NGU Report 96.054

Airborne mapping of radioactive contamination. Results from a test in Finland, RESUME95

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REPORT

Report no.: 96.054	ISSN 0800-3416	Grading: Open

Title:
Airborne mapping of radioactive contamination. Results from a test in Finland, RESUME95.

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County:		Commune:	
Map-sheet name (M=1:250.000)		Map-sheet no. og -name (M=1:50.000)	
Deposit name and grid-reference:		Number of pages: 21 Map enclosures: 2	Price (NOK): 130,-
Fieldwork carried out: 16.08.95	Date of report: 27.03.96	Project no.: 2676.00	Person responsible: [signature]

Summary:

The Geological Survey of Norway participated in the exercise RESUME95 (Rapid Environmental Surveying Using Mobile Equipment 95) in Finland, during August 1995. The purpose of the exercise was to (1)test preparedness in the Nordic countries for accidents involving the release and dispersal of radioactive material, (2)compare results from the different teams participating in the exercise, (3) establish routines for the exchange of data and (4)investigate the possibility of international assistance in the event of nuclear accidents.

The Geological Survey of Norway carried out a survey over three test areas(area I, II and III). All three areas were contaminated with man made radionucleides in the days following the Chernobyl nuclear reactor accident. The Cesium-137 contamination level was reported to be about 50 kBq/m ^{2} in area I, and this area was used for calibration. In area II mapping of Cesium-137 ground concentration was carried out. Detection of hidden artificial radiation sources were the main purpose in area III

This report describes the exercise - RESUME95, field operations, calibration, mapping of Cesium-137 ground concentration and detection of hidden point sources. Results are presented as colour maps

Keywords:		
		Geofysikk
		Radiometri
		Fagrapport

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1. INTRODUCTION

The Geological Survey of Norway participated in the exercise RESUME95 (Rapid Environmental Surveying Using Mobile Equipment 95) in Finland, August 1995. Organiser of the exercise was NKS (Nordisk kjernesikkerhetsforskning). Teams from the Nordic and other countries carried out airborne gamma ray surveys over three test areas (I, II and III) to (1) test their preparedness for accidents involving the release and dispersal of radioactive material, (2) compare results from the different teams (3) establish routines for the exchange of data and (4) investigate the possibility of international assistance in the event of nuclear accidents. All three test areas had traces of Chernobyl fallout. Ten artificial radiation sources unknown to the participants were placed in the terrain in area III. Results from the exercise include (1) mapping of ^{137}Cs ground concentration in area II and III and (2) location of hidden point sources in area III.

In order to obtain further standards of reference, measuring systems from Canada, France, Germany and Scotland participated in the exercise.

2. FIELD OPERATIONS

2.1 Description of test areas

Measurements took place in three different areas, known as areas I, II and III. All areas were contaminated with man made radionucleides in the days following the Chernobyl nuclear reactor accident. A number of radioactive sources were hidden in area III.

Measurements area I: Area I was a part of the Vesivehmaa airfield and was used for calibration of the radiometric system. Measurements were carried out for a few minutes at different altitudes (10, 25, 50 and 75 metres) over a part of the airfield where the ^{137}Cs contamination level was reported to be 50 kBq/m^2 (Multala & Erkinheimo 1995). Data from the calibration were used to find the function converting counts at height h to ground concentration of ^{137}Cs.

Measurements area II: Area II was rectangular in shape with side lengths of 3 km and 6 km. Radiometric data were collected in this area to map Cs falldown from the Chernobyl accident. Parallel survey lines were flown with a line spacing of 150 metres. Flying altitude was nominally 60 metres. Total flying distance in this area was approximately 200 km.

Measurements area III: Area III was rectangular and measured 1 km by 5 km. Ten artificial radiation sources were placed in area III (Lahtinen et al 1996). One of the sources was a line source, the others were point sources (three of them columated). The radionuclides used in the sources were ^{60}Co (Cobalt), ^{137}Cs (Cesium), ^{99m}Tc (Technetium) and ^{192}Ir (Iridium). Table 1 gives information on the radiation sources in area III. Line spacing in this area was approximately 100 metres and same flying altitude as area II was used. The total flying distance in this area was 55 km.

Table 1 **Radiation sources area III**

	Code name	Nuclide	Activity (Bq)
1	Co1	^{60}Co	$2.6x10^{8}$
2	Co2 (Columated)	^{60}Co	$3.3x10^{8}$
3	Co3	^{60}Co	$2.6x10^{7}$
4	Co4 (A 'line' of 6 point sources)	^{60}Co	$3.7\text{-}6.7x10^{7}$
5	Cs1	^{137}Cs	$2.8x10^{9}$
6	Cs2 (Columated)	^{137}Cs	*$1.3\text{-}1.7x10^{9}$
7	Cs3	^{137}Cs	$2.8x10^{8}$
8	Cs4	^{137}Cs	$5.4x10^{8}$
9	Ir (Columated)	^{192}Ir	$5.6x10^{11}$
10	Tc	^{99m}Tc	$2(1.1x10^{9})$

*Exact information on activity not available.

2.2 Description of equipment

Aircraft: The survey was flown using an Aerospatiale Ecureuil, Twin Star AS 355F.

Radiometrics: Radiometrics were recorded with a 1024 cubic inch crystal volume detector which was coupled to a Exploranium GR820 gamma-ray spectrometer system. The crystal was mounted under the helicopter. Accumulation time for the spectrometer was one second during the measurements. With flying speed 100 km/hour and altitude 60 meter the radiation from approx. 120 meter X 150 meter ground area is recorded every second.

Data Acquisition: Data were recorded digitally with a DAS-8 data acquisition system manufactured by RMS Instruments Ltd. An integrated part of the data acquisition system is a thermal graphic printer, which allows output of the system to be monitored in real time.

Navigation: The survey was flown with satellite navigation (GPS). Differential corrections were applied to the navigation data during processing, giving an accuracy of ±15 m in the positioning.

Radar altimeter: A King KRA-10A radar altimeter was mounted in the helicopter to provide ground clearance information to an accuracy of 5% of flying height. The primary use of the radar altimeter data is an aid for maintaining constant ground clearance, but the data were also used in the processing of the measured radiometric data.

2.3 General

Data were collected over all three areas in one flight during the 16th of august 1995. The weather conditions during the flight were good. Operators from the Geological Survey of Norway were Henrik Håbrekke and John Olav Mogaard.

3 MAPPING OF CESIUM GROUND CONCENTRATION

3.1 Processing of Cs maps

Software from Aerodat Ltd (Canada) and Geosoft (Canada) were used in the processing of collected data. Mapping of the Total Count, Potassium, Uranium and Thorium window is the normal procedure during geophysical helicopterborne measurements at the Geological Survey of Norway. The processing sequence normally used was modified to include mapping of Cesium ground concentration. The processing tasks for the Total Count, Potassium, Uranium and Thorium(TC, K, U and Th) window are divided into these logical steps:

- Importing data to the software system (database)
- Correcting data for instrument deadtime
- Removing background contributions from cosmic radiation and aircraft
- Correcting spectral overlapping(Compton scattering) and height attenuation effects

Output from these processing steps are required in the processing of the Cesium window (^{137}Cs). Spectrometer data are normally measured in counts per second. The spectrometer requires some time each second to process the incoming data, and during this time period (deadtime) no counts are measured. The Exploranium GR820 gamma-ray spectrometer system record the time during which the crystal is actually measuring. This resulting value is referred to as livetime (measuring period minus the deadtime). In this case the processing software applies a livetime(in sec) correction:

$$C = c / \text{livetime}$$

C - corrected count in each second

c - uncorrected data

Background radiation is caused by high energy cosmic ray particle interaction with the atmosphere and radiation from the radioactivity of the aircraft and equipment. Correction for background radiation were made by subtracting average background values from the data at each data point. The average background values were determined from measurements over water (e.g. lakes).

