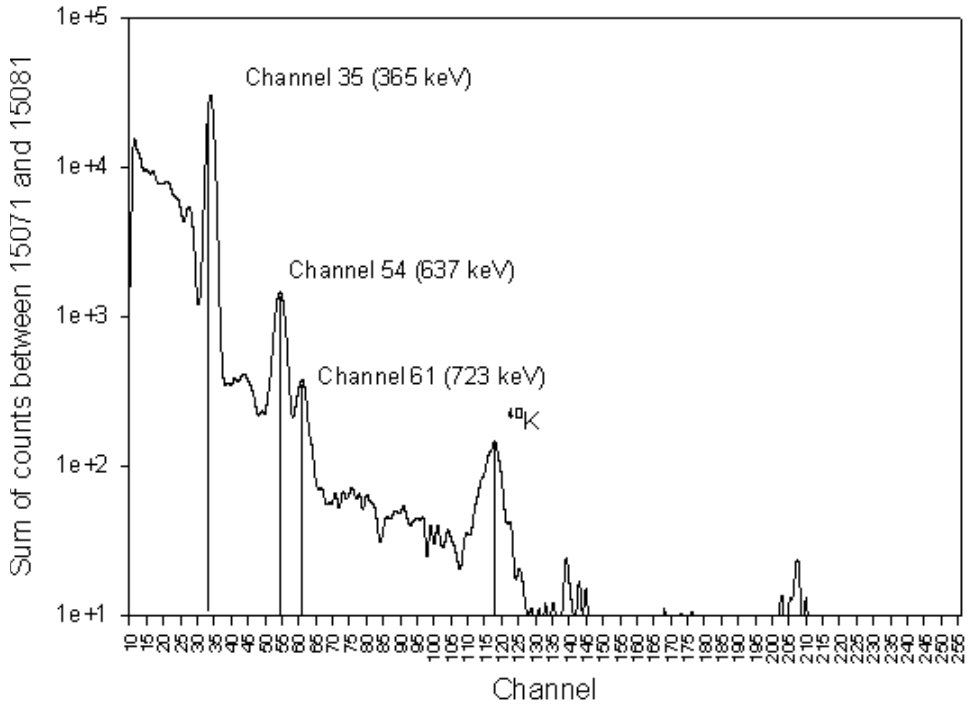


Figure 9. Combined spectra between 15071 and 15081 for Trip 2 Source 1.

3.2.2 Trip 2:Sources 2 and 3.

Sources 2 (63.437701°, 10.447270°) and 3 (63.437877°, 10.445133°) were located quite close to each other along the same stretch of road (Fig. 10). The isotopes were ^{192}Ir and ^{75}Se respectively, typical industrial sources. The objective with these two isotopes and their positioning was to present a situation where disntinguishing them from each other and identifying them correctly could pose difficulty. The sources were ”visible” between points 15146 and 15185 with the signals actually overlapping to greater or lesser extent between 15153 and 15172. On a low resolution spectrometer the two isotopes present a reasonably similar spectrum. The waterfall spectrum at first glance did not appear to differentiate between them but if automatic scaling of the plot had been chosen and the user replayed the trace a number of times, then a clear shift of the peak at approximately channel 40 to a lower channel could be observed. Combining this with the double hump nature of the kerma rate plots should have provided a solid indication of the presence of two different sources in close proximity to each other. Identification of the sources was theoretically relatively simple given that both isotopes present a series of well separated peaks at high enough energies to avoid the complexities of the low energy region. Se-75 has at least 3 peaks which should allow assignation of the isotope with ^{192}Ir having three peaks which should have been easy to assign (see Fig.’s 11, 12 and 13).

Figure 10. Sources 2 and 3 of Trip 2.

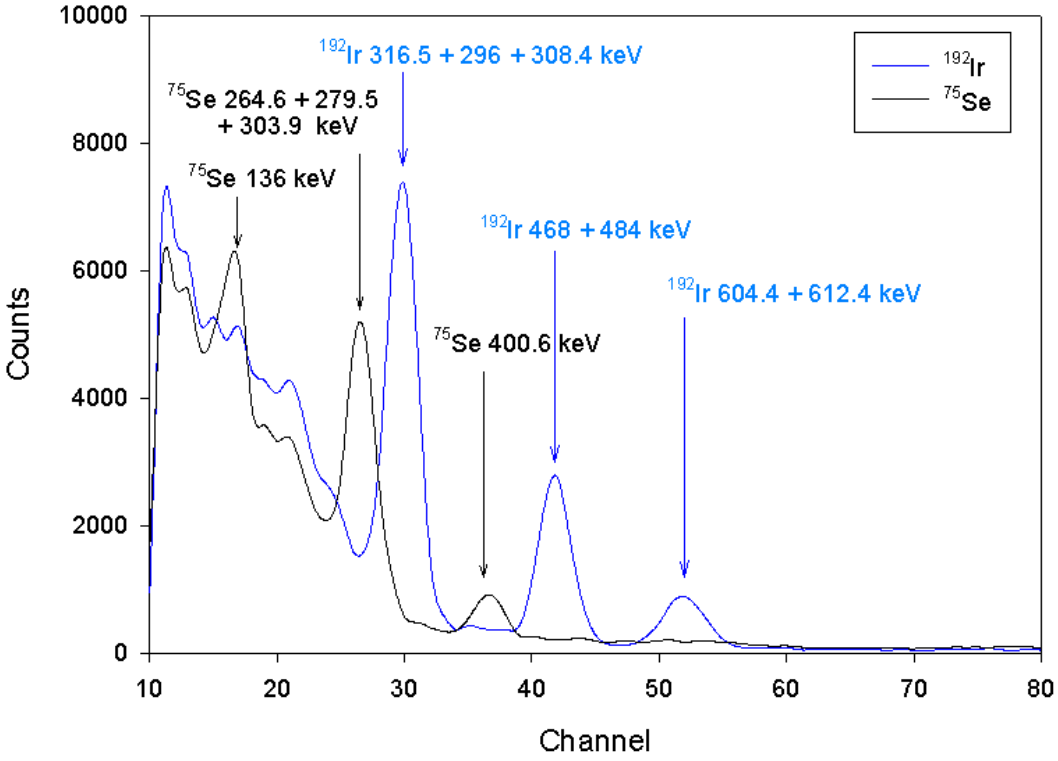


Figure 11. Comparison of summed spectra between 15146 to 15143 (solely ^{192}Ir) and 15172 to 15183 (solely ^{75}Se) showing similarities and differences.

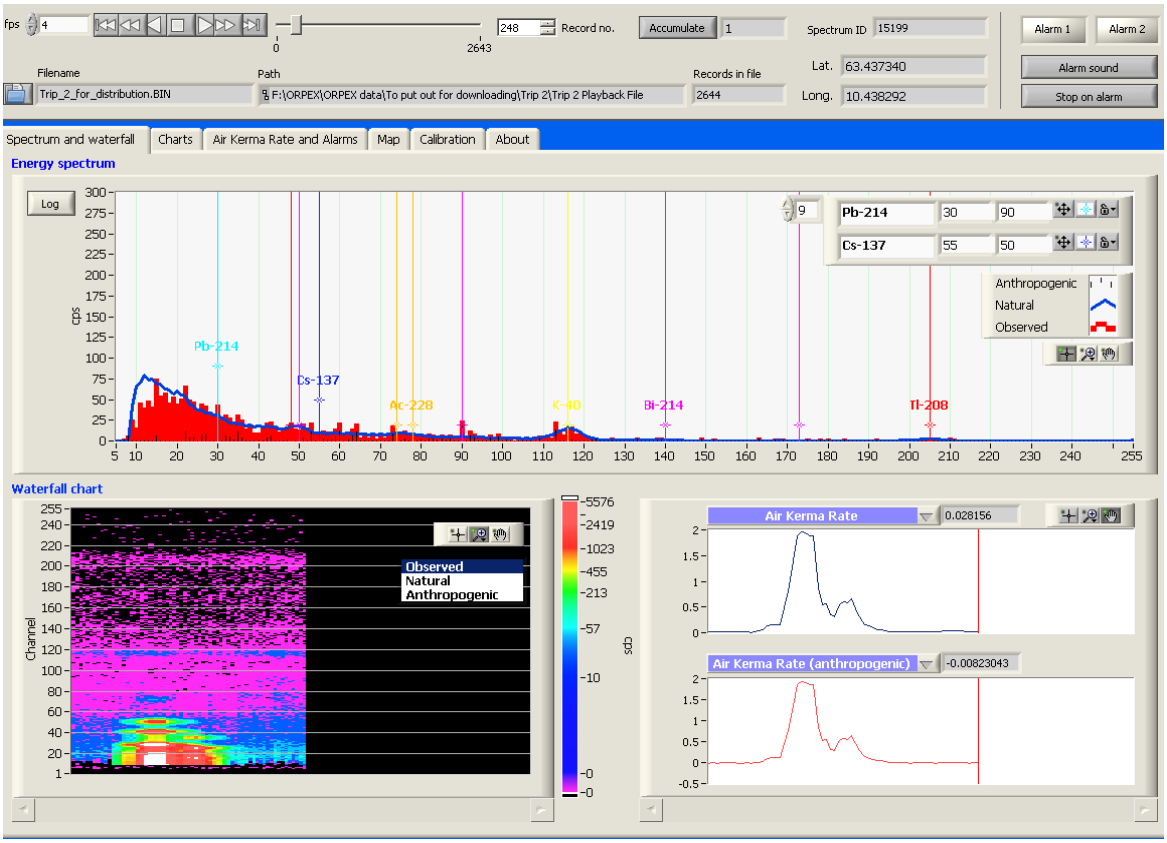


Figure 12. Sources 2 and 3 of Trip 2 as seen on the playback software. No automatic scaling of the tarce.

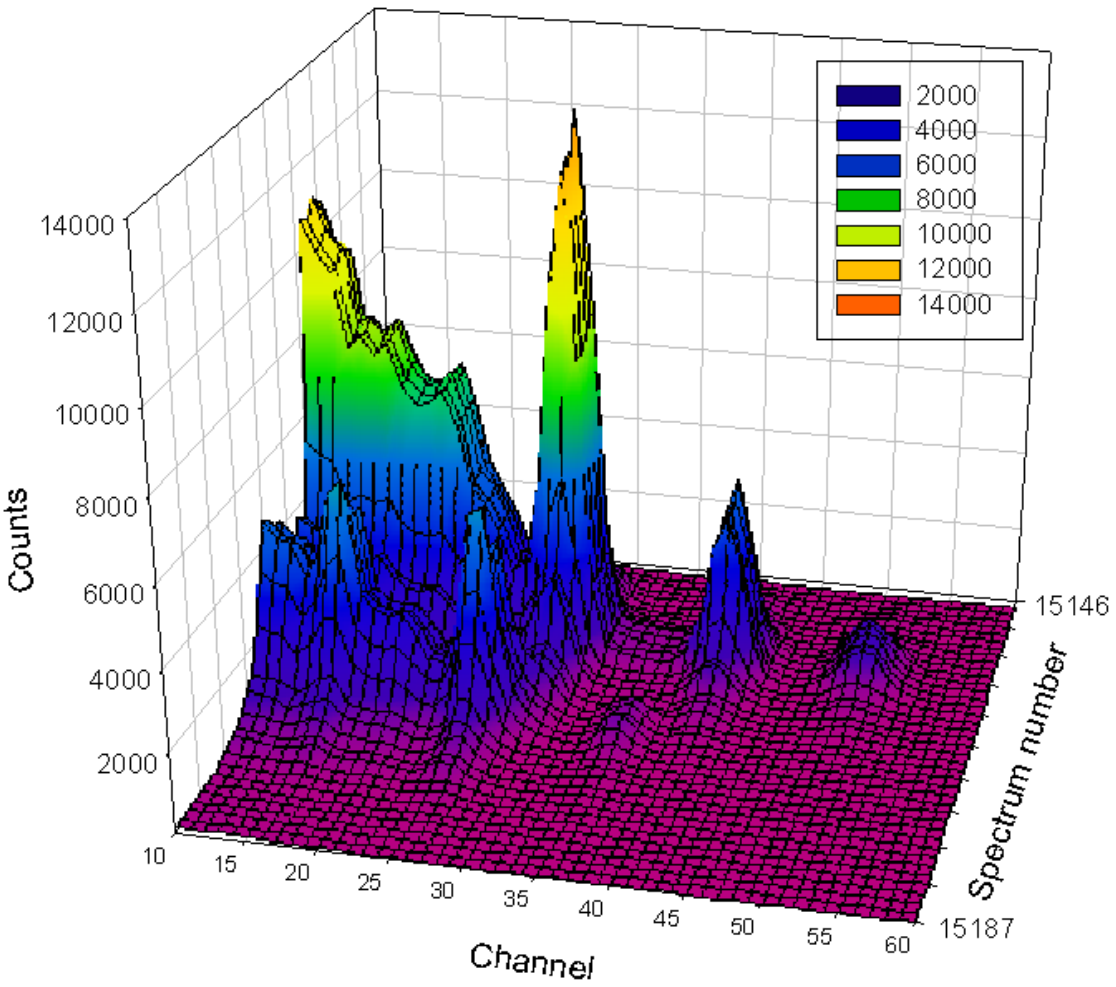


Figure 13. Graphical representation of the transition between Source 3 (^{192}Ir) and Source 4 (^{75}Se).

3.2.3 Trip 2: Source 4.

Source 4 was ^{67}Ga and was located at 63.437049°, 10.427947° (Fig. 14). This source presented a relatively weak signal and, for the spectrometer employed, difficult spectrum although it was weakly visible for a relatively long period of time. Ga-67 has a number of strong peaks all occurring in the region where natural gamma lines are also strong (between 100 and around 300 keV). This fact combined with a weak source complicated the matter for the participants. The source was most visible near to 15239 -15241 and for these points some peaks were visible. The source produced no real observable traces with respect to total spectrum counts or in kerma rate. The chances of observing Source 4 on the the waterfall plot were low but possible. The possible solution was observing the waterfall plot due to anthropogenic sources as opposed to the total observed plot (see Fig. 15). Using just the anthropogenic plot (the difference between the observed spectrum and what may be expected to be a natural spectrum based on modelled information) the source was actually visible. Observant users would also have noticed a rapid but marked change in the spectrum as the points near 15239 were passed. While these changes were not enough to elevate various parameters to a significant level above the fluctutaions produced by background, the change in the spectrum should theoretically have been enough to initiate further analysis. Whether or not Source 4 was actually identifiable is another matter. Careful examination of the spectra and waterfall plot would have indicated that the source was visible primarily between 15232 and 15246 (see Fig. 17). The best solution would have been to correct the individual spectra for background over this interval and then sum them to try and get a better picture of the source. For this purpose the 10 spectra before 15232 were assumed to be background and an average was taken (Fig. 16). The extent to which such an analysis would facilitate identifying the source as ^{67}Ga is unknown and obviously depends strongly on the nature of the energy calibration performed, etc etc.