Stripping was carried out to remove effects of spectral overlap. This is prerequisite in radiometric data processing to give the counts in the potassium, uranium and thorium windows that are uniquely from potassium, uranium and thorium. Usually the Total Count, Potassium, Uranium and Thorium window are presented as counts per second in flying altitude (250 feet) maps. This is done by normalising data to a height of 250 feet using data from the radar altimeter. Processing of the Cesium (^{137}Cs) window requires stripped, but not height corrected, data in the Potassium, Uranium and Thorium window.

Livetime correction was also applied to the data in the Cesium window (^{137}Cs) to normalise data to counts per second. The next step was to remove background radiation (cosmic radiation and radiation from aircraft). The background radiation measured over water was removed by subtracting the background from the data at each data point in the Cesium window. Due to spectral overlap Potassium, Uranium and Thorium was stripped out of the Cesium window to give the counts in the Cesium window that are uniquely from Cesium. The stripping ratios (Cs/U, Cs/K and Cs/Th) were experimentally determined by a procedure over calibration pads. Results from the calibration area (area I at Vesivehmaa airfield) were used to convert stripped data in the Cesium window from 'counts at flying altitude' to ground ^{137}Cs concentration (kBq/m^2).

3.2 Calibration

3.2.1 Stripping ratios for the Cesium window

Stripping ratios for the Cesium window were experimentally determined by a procedure over calibration pads. Three pads with pure Potassium, Uranium and Thorium spectra were used to determine interfering effects of Potassium, Uranium and Thorium in the Cesium window. A fourth low radioactivity pad (background pad) was used to remove effects of the background radiation from the surrounding ground, the equipment, cosmic radiation and radon decay products in the air. Measurements were carried out over the different pads for a period of 2-3 minutes. Data in the Potassium, Uranium, Thorium and Cesium window were recorded for the determination of the stripping ratios. Table 2 shows the average counts per second in each window over the four different pads.

Table 2 Measurements over calibration pads in unit counts per second.

PAD	Potassium	Uranium	Thorium	Cesium
Background	245.27	28.39	27.74	353.80
Potassium	1013.97	22.83	24.66	784.00
Background	244.56	28.63	27.61	363.31
Uranium	635.29	516.85	67.48	2736.64
Thorium	472.54	204.40	545.95	2540.36
Background	244.05	28.56	27.51	363.18

Stripping ratios are given by:

Potassium pad: Cs/K = (Cs - Cs background) / (K - K background)

Uranium pad: Cs/U = (Cs - Cs background) / (U - U background)

Thorium pad: Cs/Th = (Cs - Cs background) / (Th - Th background)

Cs - counts per second in cesium window
K - counts per second in potassium window
U - counts per second in uranium window
Th - counts per second in thorium window
Background values of Cs, U, K and Th are measured over the background pad.

Determined stripping ratios:

Cs/K = (784.00 - 353.80) / (1013.97 - 245.27) = 0.56

Cs/U = (2736.04 - 363.31) / (516.85 - 28.63) = 4.87

Cs/Th = (2540.36 - 363.18) / (545.95 - 27.51) = 4.20

From this we can find counts in the Cesium window using:

$$Cs^* = Cs - (Cs/K)K^* - (Cs/U)U^* - (Cs/Th)Th^*$$

Where X* represents counts uniquely from the element.

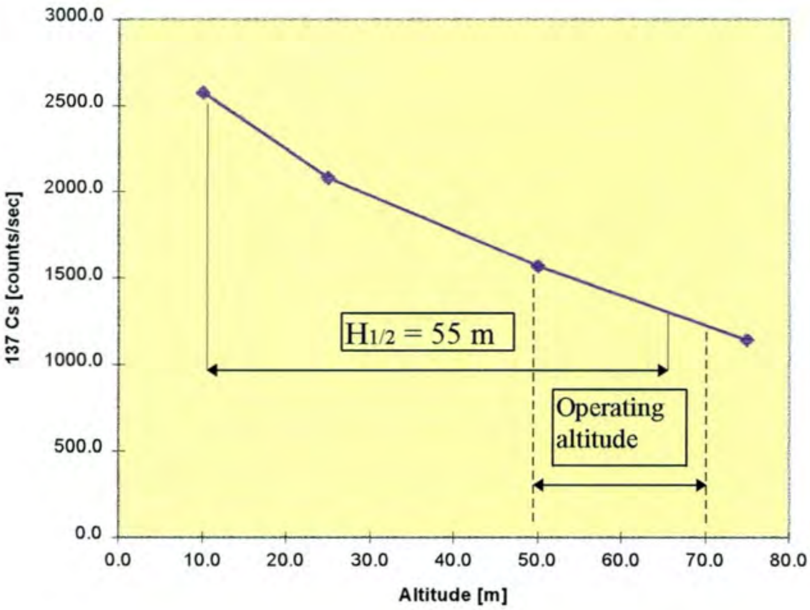
3.2.2 Ground concentration

During the exercise in Finland calibration measurements were carried out at Vesivehmaa airfield over an area with known contamination level (^{137}Cs). Measurements were taken in different altitude (10, 25, 50 and 75 metres) for a time interval of 1- 2 minutes. Table 3 shows data (average values) recorded for the Cesium-137 window in unit counts per second.

Table 3 Counts in the Cesium window (^{137}Cs) over known ground concentration - approx. 50 kBq/m^2

Altitude [m]	^{137}Cs [counts per second]
10	2569
25	2074
50	1560
75	1135

Fig. 1 Counts as a function of altitude over calibration area (area I).



The counts at ground level are calculated from counts at height h using the formula:

$$\text{Counts}_{\text{(ground level)}} = \text{Counts}_{\text{(flying altitude)}} * e^{\lambda h}$$

$$\lambda = (\log 2)\, H_{1/2}$$

Where $H_{1/2}$ is the height where counts are halved. From Fig. 1 we have $H_{1/2}$ = 55m which gives:

$$\lambda = 0.0126$$

Counts at height h to ground level is then given by:

$$\text{Counts}_{\text{(ground level)}} = \text{Counts}_{\text{(flying altitude)}} * e^{0.0126h}$$

Table 4 shows calculated counts/sec at ground level for the different altitudes.

Table 4 Counts at ground level calculated from measurements at different altitudes.

Altitude [m]	^{137}Cs - ground level [counts/sec]
10	2914
25	2841
50	2929
75	2920

Counts normalised to ground level from altitude 25 m are anomalously low compared to the other three. This may be due to inaccurate radar altimetry or inhomogenous contamination in the calibration area. The value calculated at altitude 25 m is only 2-3% lower than the other values. The average value for counts at ground level using all four values is 2899 counts/sec. The contamination level in the calibration area was known to be approx. 50 kBq/m ^{2} (Multala & Erkinheimo 1995). Counts at height h are then converted to ground concentration using :

$$\text{Concentration}_{(\text{ground})} = \text{Counts}_{(\text{height h})} * e^{0.0126h} * (50 / 2899)$$

$$\text{Concentration}_{(\text{ground})} = \text{Counts}_{(\text{height h})} * e^{0.0126h} * 0.0172$$

3.3 Results

Map 1 shows calculated Cs-137 ground concentrations in area II and III. In this map we have used the Finnish coordinate system.