Figure 14. Location of Source 4 for Trip 2.

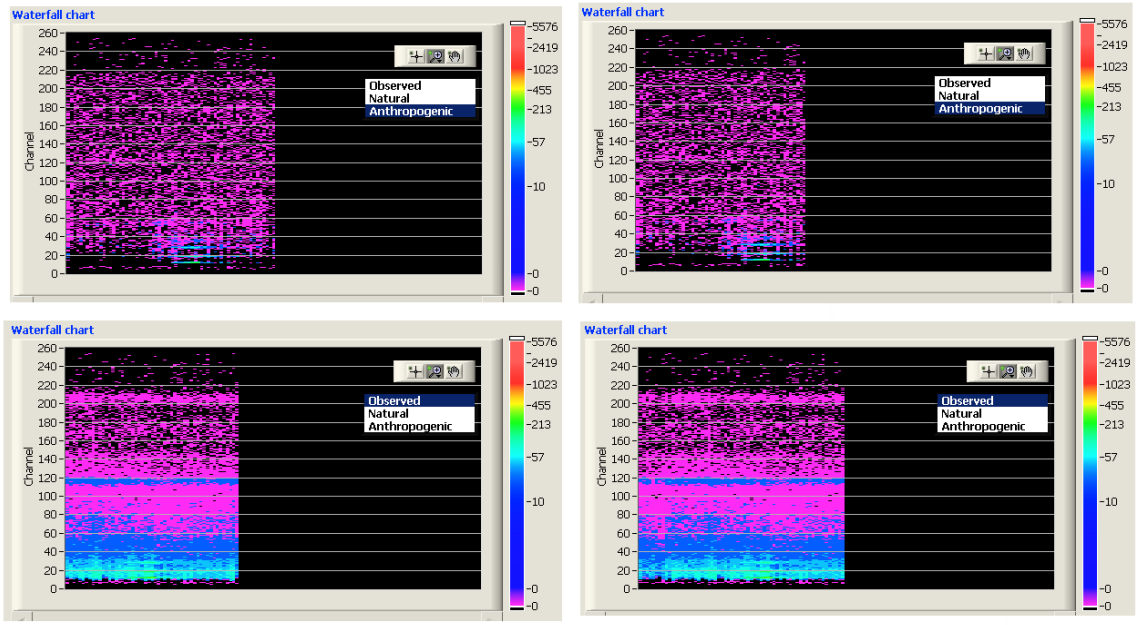


Figure 15. Source 4 as observed on the waterfall plot for (clockwise from top left) – anthropogenic, no automatic scaling; anthropogenic, authomatic scaling; observed, automatic scaling; observed, no automatic scaling. Plots are for approximately 100 spectra after 15200.

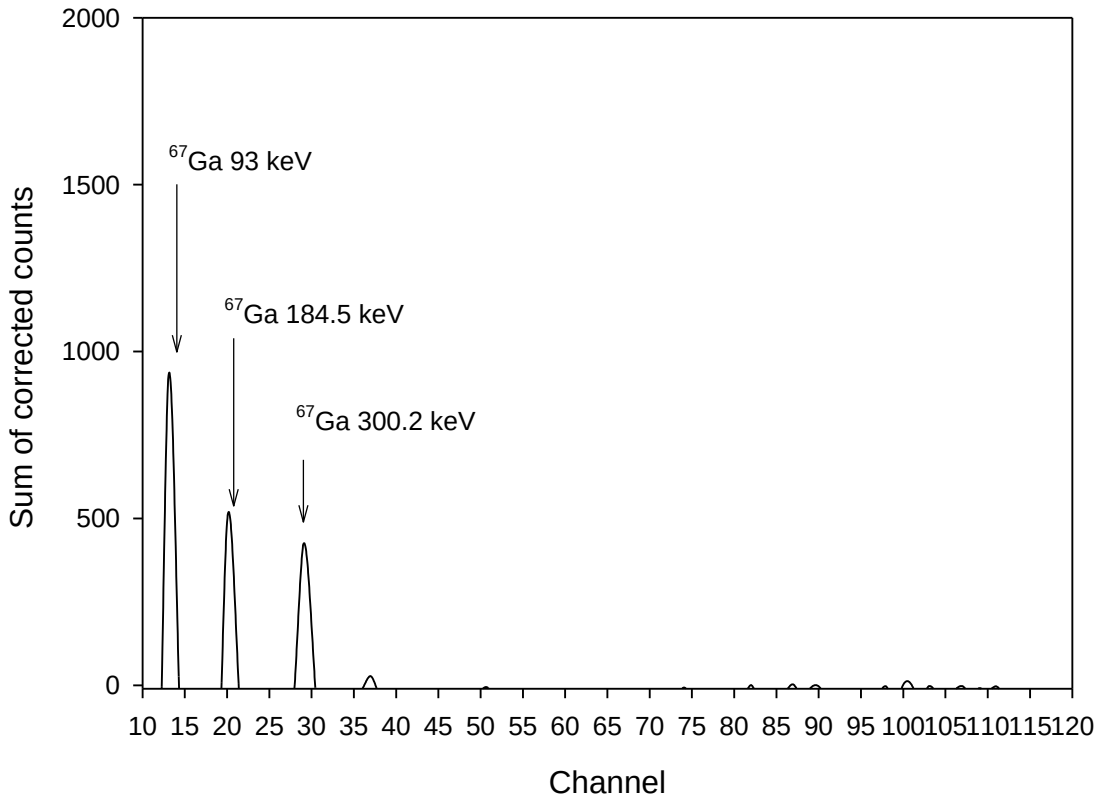


Figure 16. Sum of background corrected counts for spectra between 15232 and 15246 for Source 4.

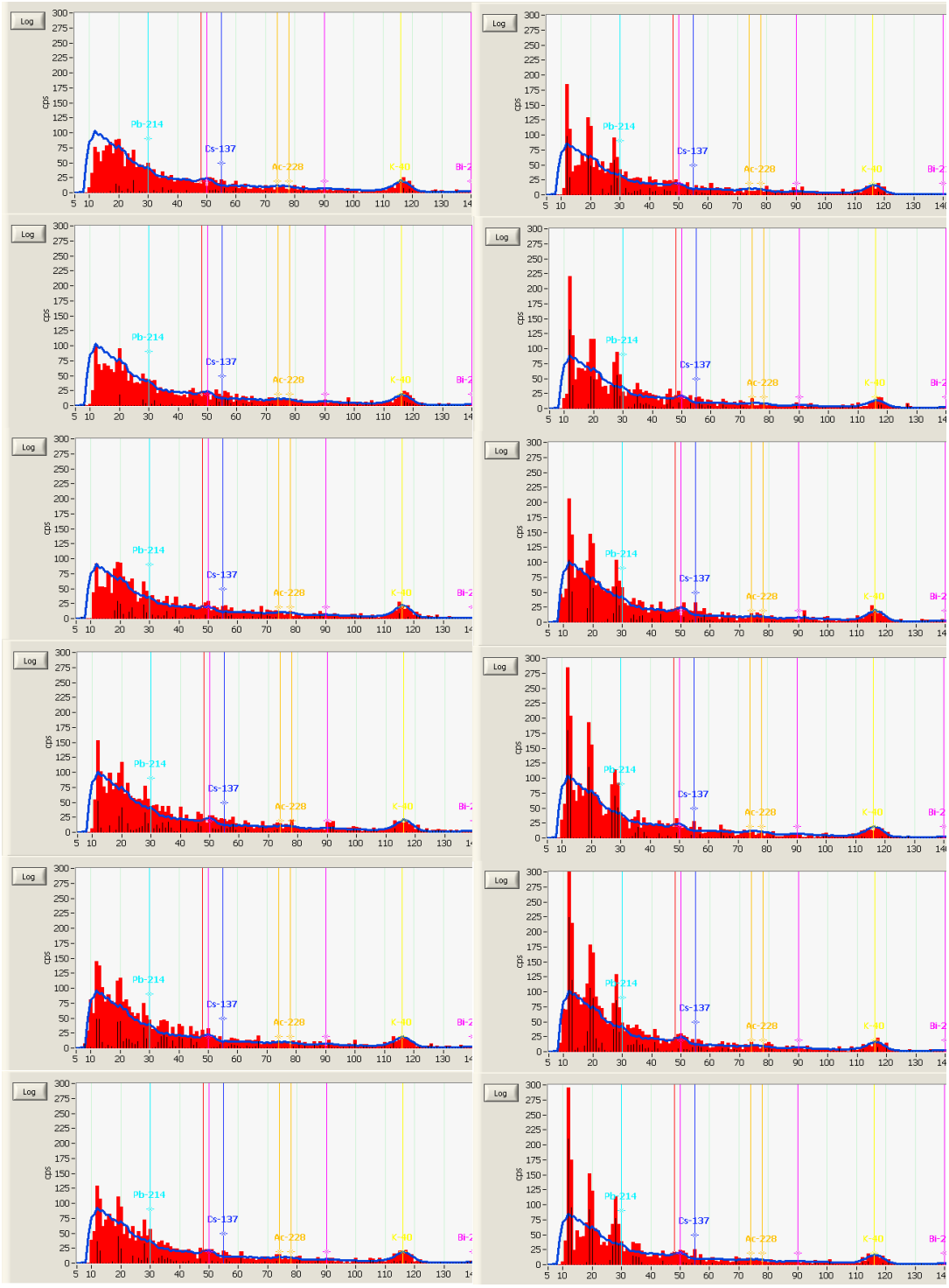


Figure 17. Changes in the gamma spectrum on approaching Source 4. Top left is 15230, bottom right is 15241.

3.2.4 Trip 2: Source 5

The source in this instance was a ^{137}Cs source (63.433793°, 10.413781°, see Fig. 18) which was collimated in a north south direction so was thereby only visible for 3 short periods as the vehicle drove around the source on two different roads. The source should have been visible as the vehicle passed between 15320-15329, 15374-15387 and 16032 – 16044 as the vehicle makes a loop along the road. The source was distinctly visible and easily identifiable, the hope was the users would be able to recognise the source for being one ^{137}Cs source as opposed to more.

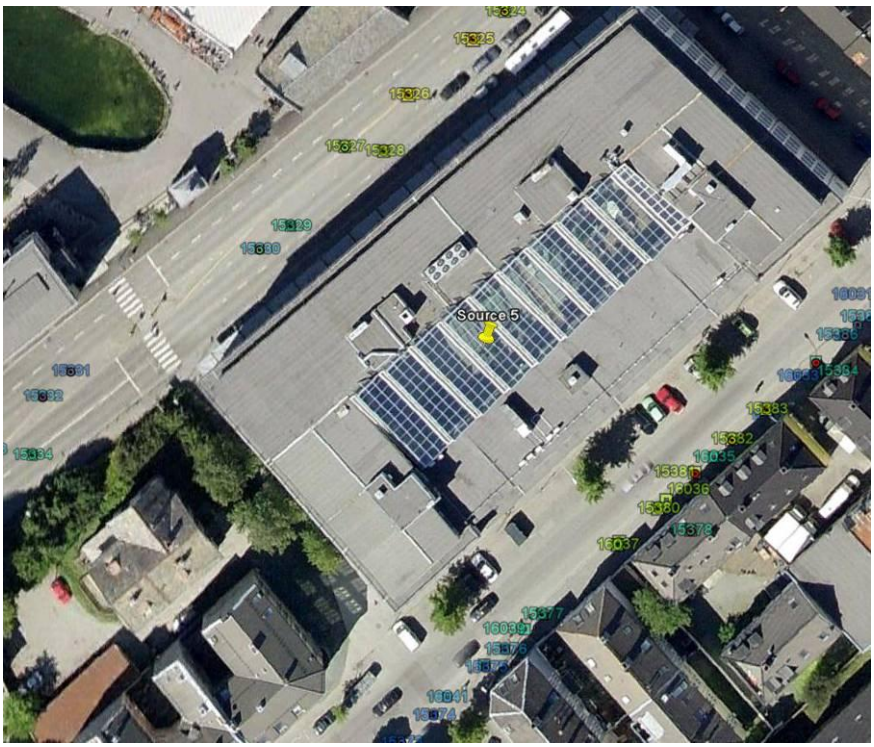


Figure 18. Location of Source 5 for Trip 2.

3.2.5 Trip 2: Source 6.

Source 6 was a ^{169}Yb source placed in a building on the corner near 16232 at 63.433242°, 10.404955° (see Fig. 19). It had 15 cm of shielding concrete. The source was relatively weak but the vehicle actually stops near it at traffic lights so it was possible to accumulate a spectrum for identification. The period over which the source was visible should have been between 16190 and 16245. On the waterfall plot (see Fig. 20) the source is clearly visible but undefined, appearing only as a low energy signal nor would the individual spectra as displayed be sufficient to allow identification.Yb-169 is not a simple nuclide to identify using NaI spectrometry as the majority of its emissions are in the sub-300 keV region (see Fig. 21).

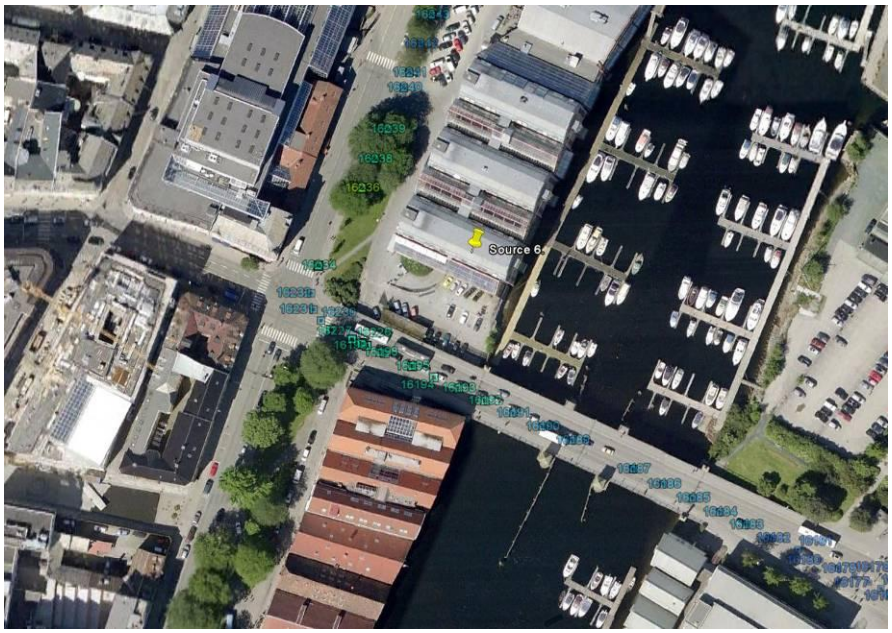


Figure 19. Source 6 location for trip 2.