The average ground concentration of ^{137}Cs in area II at the time of the exercise (August 95) was found to be approximately 60 kBq/m ^{2} (^{137}Cs). Standard deviation was found to be 16.0 (variance 16.0^2). The peak concentration of ^{137}Cs in area II was approx. 90 kBq/m ^{2} (around coordinates 2558600,6802800).

The peak concentration of (Chernobyl) ^{137}Cs in area III was approx. 70 kBq/m ^{2} (around coordinates 255300, 6801700). Note that the highest value in the Cesium window is from a artificial source (around coordinates 2552800, 6802400).

4 DETECTION OF POINT SOURCES

4.1 Software for rapid detection of point sources

One purpose of the exercise was the detection of hidden sources in area III. The Geological Survey of Norway was only capable of detecting sources leading to the production of gamma rays with energies in the Potassium, Uranium, Thorium and Cesium-137 windows at the time of the exercise. Detection of man made point sources (with unknown compositions) requires inspection the full gamma ray spectrum, and software was developed for this task after the exercise.

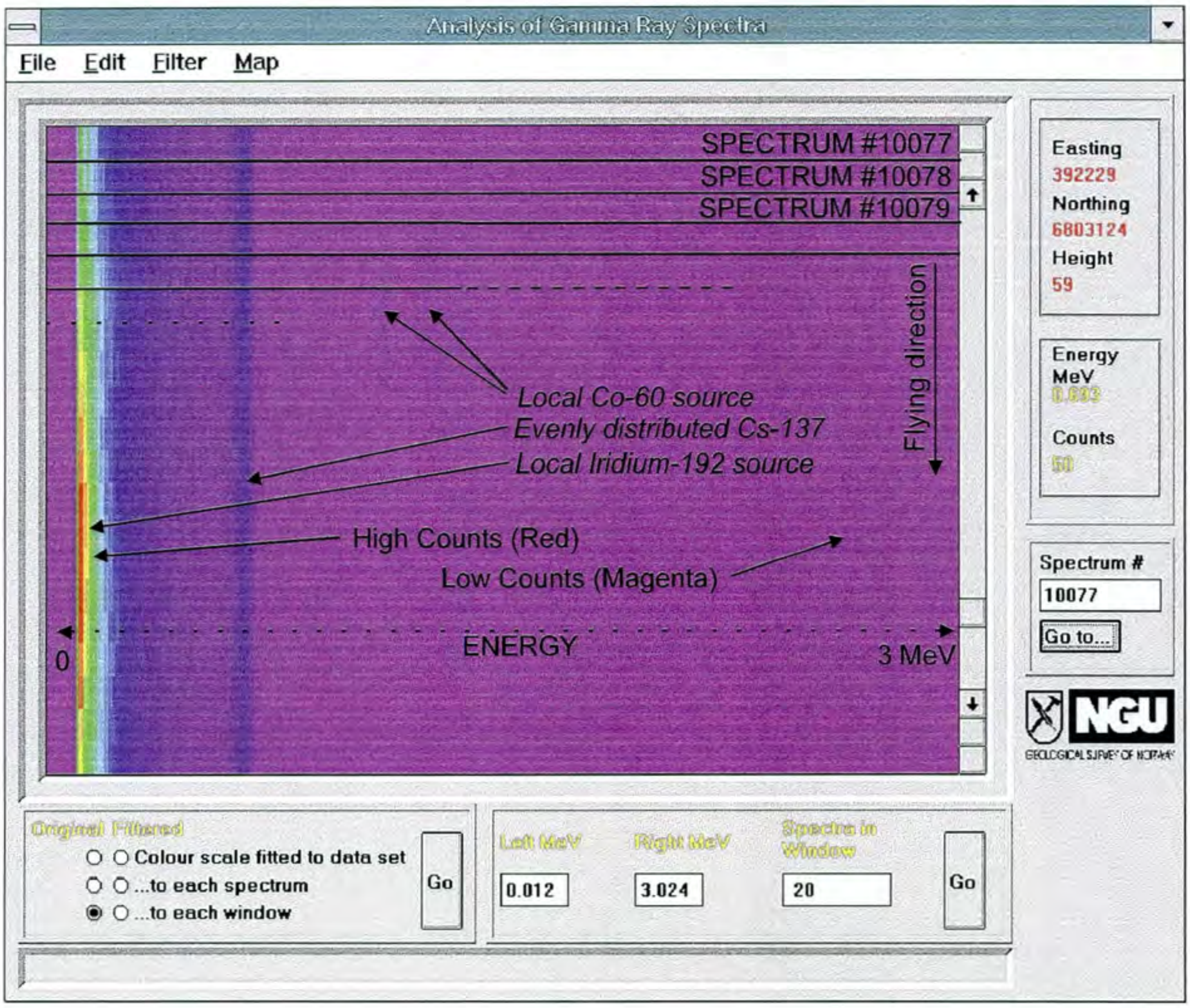
During helicopterborne surveying one (255 channel) spectrum is acquired per second. Over 12500 full spectra were recorded during NGU's survey of areas II and III. The new computer application graphically displays a single spectrum as a horizontal strip. The start (left) of the strip represents low energy gamma rays and the end (right) represents high energy. The changing colour of the strip along its length indicates changing numbers of gamma rays detected. Increasing numbers of gamma rays are represented by the colours Magenta, Blue, Green, Yellow and Red respectively. Many spectra can be displayed simultaneously as strips arranged in a graphical window one below the other. Fig. 2 shows the computer application's main window displaying 20 spectra from the Finland test. In the figure, 20 adjacent spectra are displayed in a vertical stack where the first is at the top and the last at the bottom. In this case spectrum number 10077 is the first and 10096 the last. There is a scroll bar to the right of the graphical window which can be used to scroll all 12500 spectra through the window, thereby revealing previously hidden portions of the data. It is possible to use a map of the flight plan (accessed via menu item 'Map') to jump to a part of the data set at a specific geographic location. Conversely, the map can be used to show the geographic location of the spectra in the graphical window.

As the computer mouse is moved over the strips representing gamma ray spectra the following information is displayed:

- The number of the spectrum displayed under the mouse (#10077 in Figure 2)
- The geographic location and height for the spectrum under the mouse (East=392229, North=6803124, Height=59m, WGS 84)
- The energy range being displayed (0.012 MeV to 3.024 MeV in Figure 2)
- The Energy of the channel positioned under the mouse (0.693 MeV in Figure 2)
- The number of spectra displayed in the window (20 in Figure 2)
- The state of filtering of data displayed in the window (not filtered in Figure 2, with a colour scale adjusted to fit only the spectra displayed in the window)

Fairly evenly distributed nuclides produce spectral peaks which appear in all measured spectra and therefore appear in the graphical window (Fig. 2) as vertical lines - peaks present in all 20 spectra on display (e.g. ^{137}Cs). Gamma rays due to point sources are only detected in a few spectra as the aircraft quickly passes them. In figure 2 a few adjacent spectra have high counts (red colour) at low energies caused by a nearby point Iridium-192 source.

Fig. 2 Application for examining spectra: main window (see text for explanation)



4.2 Example of spectra from hidden point sources

We detected all but one of the point sources hidden in area III (Cs2). The analysis of individual gamma ray spectra with the computer program described in section 4.1 took approximately 3 hours. Two sources (Technetium and Iridium) were easy to find (Fig. 3 and Fig. 4), although we were unable to identify the nuclides responsible for the detected radiation. It was clear from our data that the Iridium source was located to the east of the survey area (Fig. 5). The Cobalt sources were not easy to observe in the total spectrum, but looking at a window from 0.708 MeV to 1.560 MeV they were comparatively easy to find (Fig. 6). All Cobalt sources created two clear peaks in nearby gamma ray spectra at 1.17 and 1.33 MeV.

The Cesium sources were difficult to find, not least because of varying amounts of Chernobyl Cesium in the region. We identified 3 of the four Cesium sources placed in the survey area. Cs1 (Fig. 7) and Cs4 were found first, while examining spectra from the survey. Cs3 was found only because attention was being paid to the nearby Co1 source. Initially, the proximity of the source Ir made the Co1 and Cs3 sources difficult to see (Fig.8). This is because much of the colour scale used to display the spectra was used on the large anomaly caused by Ir. When the lower energy channels were removed from the display both Co1 and Cs3 became clear (Fig. 9).

Fig. 3 The signal produced by the Technetium source. Gamma radiation caused by the presence of the source is visible on only three spectra, obtained over a horizontal distance of approx. 100 m.

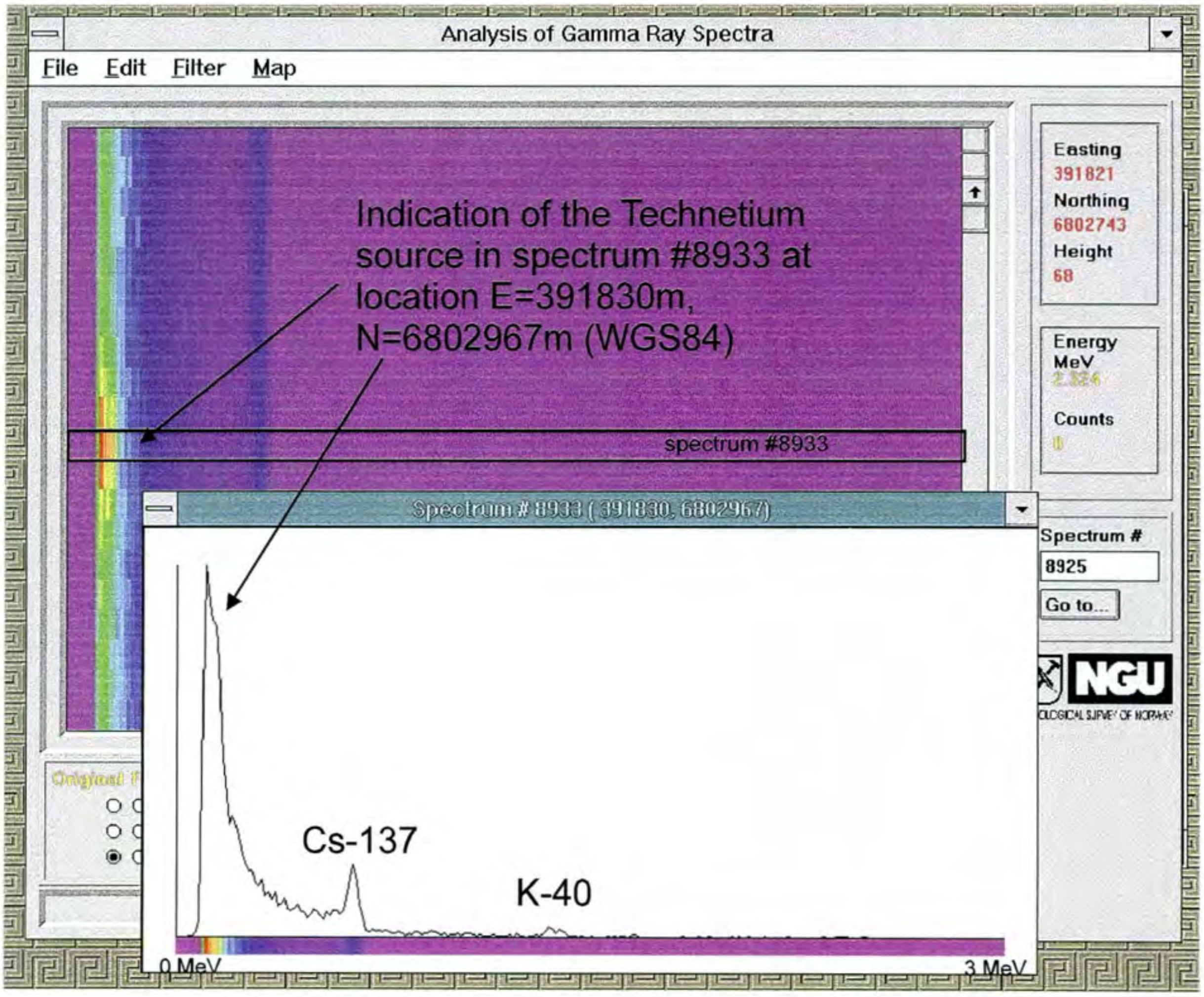


Fig. 4 The signal produced by the Iridium source.