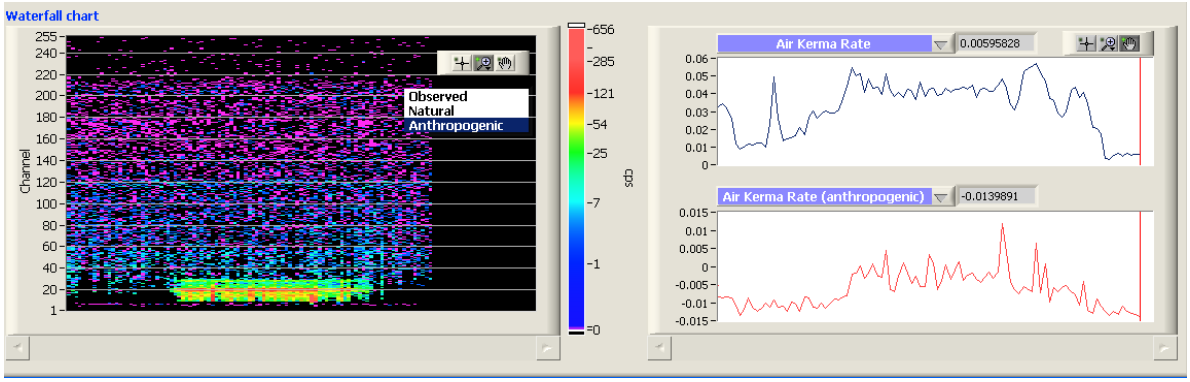


Figure 20. Source 6 of Trip 2 as it appeared in the playback software.

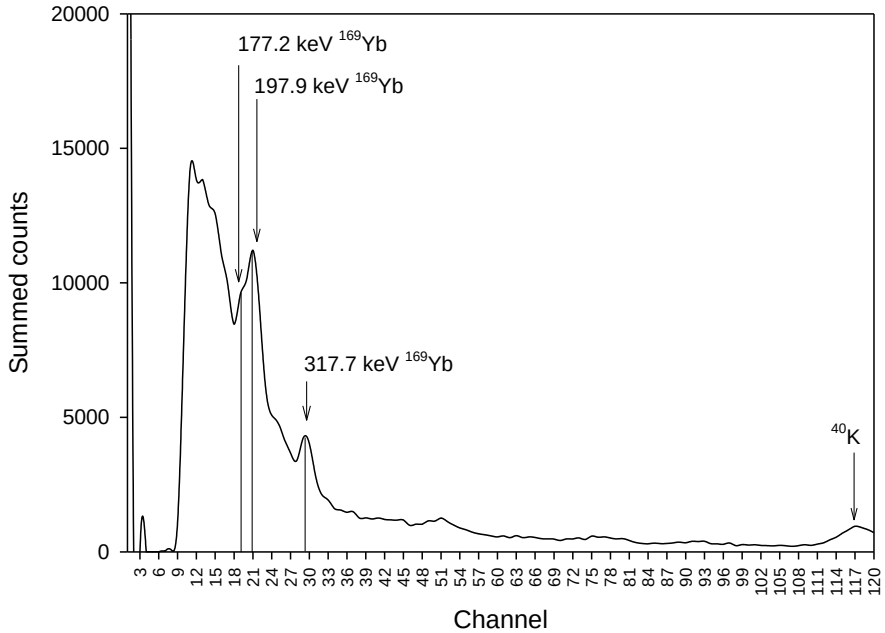


Figure 21. Summed spectra for Source 6.

3.2.6 Trip 2: Source 7.

Source 7 was a tightly collimated ^{60}Co source place at 63.436336°, 10.405122° on the roof of the building (see Fig. 22). It was collimated in an east west direction and the vehicle passed the source at three different times: 16270-16279, 17161-17185 and 17237 – 17249. The source should not have presented any problems although as the time between the first and second observation of the source was long there was a possibility that users might have identfied it as two sources if observation of the geographical information was not being conducted.

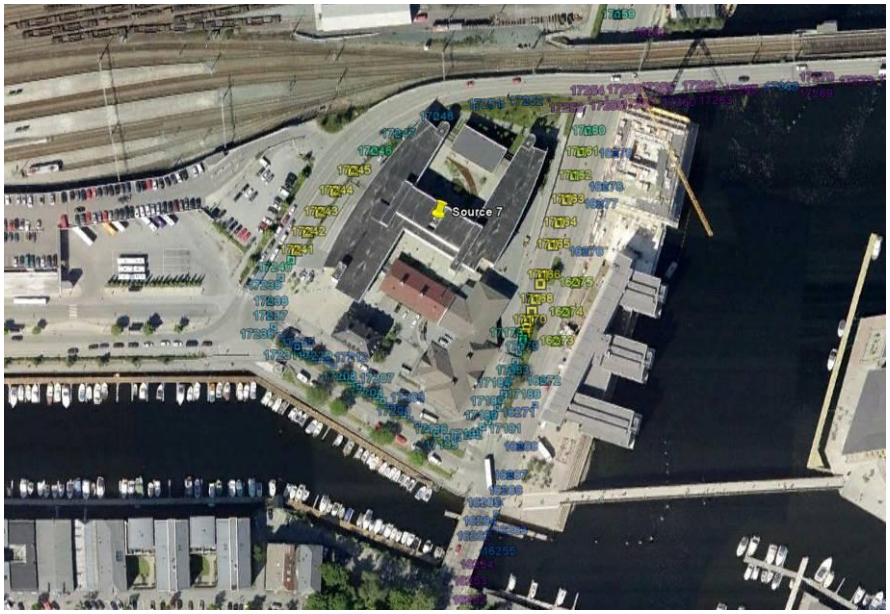


Figure 22. Location of Source 7 for Trip 2.

3.2.7 Trip 2:Source 8.

Source 8 was a large amount of 20 year old depleted uranium in a thin walled building at 63.442199°, 10.411416° (Fig. 23). It was visible twice – between 16333 and 16354 and 17065 and 17089 (Fig. 24). Between the two sightings of Source 8 is the appearance of Source 9 which presents a not dissimilar signature. There was therefore the potential for confusion between the two sources. Identification of Source 8 was probably difficult given the lack of definition in the spectrum (Fig. 25). The only possibly clear peak was a weak one at 186 keV.

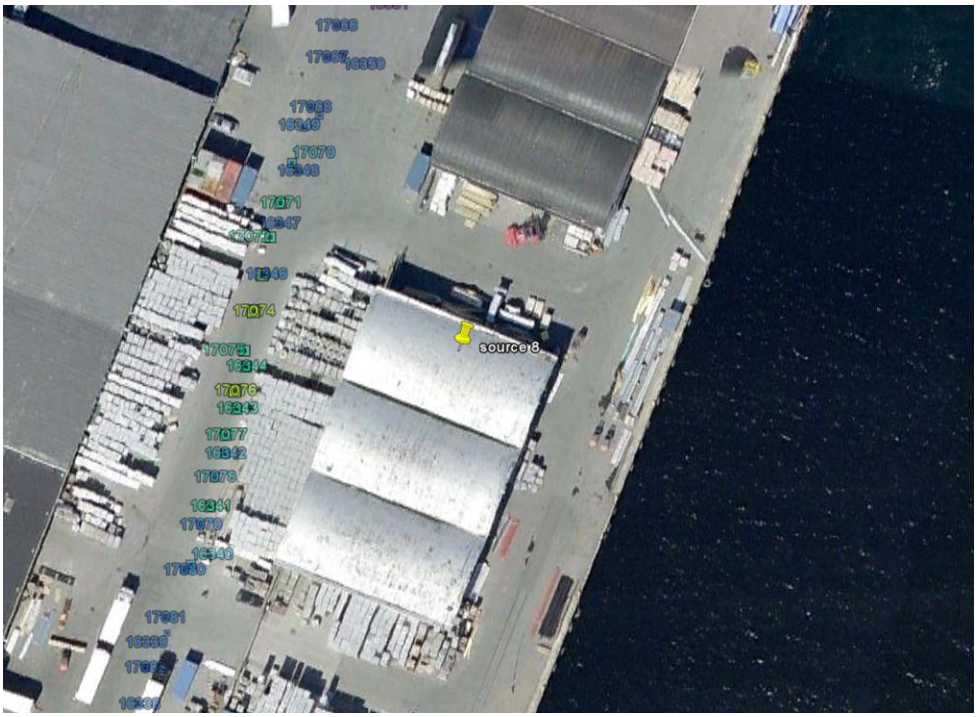


Figure 23. Source 8 of Trip 2.

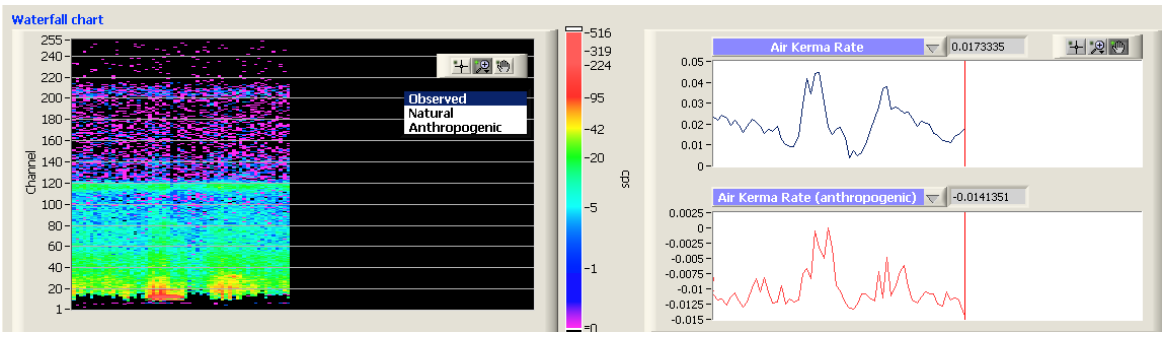


Figure 24. The first appearance of Source 8 of Trip 2 on the playback software.

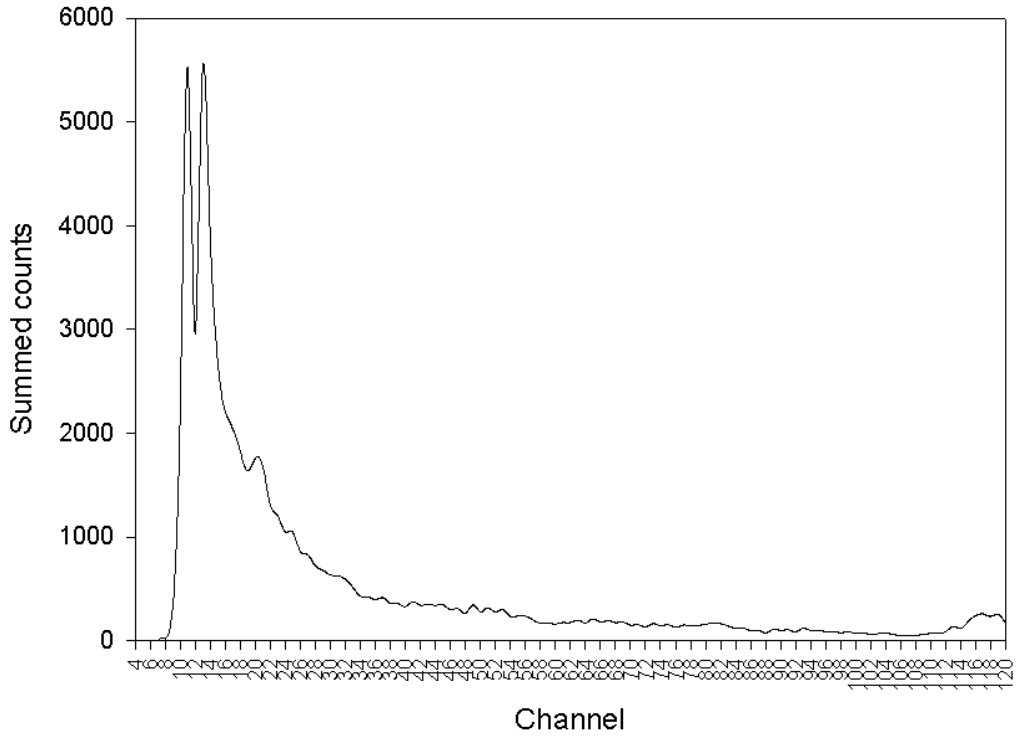


Figure 25. Spectrum of Source 8 for Trip 2.

3.2.8 Trip 2:Source 9

Source 9 for Trip 2 was a weak ^{133}Ba source in the building at 63.443256°, 10.412208° (Fig. 26). This source was relatively difficult to observe on the waterfall plots of the playback software (see Fig. 27) but some trace of it could be seen on the spectrum window. The source was only visible for a relatively short period of time. Identification of it was difficult (see Fig. 28) although summing corrected spectra may have facilitated a possible identification.

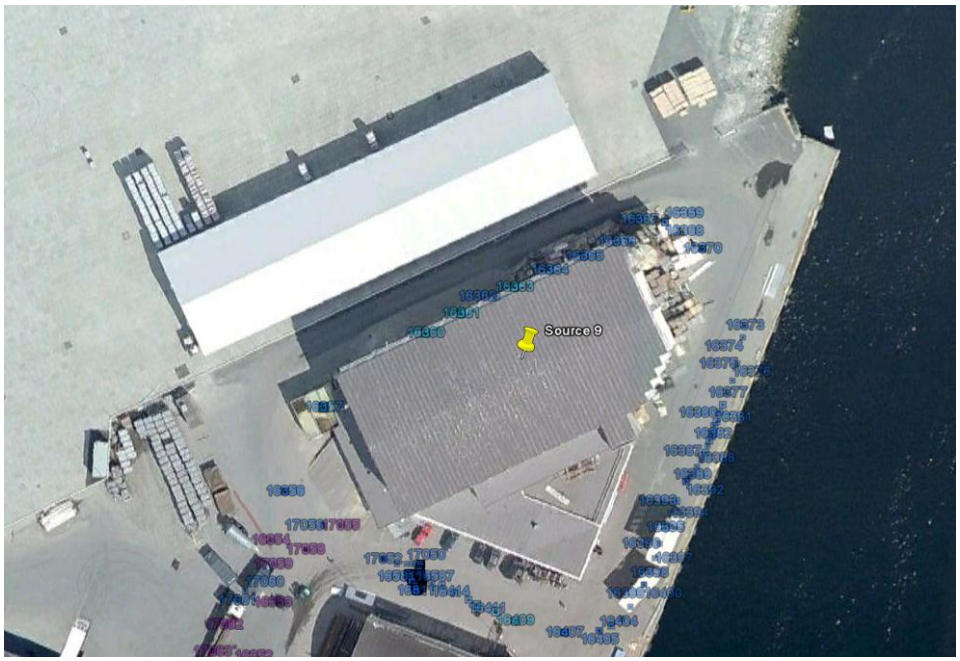
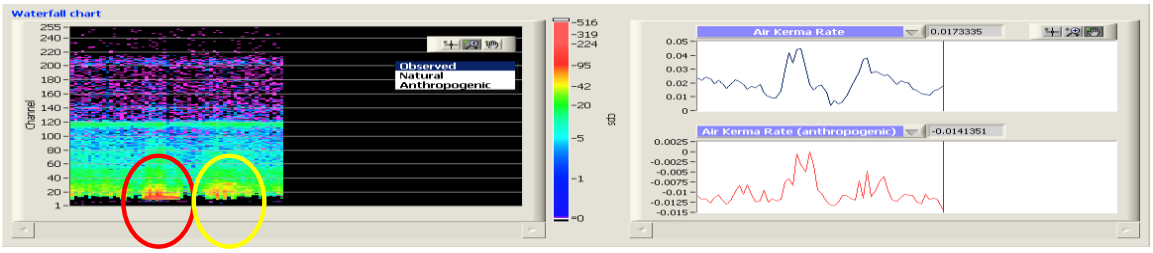
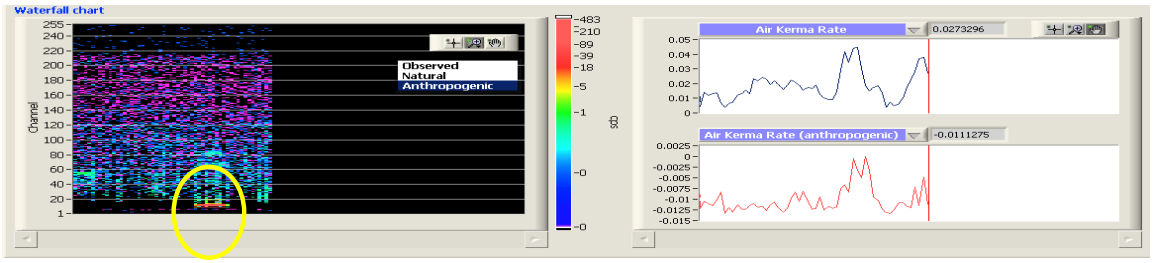


Figure 26. Source 9 of Trip 2.



Source 8 (red) and Source 9 (yellow) for the observed waterfall plot with automatic scaling.



Source 9 (yellow) for the anthropogenic waterfall plot with automatic scaling. Source 8 is now not visible as an anthropogenic signal source due to the scaling from Source 9.

Figure 27. Playback view of Source 8 and 9.

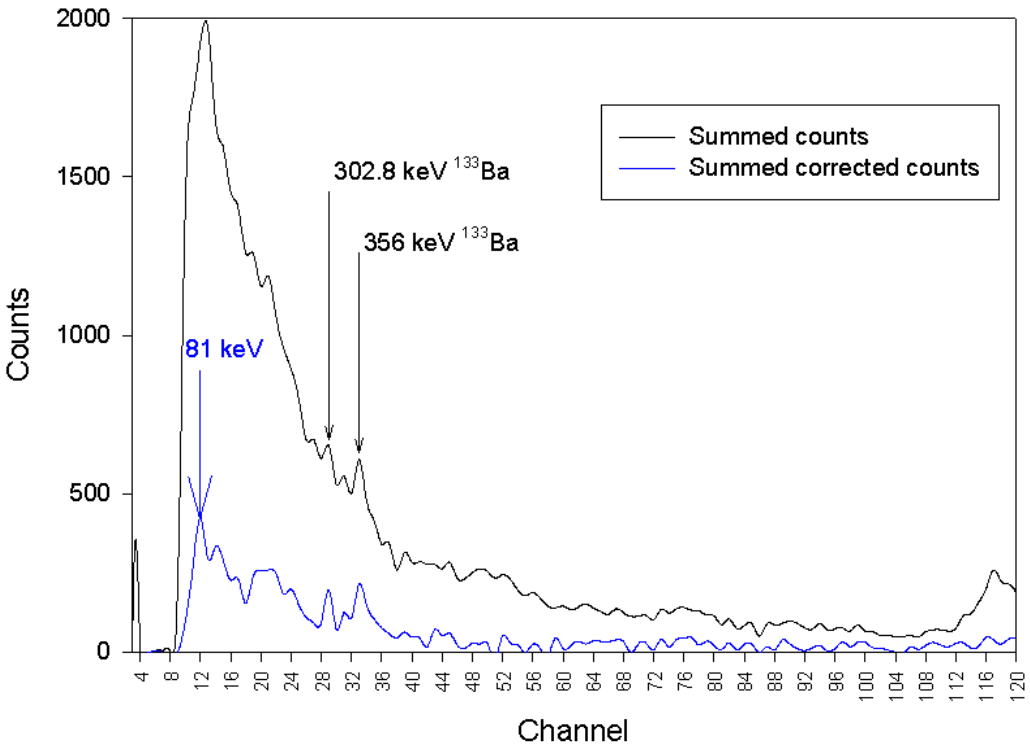


Figure 28. Summed counts for Source 9 with background correction and without.

3.2.9 Trip 2:Source 10.

Source 10 consisted of a ^{90}Sr source at 63.441050°, 10.425141° (Fig. 29). The source was in a position such that it only ”shone” southwards. The source was unmistakably visible in the playback software and could not be missed. The difficulty arose in identifying the isotope as the spectrum only presents a smooth Bremmstrahlung continuum over most of the spectrum with no peaks visible at all. In theory, users could have recognised this for what it was and assumed that the source was ^{90}Sr given the high energy cutoff of the continuum.

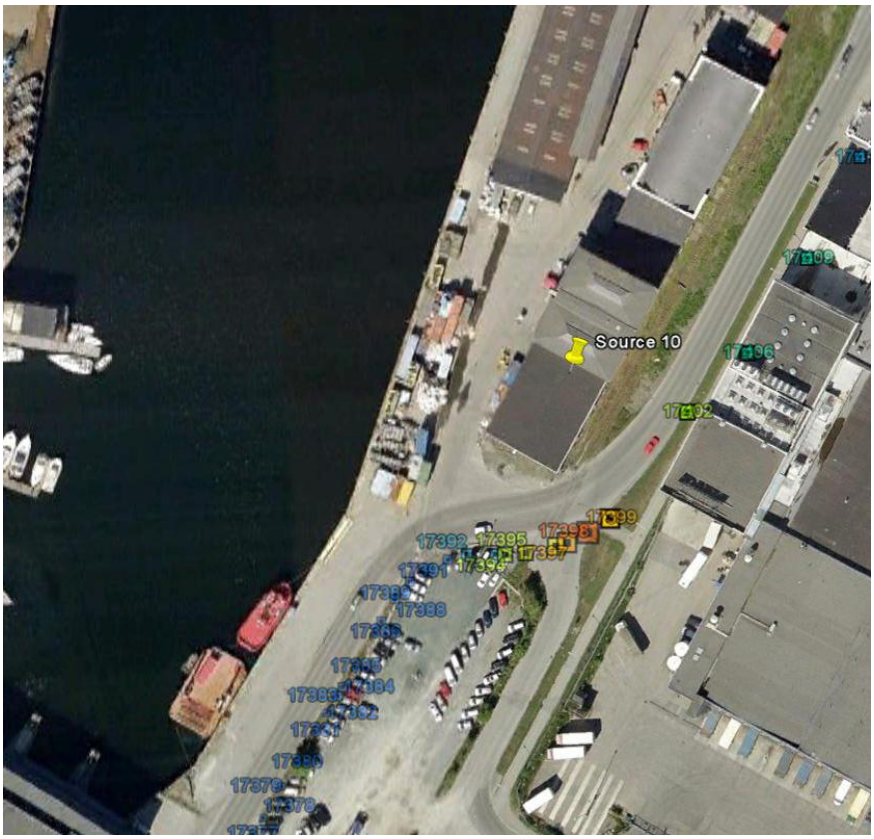


Figure 29. Source 10 of Trip 2.

3.2.10 Reported results for Trip 2.

In total, 14 participants reported results for this trip within the time limit allowed. The participants included representatives from 8 different countries and was comprised of national authorities or entities with responsibilities in the area of radiological protection, nuclear or defence research, universities and geological institutes. Some of the participants had extensive experience with mobile measurement systems for a number of applications and some had little or no experience with mobile measurements. The majority of participants had gamma spectrometry experience although for many this was primarily laboratory based. All participants could have been expected to conduct or participate in mobile measurement missions and subsequent data analysis. The practice route, Trip 1, presented no major difficulties for any participant.

	1	2	3	4	5	6	7	8	9	10	T.N.S.	FP
P1	y/n[13]	y/n		y/n	y/y	y/n[14]	y/n	y/n[14]	y/n	y/n[14]	14	1
P2	y/y	y/y	y/y	y/y	y/y	y/n	y/y	y/n[4]	y/n	y/n[5]	9(6)	2
P3	y/y	y/y	y/y		y/y		y/y	y/n		y/y	8	1
P4	y/y[1]	y/n[2]	y/n[1]		y/n		y/y[3]				6	0
P5	y/y	y/n	y/n	y/n	y/y	y/n	y/y	y/n	y/n[6]	y/n[7]	18(13)	
P6	y/y	y/y	y/y	y/y	y/y	y/n[8]	y/y	y/n[9]		y/y	11(2)[26]	0
P7	y/y	y/y	y/y	y/y	y/y	y/n[22]	y/y	y/m[23]		y/m[24]	10	
P8	y/y	y/y	y/y	y/n[10]	y/y	y/n	y/y	y/n[4]	y/n[11]	y/n[12]	12	2
P9	y/y	y/y	y/y	y/y	y/y	y/n[25]	y/y	y/n	y/n[26]	y/n	12	2
P10	y/y	y/y	y/y		y/y		y/y	y/n		y/n[7]	6(8)	0
P11	y/y	y/y			y/y	y/y	y/y	y/n[21]		y/y	11	2
P12												
P15	y/y	y/y	y/y	y/y	y/y	y/y	y/y	y/n[18]	y/n[19]	y/n[20]		
P16	y/y	y/n			y/y		y/y	y/n[27]		y/n	6(3)	1
P17	y/y	y/y	y/n[15]	y/n[16]	y/y	y/n[17]	y/y	y/m[18]	y/n[11]	y/n[7]		
P18												
P19												

Table 1. Summarised results for Trip 2. Key: First letter denotes correctly loctated - yes(y) or no(n); second letter denotes correctly identified – yes(y), no(n) or maybe(m); T.N.S. – Total number of sources reported, the number of individual sources ascribed to the route (numbers in paranthesis indicate number of sources defined as possibles., F.P. – false positives, sources reported where no sources had been placed.

Annotations: [1]Source ascribed as ^{131}I and ^{137}Cs; [2]source incorrectly identified as ^{134}Cs and ^{131}I; [3]source incorrectly located later as a second ^{60}Co source; [4]misidentified as possibly ^{241}Am and ^{57}Co; [5]misidentified as shielded ^{60}Co; [6]misidentification as possibly ^{75}Se; [7]misidentified as possibly heavily shielded compton spread; [8]misidentified as possibly ^{67}Ga; [9]misidentified as ^{155}Eu; [10]misidentified as a low energy nuclides, possibly ^{241}Am; [11]misidentified as NORM material; [12]located and identified as a beta emitter; [13] source incorrectly identified as ^{137}Cs; [14]source located and ascribed to scattered radiation; [15] source is posited to be ^{226}Ra; [16]source suggested as ^{177}Lu; [17]source suggested to be ^{241}Am; [18]source is ascribed as possibly ^{177}Lu but also potentially ^{235}U; [18]misidentified as ^{201}Tl; [19]misidentified as ^{131}I; [20]misidentified as Bremmstrahlung from ^{32}P; [21] identified as possibly ^{176}Lu, ^{252}Cf or ^{241}Am; [22] misidentified as ^{67}Ga or possibly a uranium isotope(s); [23] identified as probably nuclear material $^{235}U/^{238}U$; [24] identified as a beta emitter possibly $^{89}Sr/^{91}Y$; [25] suggestion as to ^{154}Eu: [26] suggested as ^{131}I; [26] these two sources were reported but were noted as being just high background rather than discrete sources; [27] suggested as being ^{241}Am or ^{210}Pb;

An overview of responses for Trip 2 is provided in Table 1 with some explanatory text. Based upon the reported results, the sources present in Trip 2 could be conveniently divided into a number of categories based upon difficulty in either finding or identifying.

The first category of sources (sources 1,5 and 7) were easy to find and easy to identify. Source 1 was found and identified by all of the participants having been clearly visible on every Playback display and an easily recognisable spectral shape being exhibited by the source. Although found by every particpant, it was incorrectly identified by one as a ^{137}Cs source and by another as being ^{137}Cs and ^{131}I together. Sources 5 and 7 (^{137}Cs and ^{60}Co) proved similarily easy to identify and locate in the data records although some participants failed to recognise (or at least to report) that the same two sources were being detected from multiple locations in the driving route. It is unclear from the provided reports for these participants whether or not the sources were actually being reported as one source with multiple sightings or as discrete sources.

The second group of sources (sources 6,8 and 10) were those sources that were, or should have been, easy to locate but were difficult to identify with the information to hand. Source 6 was relatively easy to locate using the provided software – it was visible for a reasonable period of time as the vehicle came to a halt next to the source. The source strength was sufficient to generate clear signals on the waterfall plot or any other plot that participants may have employed. Yb-169 exhibits a range of gamma emissions (Fig. 30) that, in a laboratory environment, facilitate easy identification. For a low resolution spectrometer with a high lower level discrimination –like the one simulated in the exercise- the situation is significantly more complex.