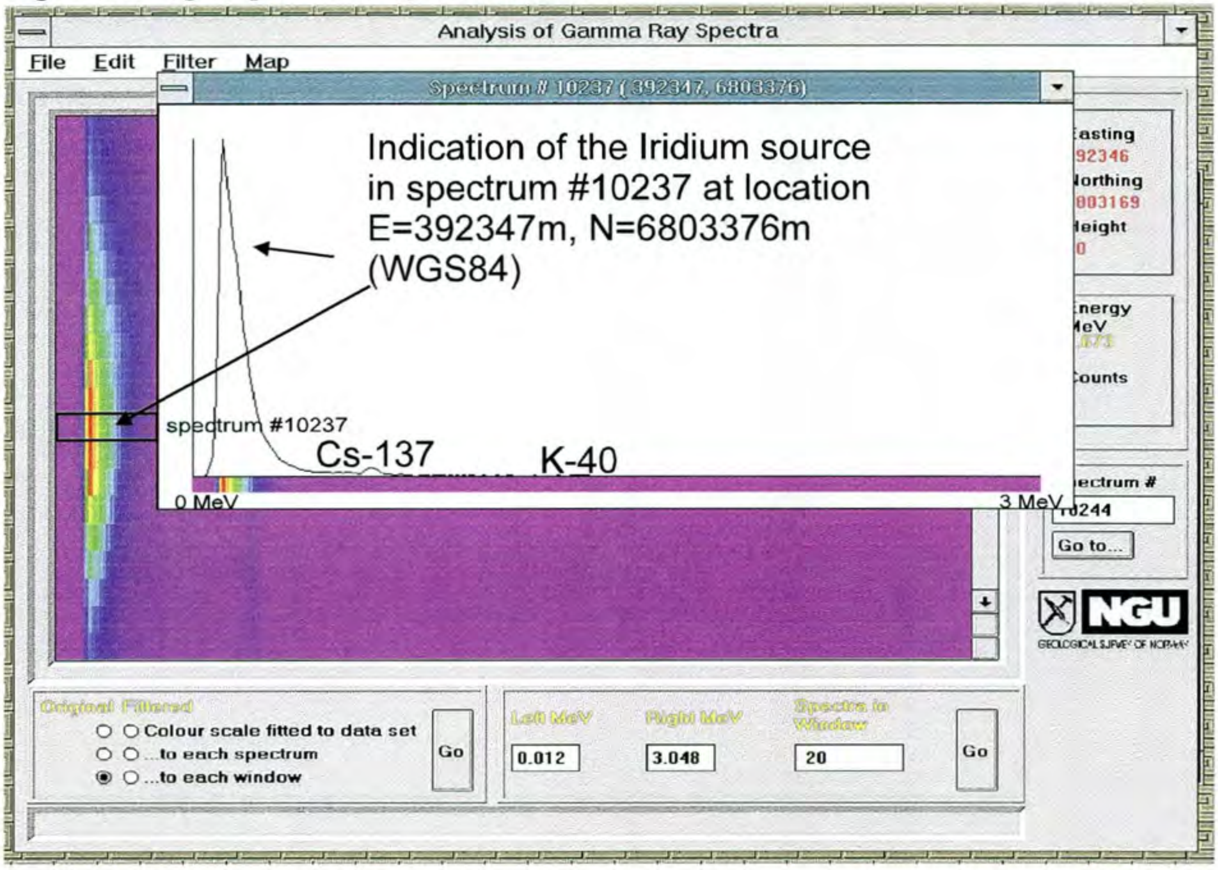


Fig. 5 Location of the Iridium source

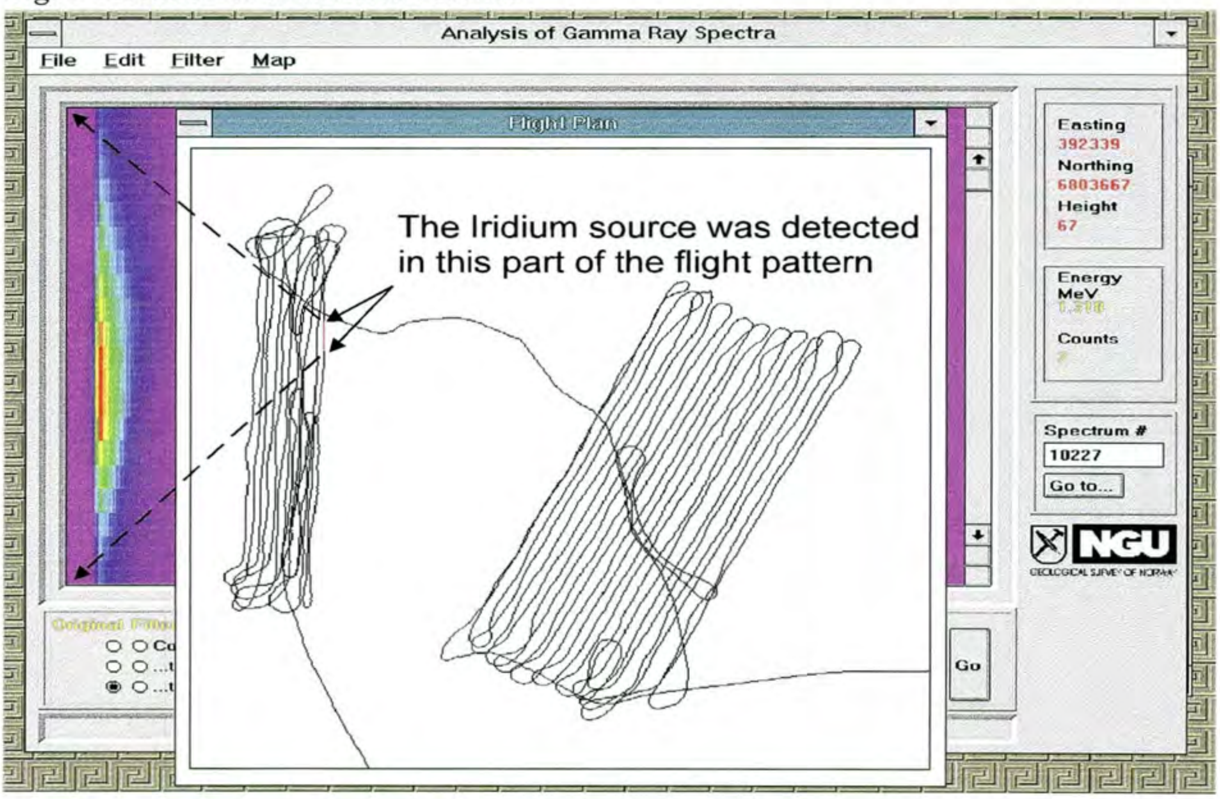


Fig. 6 Gamma ray spectra over Cobalt-60 source Co2. Note that in the lower diagram the energy window 0.708 MeV to 1.560 MeV is used to enhance the view of the Cobalt-60 peaks. This energy window was used to 'scan' the data set for Cobalt-60 sources.