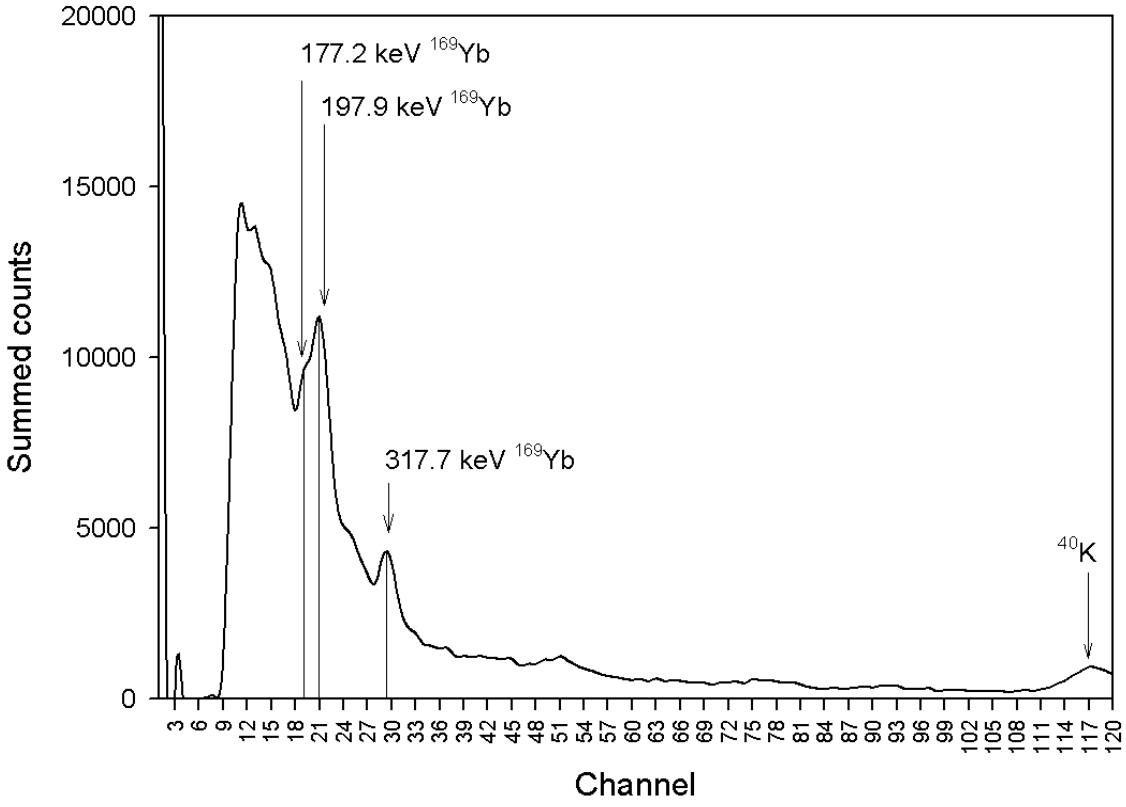


Figure 30. Summed channel counts for Source 6.

Ten out of 14 participants found this source, but only two out of the 10 correctly identified the isotope. Yb-169 is a significant and commonly used radiography source and a greater degree of success in identifying it was expected. Three peaks are clearly visible in the spectra however, the limited extent to which the energy of these could be established was a mitigating factor. Isotopes that were suggested by participants as possible candidates for source 6 included ^{67}Ga, ^{154}Eu, ^{241}Am and scattered radiation. Source 8, a large mass of relatively fresh depleted uranium, was a source that was simple to locate given its strong signal yet difficult to identify (see Fig. 31) largely due to the daughters of uranium with their strong gamma emissions not being present (due to the long half life of ^{226}Ra relative to the short time since processing, and also due to the absence of ^{235}U). This was reflected in its being located correctly by 13 out of 14 participants but being correctly identified with certainty by none. Two of the participants concluded that the source could be nuclear material containing ^{235}U and/or ^{238}U. A range of suggestions were put forward as to the possible identity of the source, most of which focussed on low energy emitters such as ^{241}Am, ^{57}Co, ^{252}Cf, ^{177}Lu and ^{210}Pb. Source 10 was perhaps the most clearly visible of all the sources in Trip 2 and but was however the most difficult to correctly identify. The majority of participants located the source yet only 3 identified it with certainty and 1 was uncertain but suggested the correct isotope as a possible candidate. Identification was obviously difficult but it was hoped that the high energy Bremsstrahlung photons (determined by the maximum beta energy, 2.281 MeV from the daughter ^{90}Y) at the cutoff would have led users to conclude ^{90}Sr. Candidates put forward by participants included unspecified beta emitters, ^{32}P, scattered radiation or heavily shielded ^{60}Co sources.

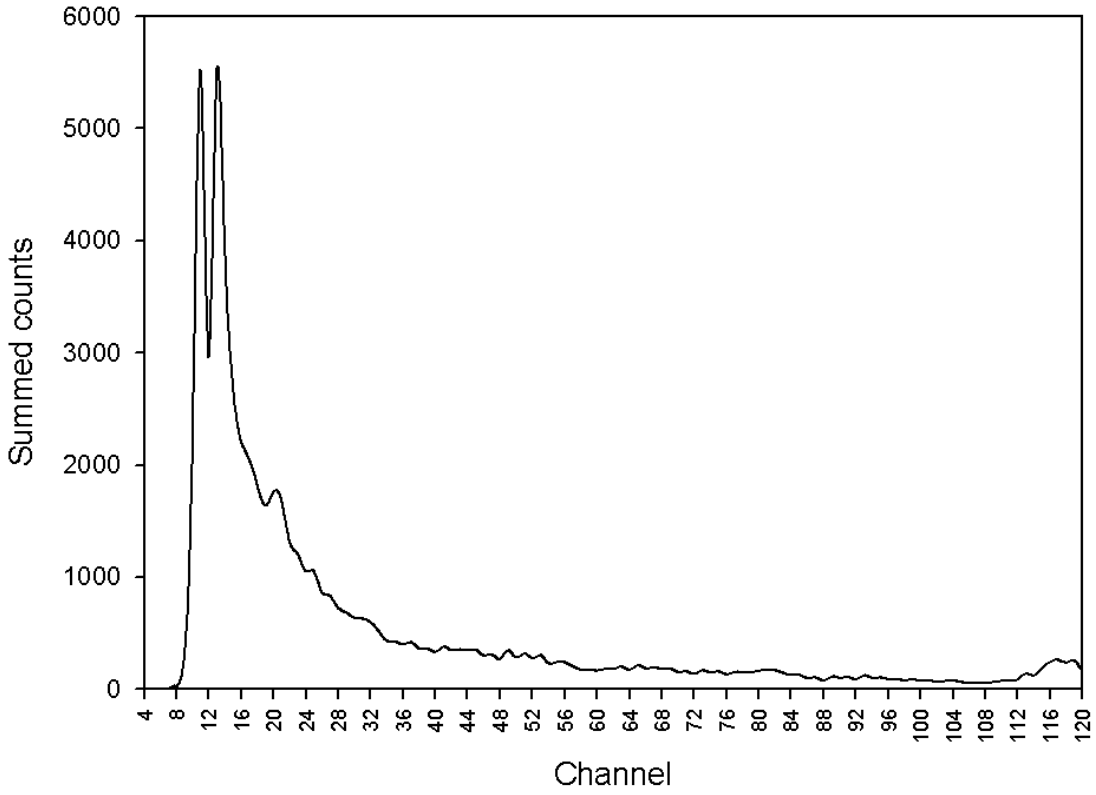


Figure 31. Summed spectra for Source 8.

The third group (sources 4 and 9) were those sources that were both difficult to locate and difficult to identify. Source 4, a weak ^{67}Ga medical source placed a long distance from the road was the first in this category. Only 9 of 14 participants managed to find this source and only 5 correctly identified it for what it was. The source was visible in the waterfall plot of the Playback software should the participant have experimented with the display options. Source 4 was barely visible on the default waterfall plot, while it became clear when examining the assumed anthropogenic component of the signal in the same plot. There was little or no evidence of the source on any other Playback visualisation. Identification was not trivial but could have been achieved with modification of the relevant spectra and summing. In this case, had each individual spectrum over the period for which the source was visible been corrected for background (by subtracting the average of a number of spectra prior to or after the source made its appearance) and then summed, a reasonable picture of the source was evident. The two participants who located but incorrectly identified the source selected ^{241}Am or ^{177}Lu as the likely candidates. Source 9 proved even more difficult for participants. This was a weak ^{133}Ba source located between two appearances of Source 8. The signal from this source was exceptionally weak and primarily consisted of relatively low energy lines. Nonetheless, the source was clearly visible on a number of Playback visualisations and an observant operator should have registered it. Even though its trace might have been seen, the nature of the spectrum for ^{133}Ba and its occurrence near an observation of Source 8 presented the potential for its being deemed not to been an individual source. Only 7 out of 14 reported this source and no participant managed the difficult task of identifying the isotope. The source was suggested variously as being naturally occurring radioactive material (NORM), ^{75}Se, ^{131}I and simply as being elevated background. Sources 2 and 3 (^{192}Ir and ^{75}Se) presented different challenges to those of the previous three groups of sources. Placing the sources with similar signals (on a low resolution system) close together presented the challenges of recognising that there were two sources and that they were of different isotopes. Three of the fourteen participants reported only a single source at this location.

Enough information was present to locate some of the source's quite precisely. Sources were occasionally visible from several locations and they were simulated so that the distances between the sources and observation points were reflected in the spectral shapes. On occasions, the effects of the surroundings were also taken into account. The participants approached the task of locating the sources in different ways – some made quite accurate estimates of the off-road positions of sources while other participants chose to report the positions of the carborne measurements exhibiting the strongest signals from the sources. Most participants reported a position on the road for sources 1,2,3,4 and 6 (where the strongest signals were observed). Two participants, however, correctly narrowed down the locations (see Fig.s 32 and 33). Although full details were not provided, based on the data provided by the participant it would appear that a form of triangulation was used where differences in a spectrum parameter such as counts in a specific channel or the SDI value between two points separated by a known distance was used to estimate the distance to the source. It should be noted that in the participants' written descriptions of the source locations, where provided, some were willing to provide descriptions of where they thought the source may be as opposed to actual coordinates. In many cases these descriptions were more detailed and more accurate than the coordinate information provided.

Several false source locations were reported at the start of the trip and towards the end. These locations were associated with large exposed open areas such as a football pitch or sportsground where traces of Chernobyl fallout remain. In some other instances, sources were reported that were not present nor could be attributed to Chernobyl fallout. The reasons for

these false reports were not unidentified but it is assumed they were most likely caused by strong local variation in the background signal related to the passage of a building made of granite or similar. In particular, 2 reports of a ^{137}Cs source at 16309 could not be explained. During recording of the original data one or two data points were affected by a loss in the GPS 1 Hz signal which resulted in the spectra being measured for a period approaching two seconds as opposed to one. This however did not occur at the point in question.

Figure 32. Estimated position of Source 1 as reported by Participant P17.

Figure 33. Pictorial representation of the location of sources 2 and 3 as provided by one participant.

From the participant reports it was unclear to what extent the participants had attempted to extract more information from the data through further numerical processing. There was the

potential to locate the sources using 1st and 2nd order differentials, or perhaps use a moving average method, also potential to identify sources by summing spectra to improve statistics or by recording and subtracting backgrounds. A number of participants did not report their processing procedures in detail, but post exercise dialogue with some of them revealed that numerical methods had been employed. Other participants offered detailed breakdowns of their procedures and from these reports it is clear that variation in spectrum intensities along the driving route was used to estimate the distances to sources and that this method produced significantly better results than simply reporting the measurement waypoints at which source signal maxima were observed.

The exercise was formulated around the premise that the carborne search would be followed up by a team on foot to conduct a more thorough search. In this regard it should be noted that even being in a position to estimate which side of the road the source was located would significantly enhance the efficiency of the follow up team by reducing their search area or time required by 50% or so. The following report for Source 4 is a good example of the level of information that could be provided to a follow up team, although this level of detail is only attainable after considerable post-survey analysis and therefore could not be made available to the follow up team for some time: ”Source 4 Given the spread of intensity (here the intensity of the raw spectrum at channel 28) against distance, we estimate a point source located c. 70m from spectrum 15240. We speculate that the source is located to the right of the track, as a location to the left would involve collimation / shielding of the source, and we do not see evidence of this. A possible location is a little behind the fountain in the park to the right. Approx 63.26'13.90, 10.25'40.16. Likely source Ga-67.”

A number of techniques and systems have been developed and employed in mobile gamma ray spectrometry over the years that offer some advantages to the user in both locating (see for example Kock et al, 2010; Gutierrez et al, 2002) and identifying sources (Aage et al, 2006). Many of these systems rely on system specific parameters that could not realistically be accounted for within the framework of ORPEX. This obviously set some teams at a disadvantage in that methods they would usually employ were not available - although a common playing field did exist for all teams. A number of other weaknesses were also evident in the exercise, most related to the difficulty or practicability of simulating the environments in which the sources were found. Although simulation of a limited laboratory environment is relatively simple, taking account of all possible facets of an outdoors environment in a simulation is no trivial matter and for this reason complex shielding or scattering effects were not included in the synthetic materials. For Trip 3, the assumption of steady state isotopic composition of the contamination was probably unrealistic. In addition, well known problems such as vehicle/equipment contamination or data overflow in highly contaminated areas were not accounted for.

3.3 Trip 3.

Trip 3 was intended to be representative of a situation where localised contamination has occurred as a result of an incident or accident and participants are asked to delineate areas of relevance with respect to contamination levels and hazard an identification of the source. For the purpose of this activity, the incident was assumed to be a fire at a facility containing medium level nuclear waste materials which results in localised contamination with a number of isotopes. Due to the weather pattern during the duration of the fire, two distinct plumes of contamination were present (see Fig. 34). The route of the vehicle intersects the plumes at

various times. It was of course recognised that in reality the vehicle would be able to choose its own route but it was felt that th eroute chosen for the exercise covered the main arteries of the area and should have been sufficient to delineate areas of concern. The participants were asked to sketch out areas of contamination and indicate relative contamination levels on a picture of the area or by any means of their choosing. Difficulties were present due to the amount of information being displayed on screen for relatively long periods of time which made differentiation between areas of different levels of contamination relatively difficult. The isotope suite itself had one or two components that were reasonably easy to identify (see Fig. 35) although an identification of all the isotopes would have been more problematical.

Results for Trip 3 indicated that most participants had no significant problems identifying the two areas where fallout had occurred. However, there was marked variability in what the participants chose to report. The majority provided graphical respresentations of the spatial extent of the fallout. Some participants went markedly further by providing information on the relative concentrations and composition of the fallout and the relationship between the fallout plumes and the weather conditions. Only one participant reported the possible presence of ^{154}Eu although the majority of participants were able to correctly identify ^{137}Cs and ^{60}Co. Although the information provided to the participants did not lend itself to the determination of activities deposited – largely due to the difficulty of correctly simulating a 3-D environment – it was hoped that participants would express the varying levels of contamination relative to a reference, be that reference the background radiation level or the lowest level of contamination observed. A simple grading of the contamination in different areas was desirable, either with respect to the chosen reference or a parameter like total count rate or energy weighted count rate. Only two participants attempted to quantify the contamination relative to non-contaminated areas. Individual results are depicted in Annex 1.