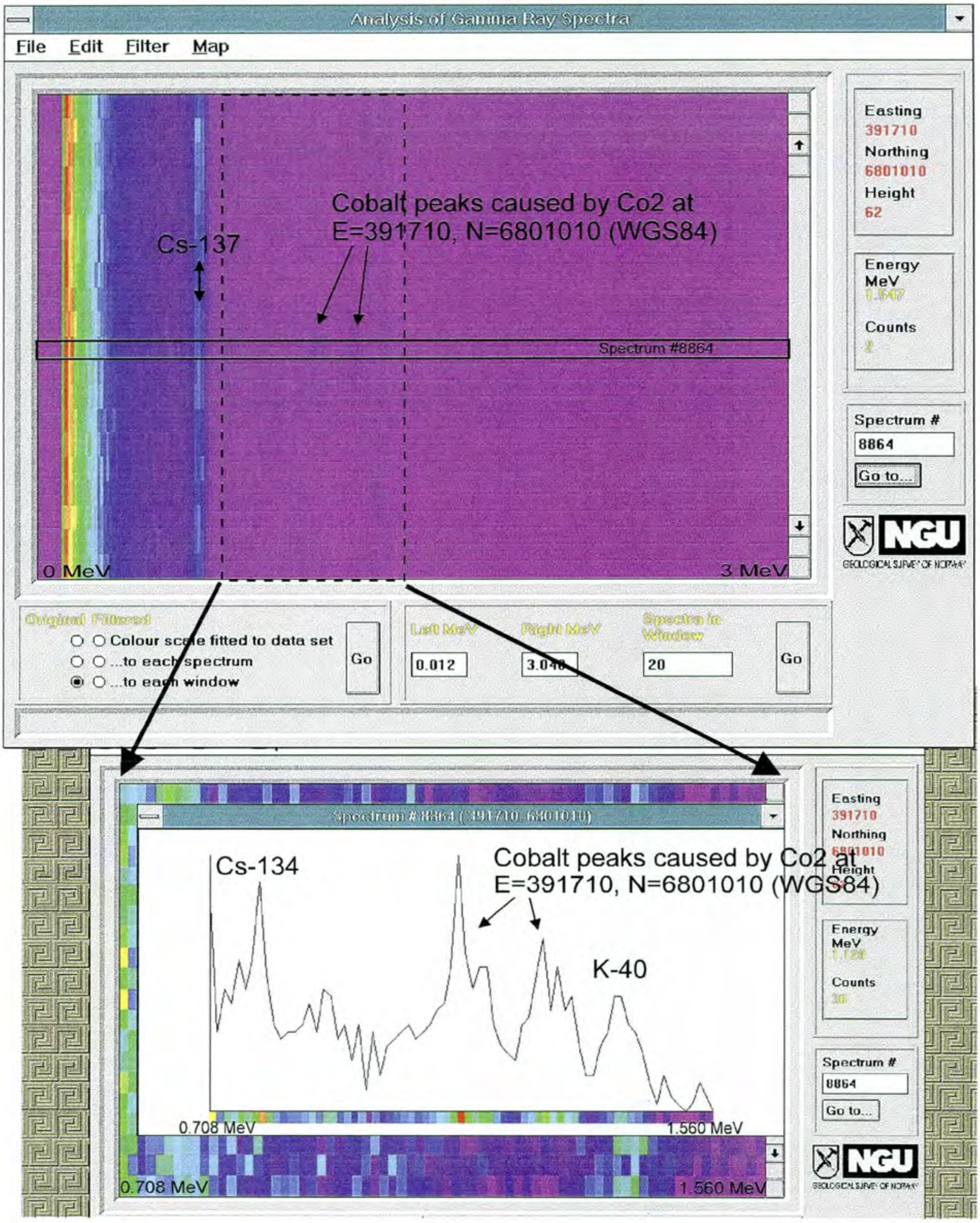


Fig. 7 Spectra obtained above source Cs1. Low energy channels (<0.324 MeV) are not shown.

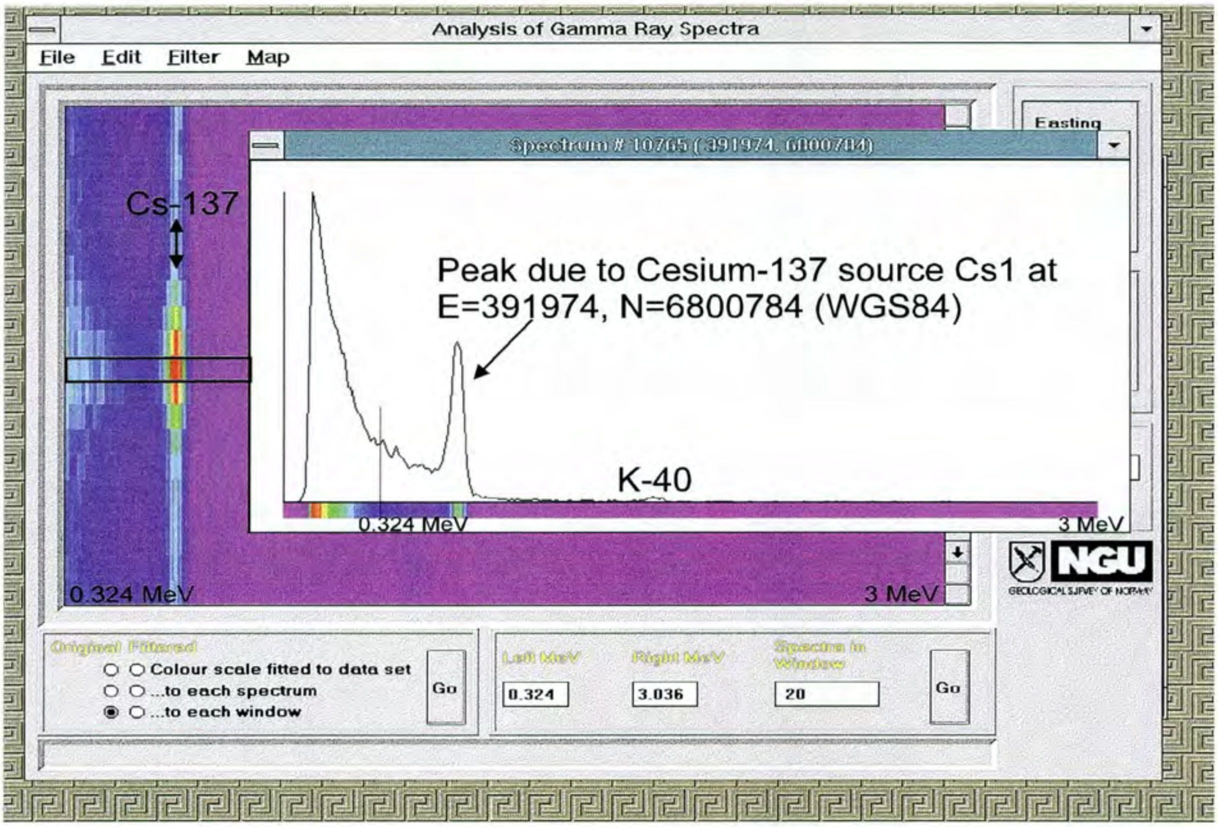


Fig. 8 Spectra obtained in the vicinity of the Iridium source are domintated by it.

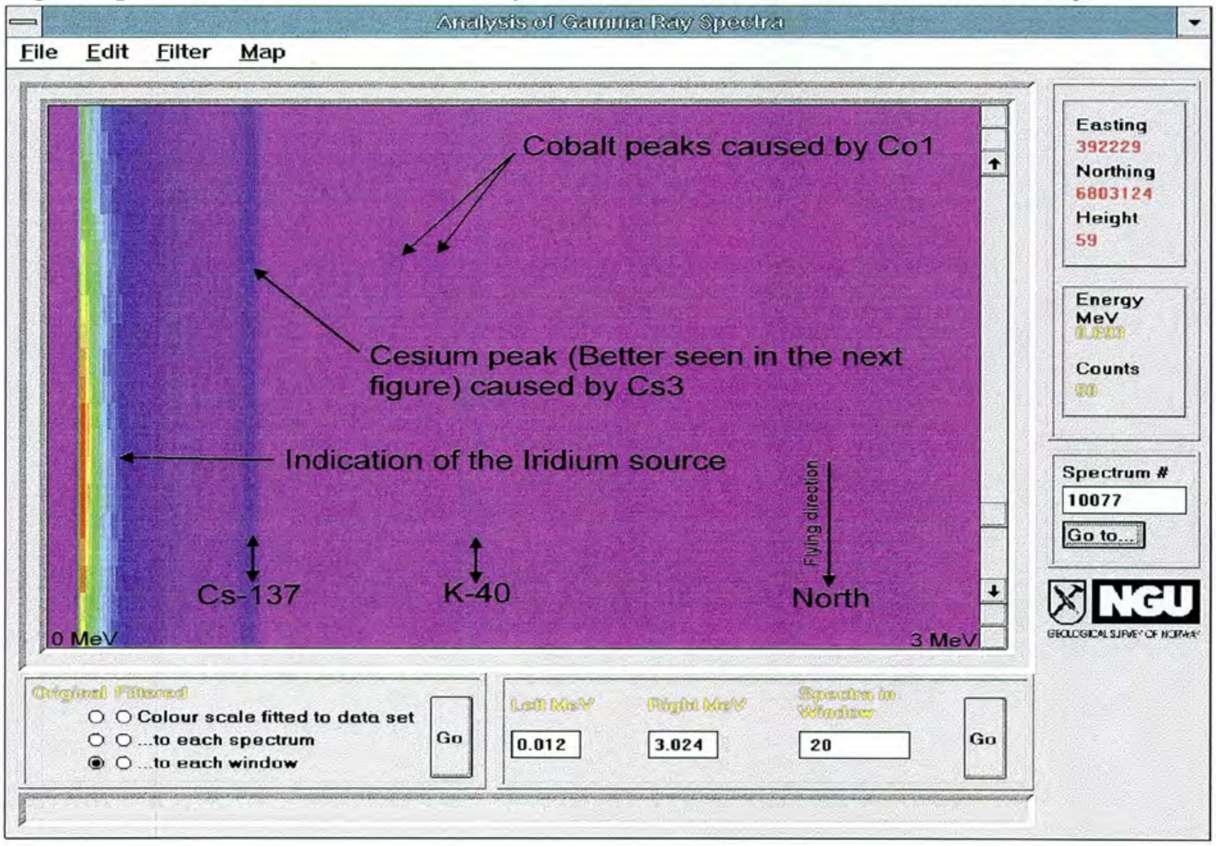
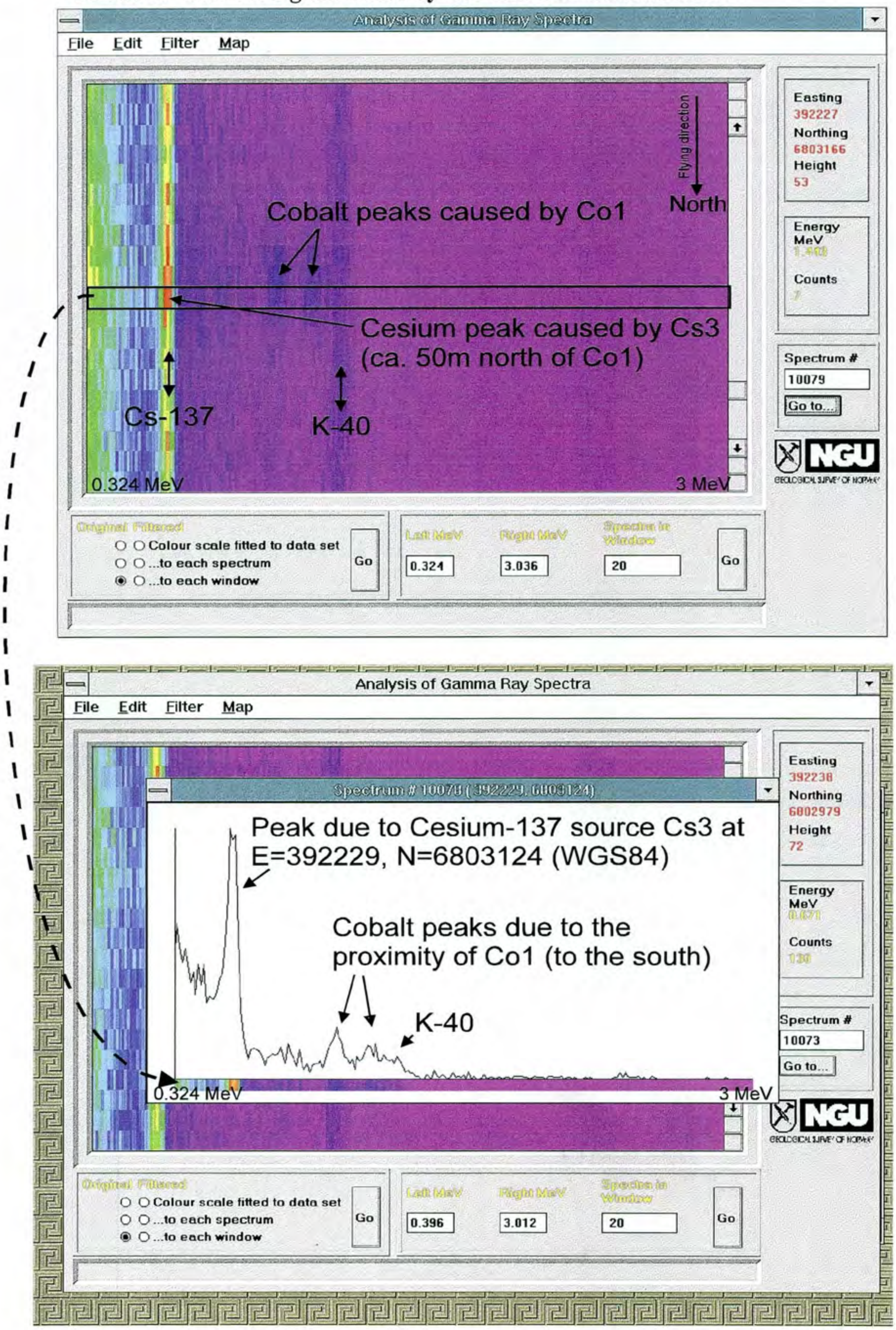


Fig. 9 When the low energy (< 0.324 MeV) parts of the spectra in Fig. 8 are excluded view the signals cause by Cs3 and Co1 become clear.



4.3 Results as map presentations

A hard copy Cesium source map was produced in approximately 20 minutes (Map 2b, WGS84 coordinates). In this case we created a Cesium-137 map extracting counts in the cesium energy window, and performed two-dimensional high-pass filtering to retain just the sharp detailed spatial features of the cesium-137 distribution. Filtering was carried out in the frequency domain using a Gaussian cut-off with a standard deviation of 0.004 cycles per metre (which has the effect of eliminating Cesium anomalies with wavelenghts much in excess of 500 m). The Cesium source map (Map 2b) clearly indicates the positions and relative activities of Cs1 and Cs4. Although Cs3 was identified during examination of the spectra, it does not appear on the map. One anomaly appears on the map which does not correspond in position to any of the cesium sources. This feature is caused by high-pass filtering of the gamma radiation from a small island or peninsula. The high-pass filtering procedure hides low radiation areas such as lakes (which are easy to see in the original Cesium map). Conversely, the sharp increase in Cesium on an island will be retained in the high-pass filtered data set. We returned to the original spectra to check this Cesium anomaly and immediately noticed that all spectra peaks (Cs-137, U, Th and K) fell to zero on either side of the Cesium anomaly, as would happen over water.This anomaly could therefore be discounted as a source without ground follow-up work. Another feature was found of the Cesium map approximately 1 km north of Cs1. There was no Cesium source placed at that position and it is therefore of unknown significance. There is wet ground in the vicinity of the feature which might enclose a small dry region - a pattern which could result in a sharp local Cesium anomaly. This feature is crossed by two flight lines. The columated Cs2 source was not detected by NGU, probably due to the line spacing.

Once the Cobalt sources were recognised it took approximately 20 minutes to extract counts in the two energy windows (for Co-60) and make and print a Cobalt map (see map 2c). All three of the Cobalt sources placed within the survey area are clearly represented on the map, along with an indication of their relative activities. The shape of the line-source Co4 is reproduced well in the map. The fourth is located outside the survey area to the east.

5 CONCLUSION

The purpose of the exercise in Finland was to obtain standards of reference and detection of hidden sources in area III. A reference for calculation of Cesium-137 ground concentration was obtained through the calibration test over area I. This reference can be used when mapping Cesium-137 contamination level after a fall out. The average ground concentration of ^{137}Cs in area II was found to be 60 kBq/m^2 with a peak value of 90 kBq/m^2.

The software application developed at the Geological Survey of Norway detected all but one hidden source in area III. The application allows analysis of gamma ray spectra almost immediately after a flight.