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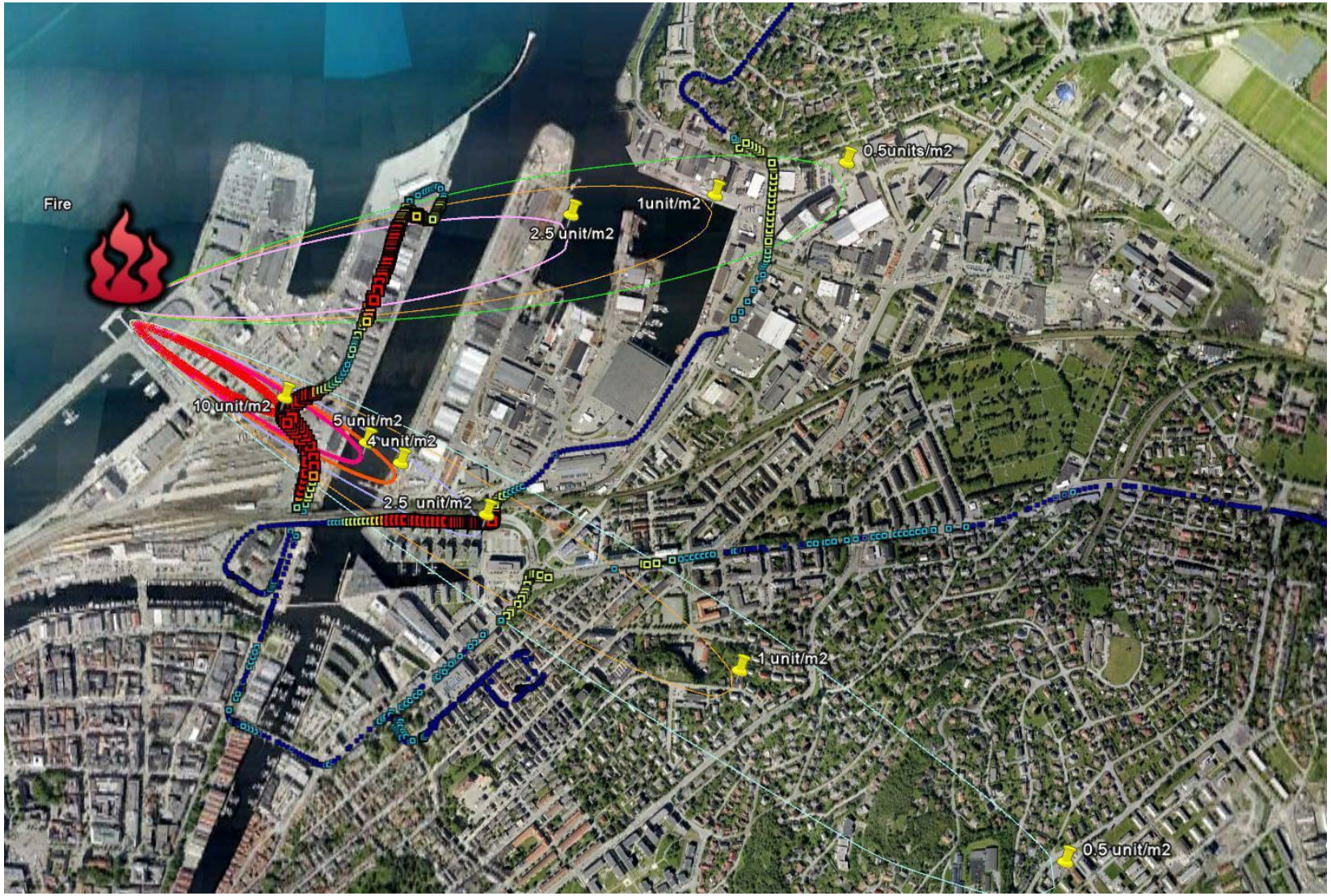

Figure 34. Overall pattern and levels of contamination as simulated for Trip 3.

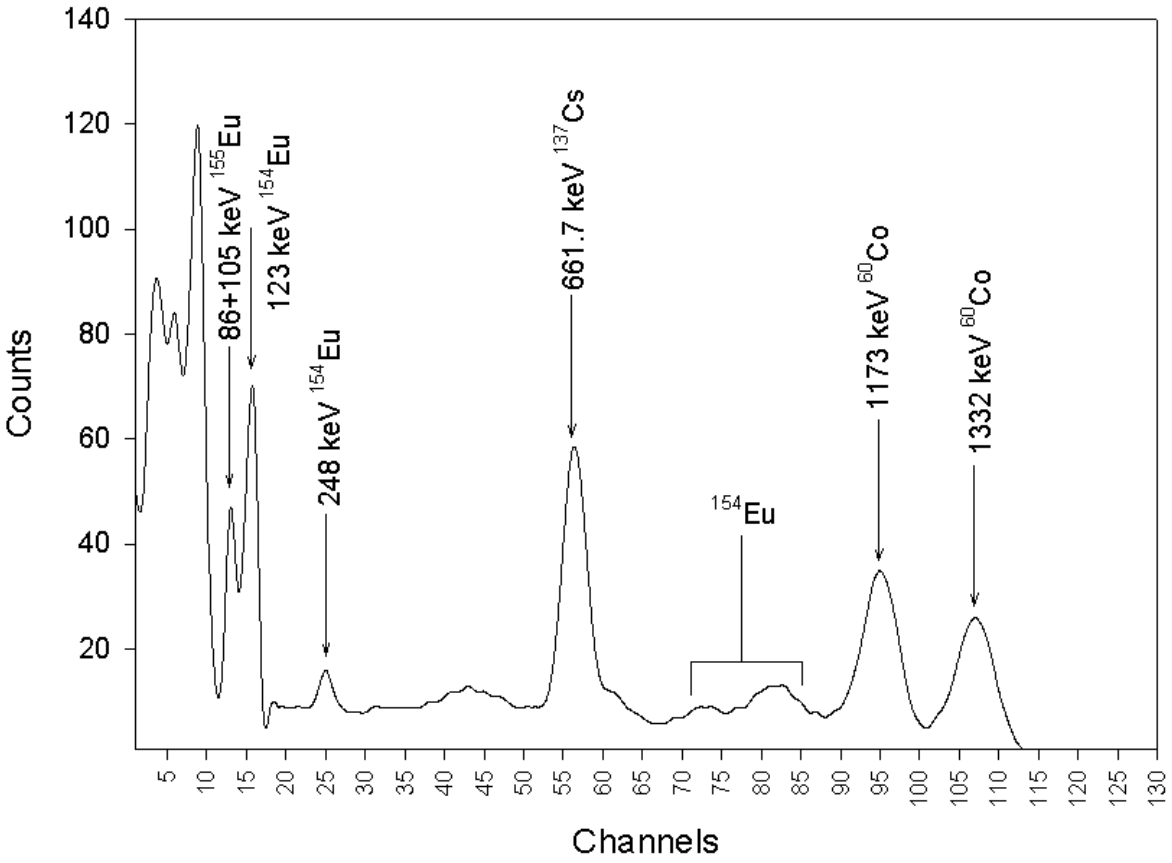

Figure 35. Spectrum for the contamination present within the scenario of Trip 3.

4.0 General Conclusions

Participants were provided with a number of options in terms of how they approached the analysis for both Trips. The data could be analysed using the software provided, using individual spectra in any commercial or other gamma analysis software, using the tabulated spreadsheet data, using the geographic data or by importing the data into another software system for analysis of mobile spectrometry data. Participants were asked to report what methods they used in analysing the materials provided. The majority of participants reported using a combination of the Playback software, the kml file (most probably in Google Earth), and other software, most typically gamma spectra analysis packages from major manufacturers. It is worth noting that 2 participants, P11 and P2, reported only using the Playback software and were still in a position to identify sources such as ^{169}Yb and ^{67}Ga that taxed teams who reported employing both the Playback software and a range of other utilities. This suggests that the information provided by the Playback software in combination with a user familiar with gamma spectrometry and what sources are possible candidates in such situations, is sufficient to facilitate a good level of performance. For limited data sets like those generated for this exercise it is difficult to separate the contributions of analyst and software with respect to success in the task. Probably the best conclusion is that an experienced analyst using limited tools can perform as well as any other analyst, experienced or not, using more advanced utilities with respect to identifying found nuclides. In terms of locating sources – the premise of Trip 2 – the vast majority of participants reported the waypoint nearest the strongest signal observed for any individual source. A lesser number of participants were willing to estimate specific locations for sources using triangulation or other methods. In these cases, attempted locating of the source proved quite accurate. Follow up of these instances indicated that these participants had experience of mobile measurements – experience which it must be presumed proved useful in establishing a more accurate picture of the sources location.

Based on the results reported it is possible to draw a number of conclusions which may be of use in the designing of further activities of this type. First and foremost, it is evident that with measuring systems of the type that are most frequently employed in carborne surveys, identification of isotopes without high energy gamma emissions is difficult but not impossible. For sources such as 90Sr, which is not a typical ”gamma source”, and depleted uranium, the difficulties evident in the participants responses indicated that expansion of the suite of practice souces employed in future exercises would be of some advantage. Analyst experience is of paramount importance in this regard. An experienced analyst with no experience in mobile measurements is more likely to successfully identify the source isotope, even with limited information, than a less experienced analyst irrespective of whether or not they are very skilled in making mobile measurements. On the other hand, it was obvious from the results that participants with experience in mobile measurments were more willing to attempt to draw as much information out of the data as possible, producing more accurate estimates of source locations and utilising all the information to hand in their interpretation.

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ANNEX 1

Figure A1.Trip 3 Results for Participant 1.

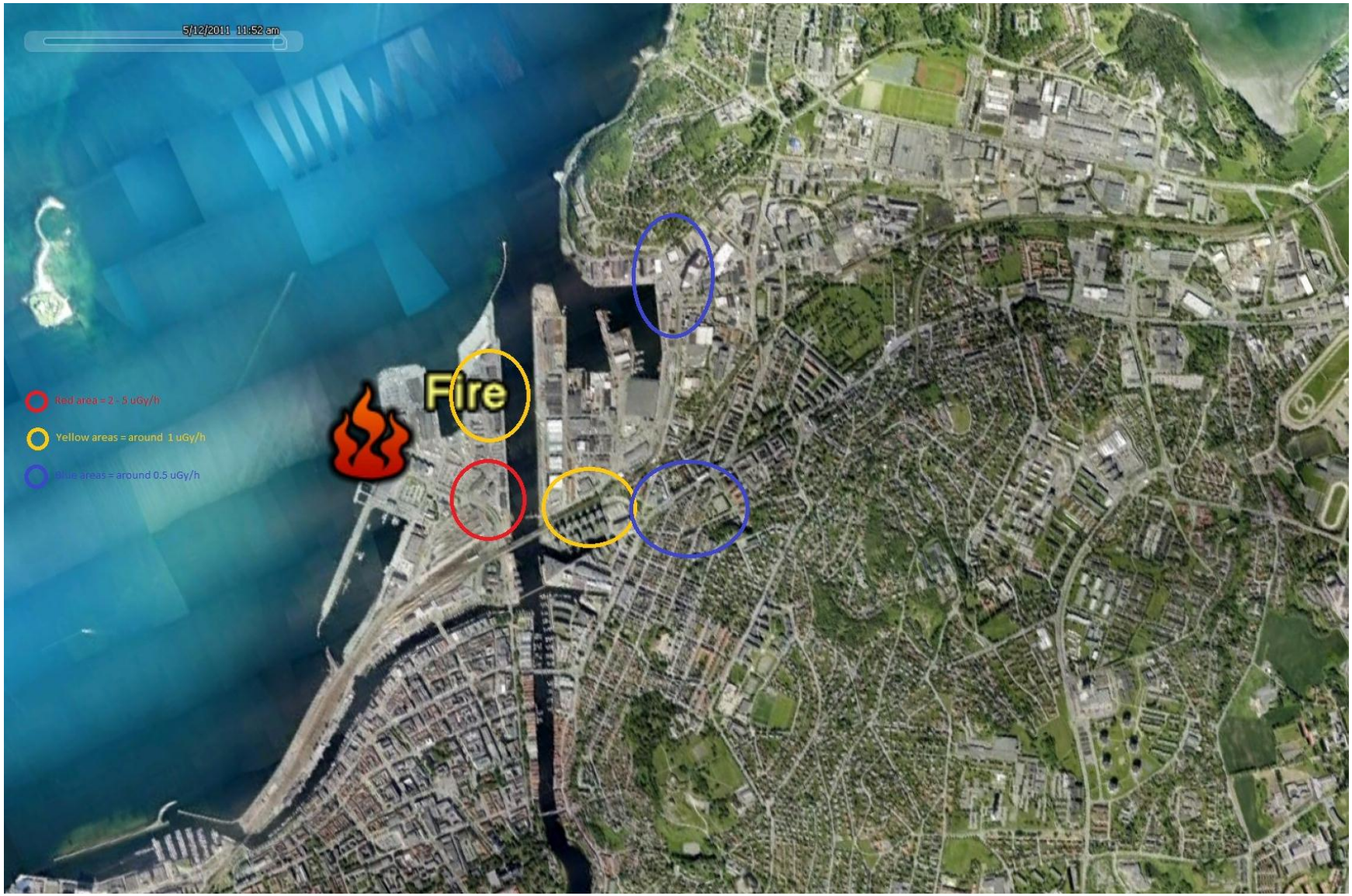


Figure A2.Trip 3 Results for Participant 2.

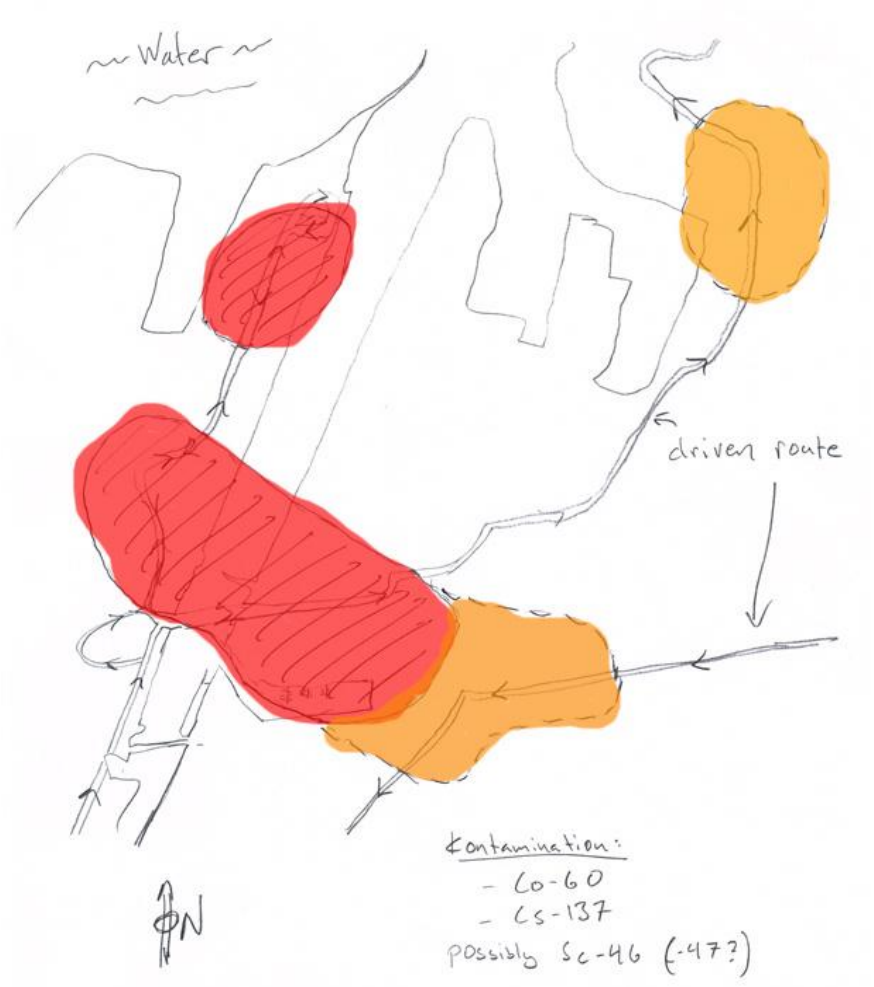


Figure A3.Trip 3 Results for Participant 3.

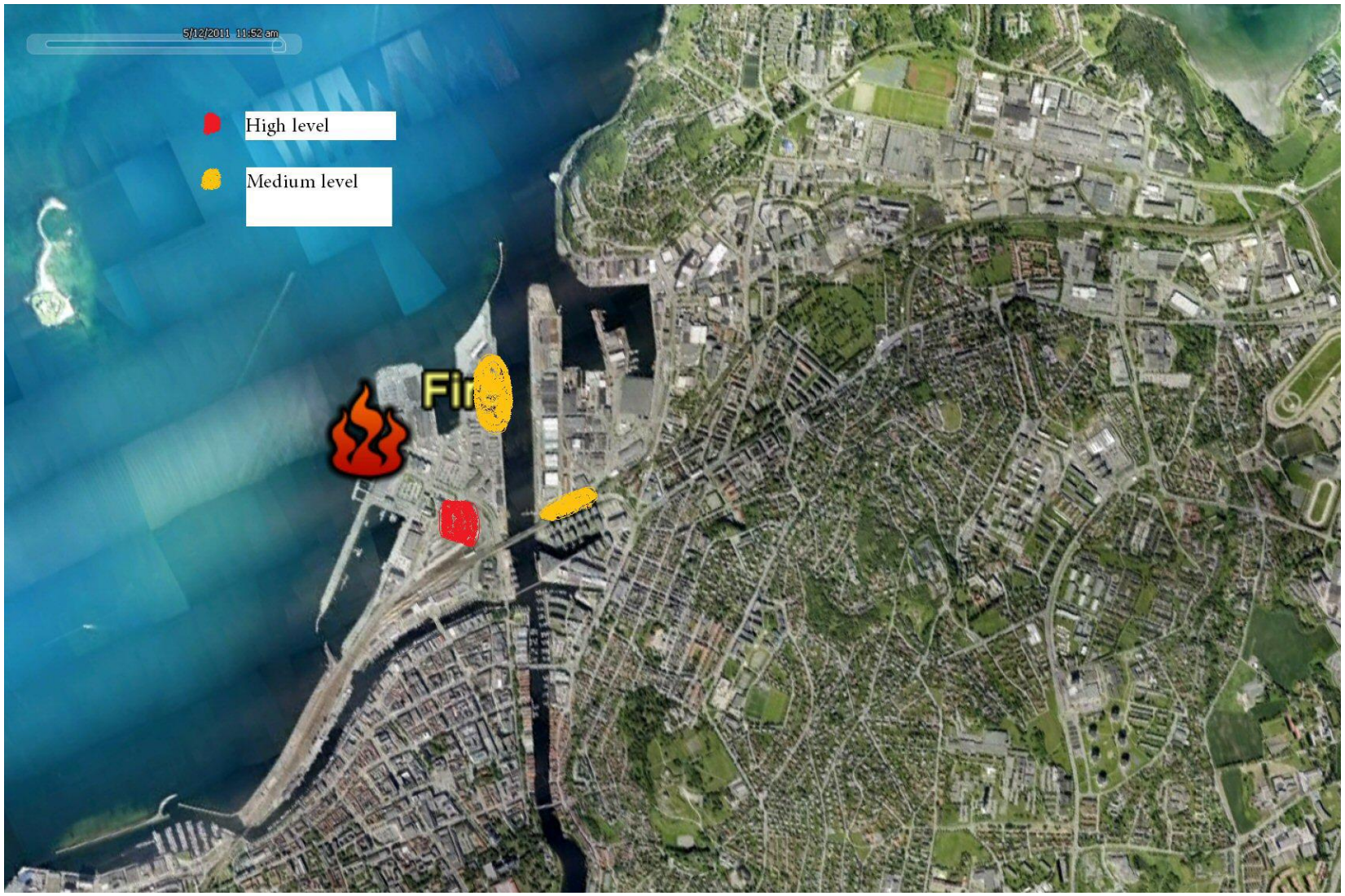


Figure A4.Trip 3 Results for Participant 4.

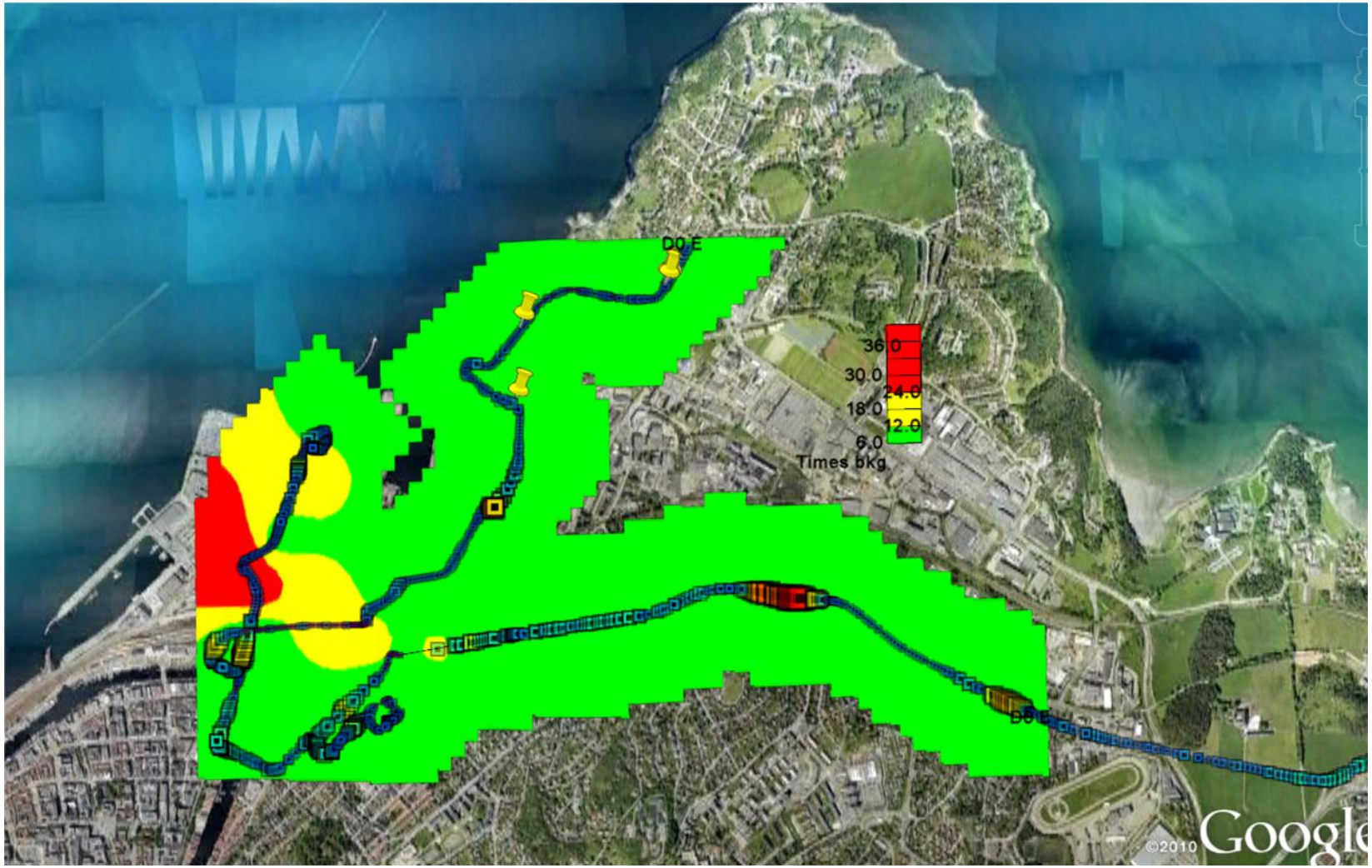
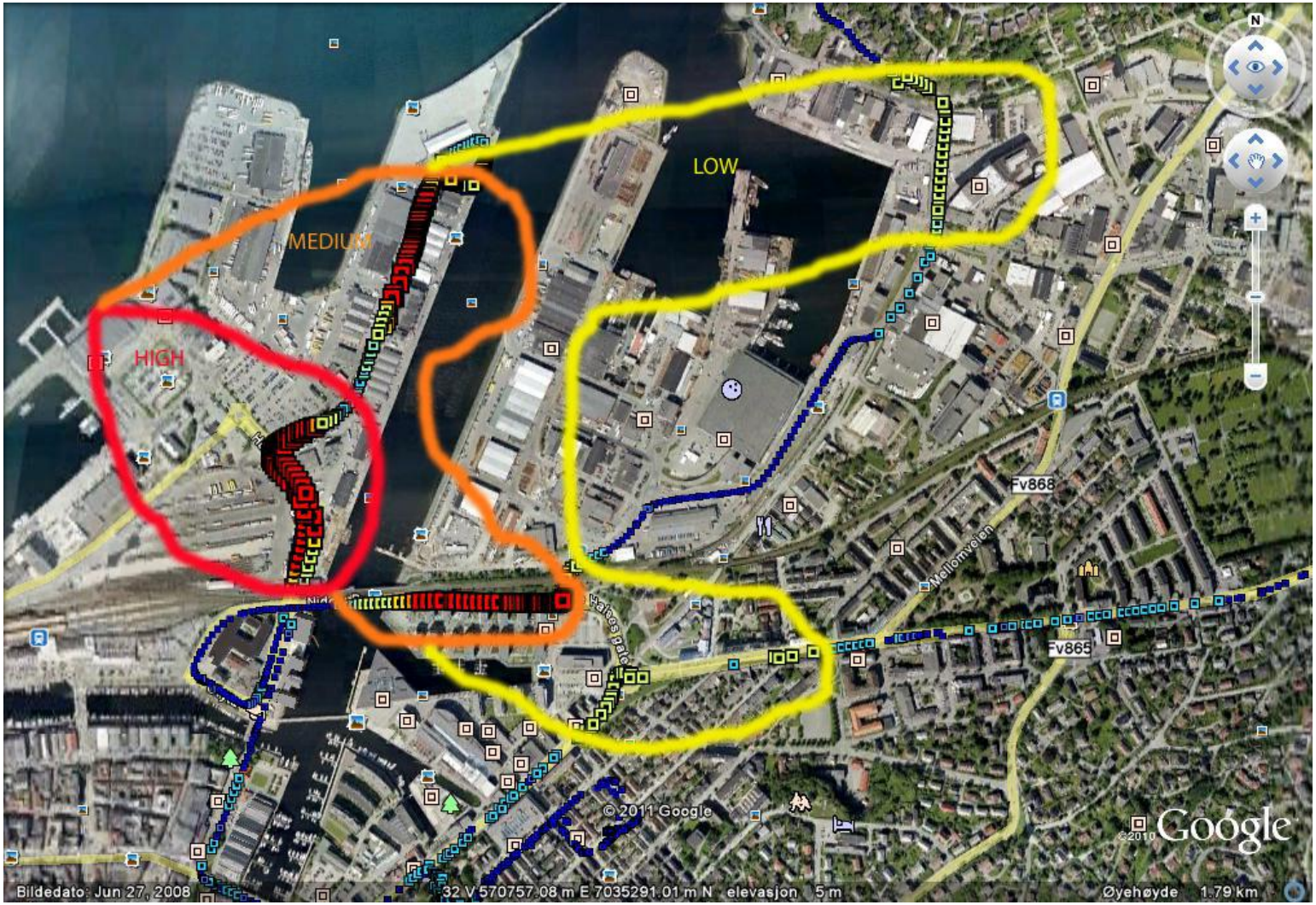


Figure A5.Trip 3 Results for Participant 5.



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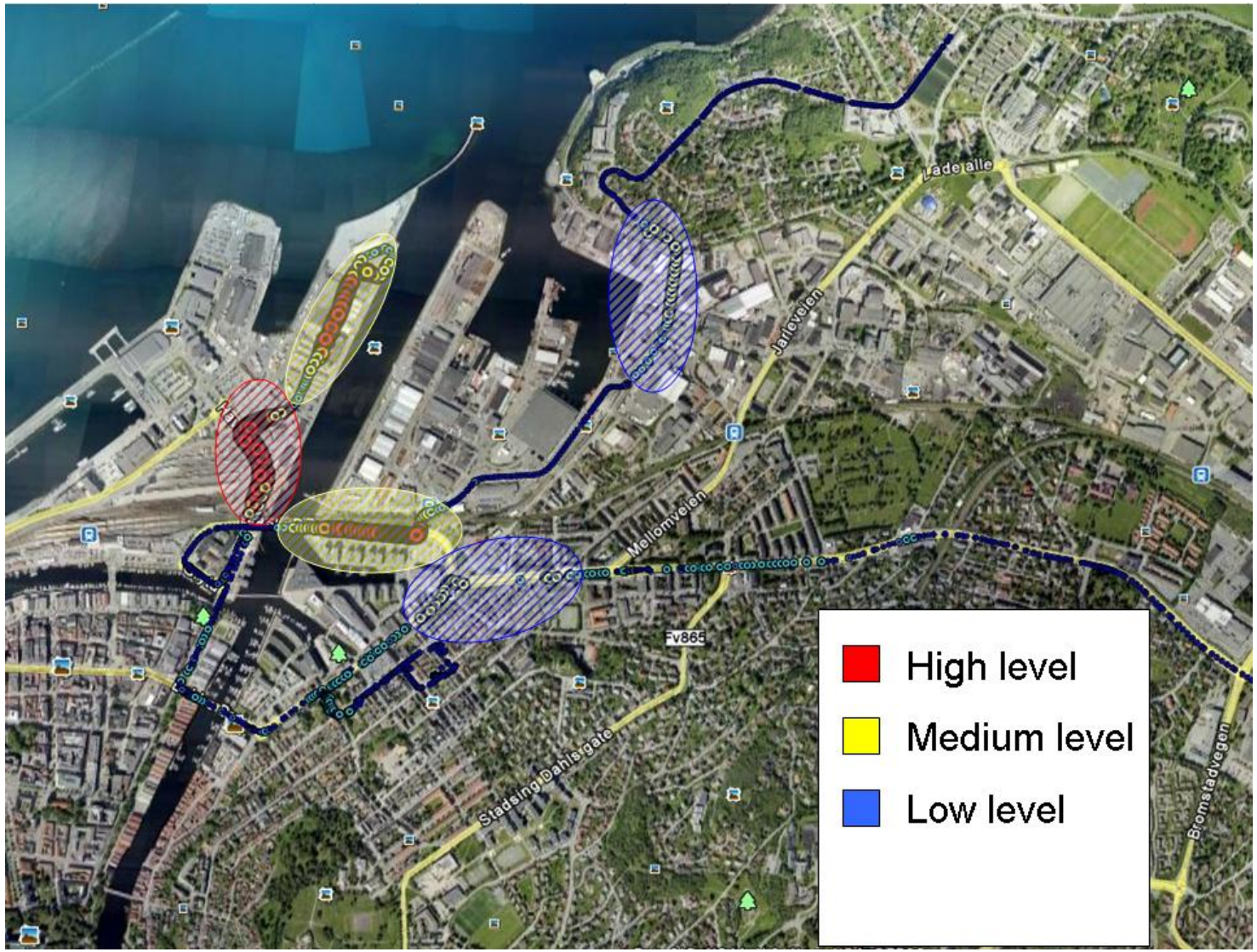

Figure A7.Trip 3 Results for Participant 7.