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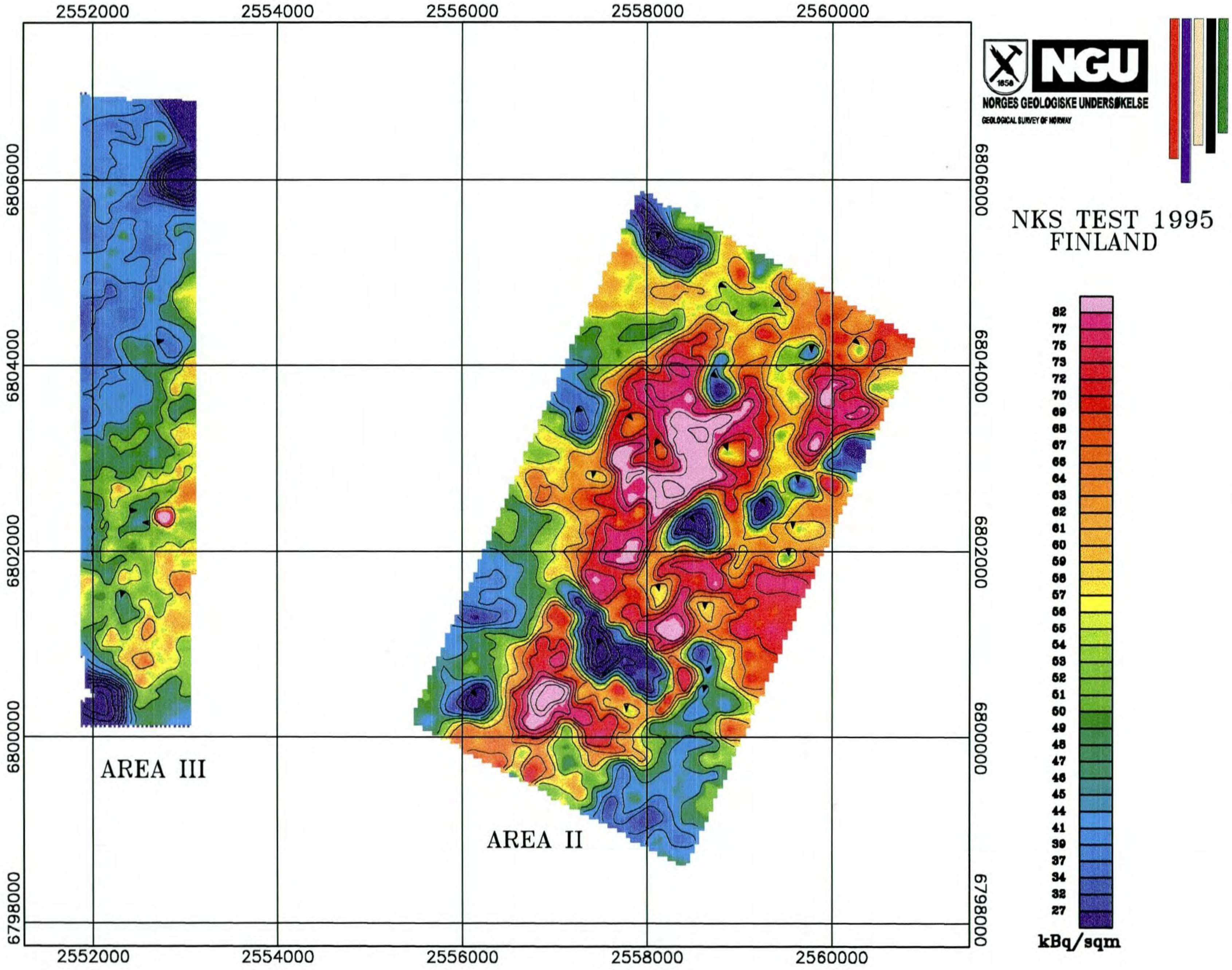


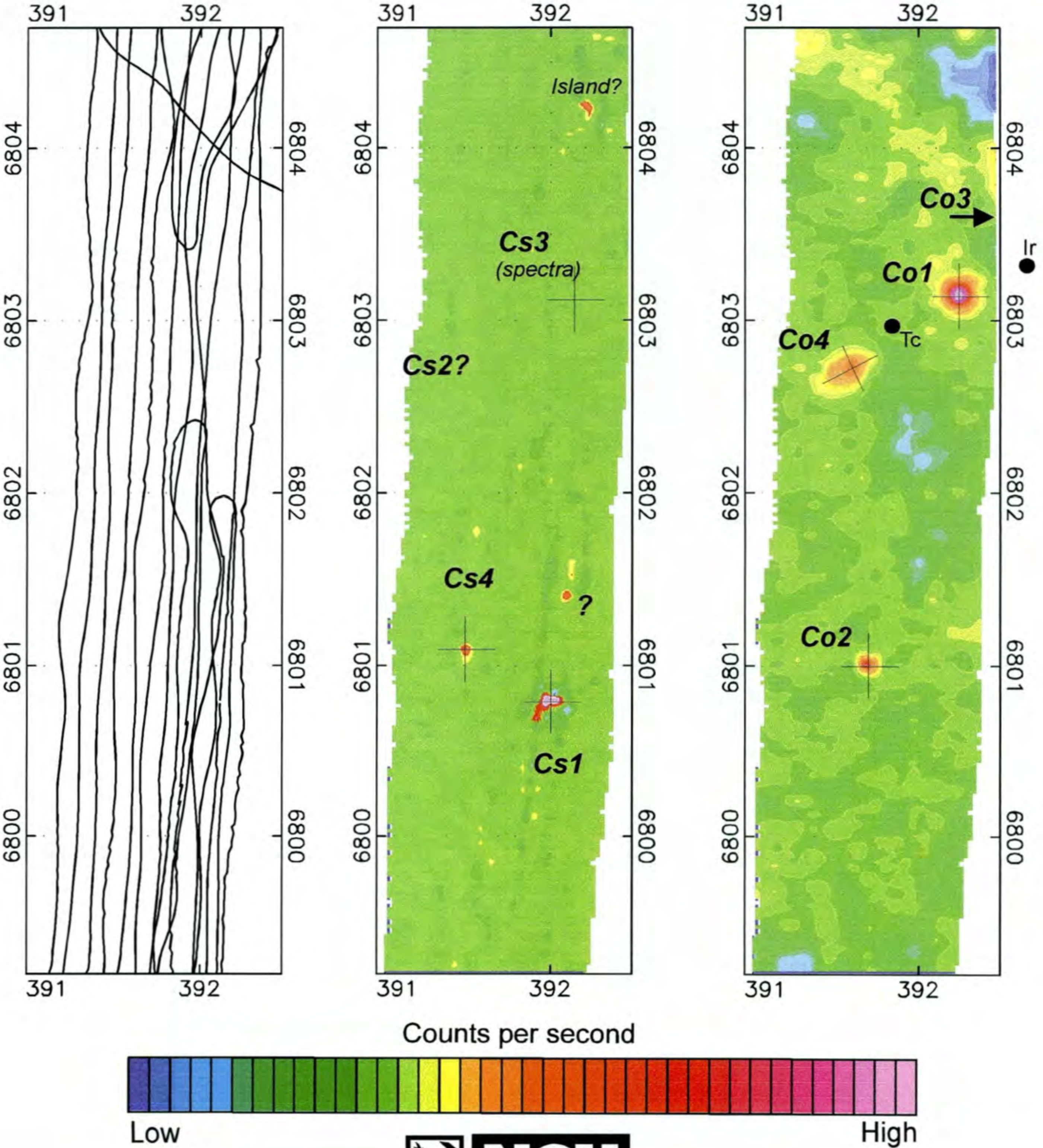
MAP 1 CESIUM GROUND CONCENTRATION

Map 2 Point source detection area III

a)
Flight pattern

b)
Cesium-137 point source detection

c)
Cobalt-60 point source detection



GEOLOGICAL SURVEY OF NORWAY