Figure A8.Trip 3 Results for Participant 8.

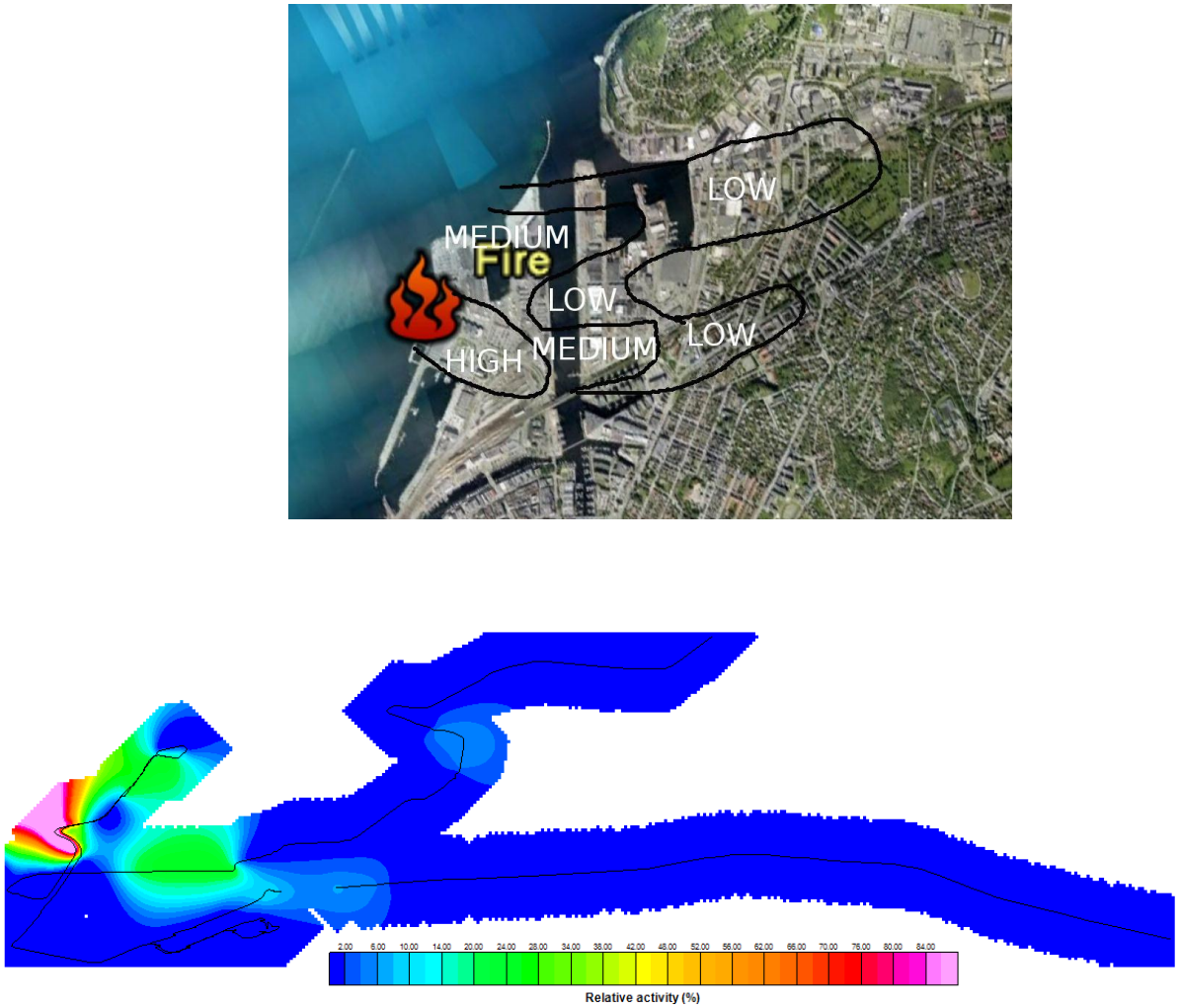

Figure A9 .Trip 3 Results for Participant 9.

Figure A10.Trip 3 Results for Participant 10.

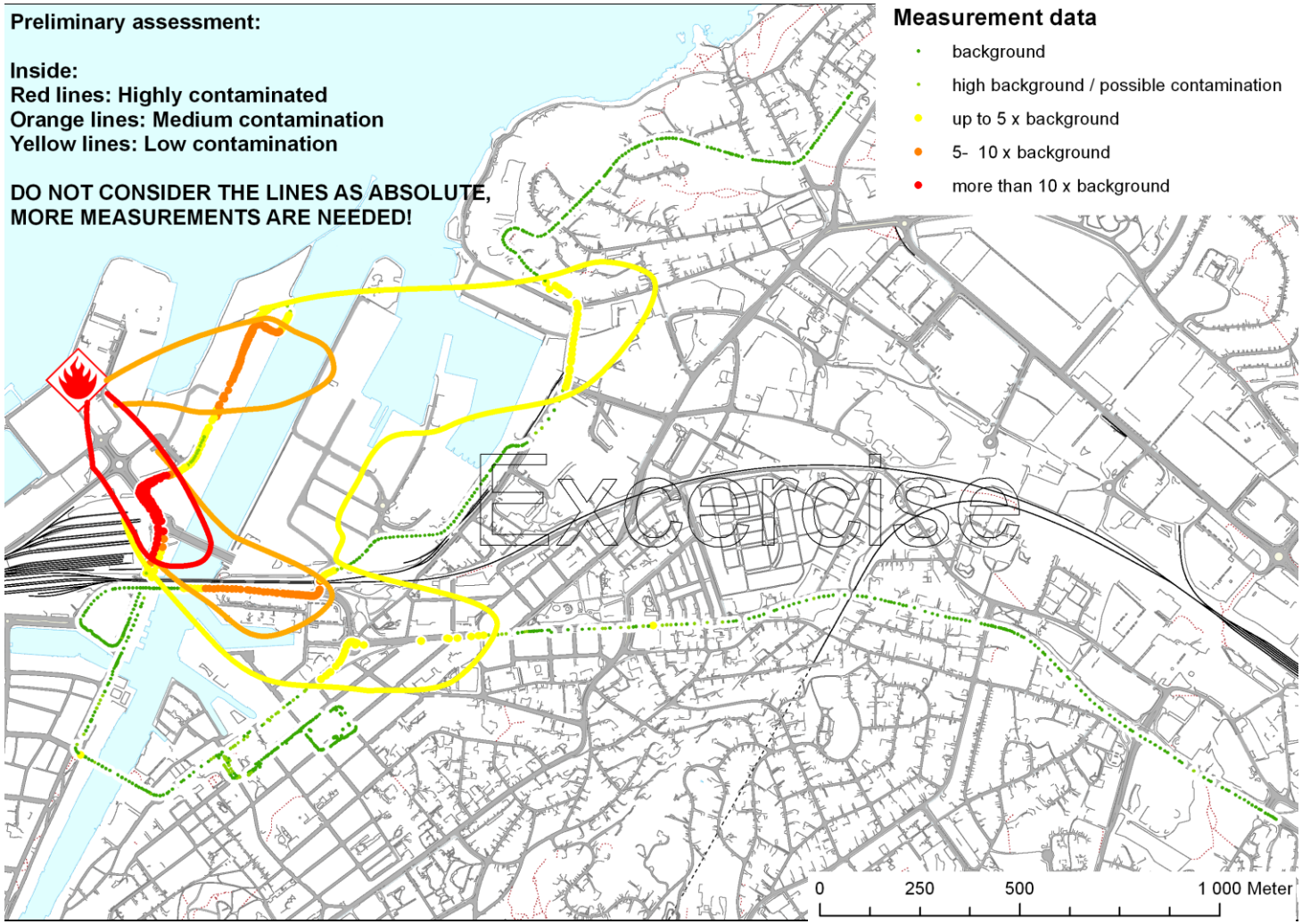

Figure A11.Trip 3 Results for Participant 15.

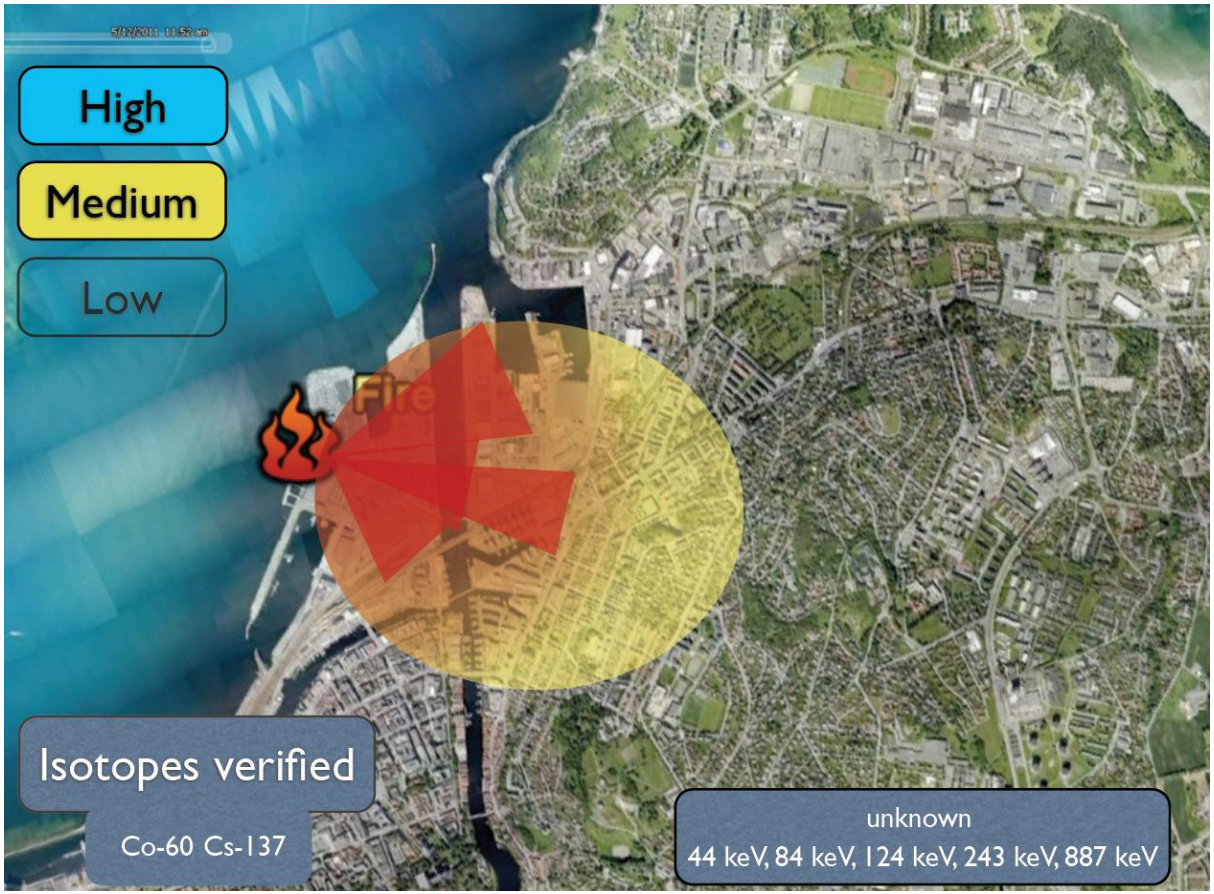

Figure A12.Trip 3 Results for Participant 16.

Figure A13. Trip 3 Results for Participant 17.

Bibliographic Data Sheet **NKS-252**

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Abstract	In recent years carborne gamma spectrometry has expanded from its role as a geological survey platform to serving as a useful asset in the field of emergency response to radiological and nuclear situations. Its two main applications are searching for orphan sources and for surveying in the aftermath of an accident involving the release of radioactive materials. Despite this expansion, the opportunities for gaining practical experience in the field are limited by cost considerations and practicability. These limitations are exacerbated by the fact that data generated and displayed in the field differ significantly from gamma spectral data generated in a laboratory environment. As a means of exercising existing emergency measuring/surveying capability and introducing carborne measurements to a larger group, a virtual exercise was devised. The exercise ORPEX (Orphan Sources and Fresh Fallout Virtual Exercise in Mobile Measurement) featured two typical emergency scenarios in which carborne measuring systems might be deployed: firstly a search for multiple orphan sources and secondly surveying to delineate patchy fallout from a local release point. In the first scenario, synthetic spectral data were generated for imaginary point sources and inserted into genuine carborne measurements from in the Trondheim area of Norway. Participants were presented with a typical software tool and data in a range of typical formats and asked to report the source locations and isotopes within a time limit. In the second scenario, synthetic spectral data representing fallout from a local fire involving radioactive material were added to real carborne data from the Trondheim area. Participants were asked to produce maps that identify and characterise the regions of contamination within the same time limit. Fourteen individual organisations from seven different countries supplied results. Results from participants indicate that for strong sources of isotopes with simple spectra featuring high energy peaks, location and identification is not a problem. Problems arise for isotopes with low energy signals or that present a weak signal even when visible for extended periods. Experienced analysts tended to perform better in identification of sources even if they were inexperienced in mobile measurements whereas those with experience in such measurements were more confident in providing more precise estimates of location. The results indicated the need for the inclusion of less frequently encountered sources in field exercise related to mobile measurements.
Key words	Mobile gamma spectrometry, orphan sources, exercise

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