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REPORT

Report no.: 2000.088	ISSN 0800-3416	Grading: Open

Title: A mobile gamma ray spectrometer system for nuclear hazard mapping	
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County:	Commune:
Map-sheet name (M=1:250.000)	Map-sheet no. and -name (M=1:50.000)
Deposit name and grid-reference:	Number of pages: 35 Price (NOK): 172 Map enclosures:

Fieldwork carried out:	Date of report: 13. December 2000	Project no.: 273700	Person responsible:

Summary:

The Geological Survey of Norway has developed a system for mobile gamma ray spectrometer surveying suitable for use in nuclear emergencies where potentially dangerous radioactive materials have been released into the environment. The measuring system has been designed for use with different kinds of transportation platform. These include fixed-wing aircraft, helicopters and vans. The choice of transportation platform depends on the nature of the nuclear emergency. Widespread fallout from a distant source can be mapped quickly from the air while local sources of radiation can be delineated by a car-borne system.

The measuring system processes gamma ray spectra in real-time. The operator of the system is therefore able to guide surveying in accordance with meaningful data values and immediately report these values to decision-making authorities. The operator is presented with a number of different displays suited to different kinds of nuclear emergencies that lead to more efficient surveying. Real-time processing of data means that the results of a survey can be delivered to decision-makers immediately upon return to base. It is also possible to deliver data via a live mobile telephone link while surveying is underway.

The measuring system can be adjusted to make measurements lasting between 1 second and 5 seconds. The spatial density of measuring positions depends on the duration of each measurement and the speed of travel of the measuring system. Measuring at 1s interval while travelling at 50 km/h in a car results in a measurement every 14 m along the road. Measuring with 1 s interval in an aeroplane travelling at 250 km/h produces a measurement for every 70 m travelled. Eight hours surveying can produce up to 30,000 measurements over a region hundreds of kilometres across.

Keywords: Geofysikk	Radiometri	Atomberedskap
		Fagrapport

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1 INTRODUCTION

In most nuclear emergencies involving the release of radioactive materials it is important that data on the geographic distribution of the potentially hazardous radioactive materials be quickly presented to the authorities in an easily assimilated form. The Geological Survey of Norway (NGU) has developed a mobile gamma ray spectrometry system that carries out all necessary data logging and processing tasks in real-time so that data can be delivered to the appropriate authorities without delay.

A variety of data displays are available to the system operator. These are updated every second as each new measurement is made and provide a clear view of spatial and temporal variations in contamination level and can therefore be used to guide surveying while it is underway. With a live telephone link it is possible to send meaningful data to decision makers in real-time.

1.1 Transportation platform

Choice of transportation platform for the measuring system depends on the nature of the nuclear emergency and geographic scale of the radioactive contamination. The measuring system can be mounted inside a fixed wing aircraft, inside or beneath a helicopter or inside a car (Figure 1). Separate instrument calibrations are required for each of these platforms. In the event of widespread contamination, an overall view of the fallout pattern can be obtained from a rapid airborne survey. Airborne surveys are also appropriate when the contaminated region is not readily accessible by road. A car-borne survey might be appropriate in an urban area or may be used to add important local information to the results of a regional-scale airborne survey. Airborne measurements of contamination on the ground provide a smooth overview of the contamination. Travelling at 50 m/s, 60 m above the ground, the measuring system registers gamma rays from an area on the ground approximately 100 m wide by 150 m in the direction of travel. Car-borne measurements are made at as little as 2 m from the source of radioactivity and consequently very local variations in contamination are detectable that would be indistinct in an airborne survey of the same region. Clearly choice of measuring platform is important and depends on the nature of a nuclear emergency and the ground surface characteristics of the affected region.

1.2 Measuring strategy

Whether measurements are being made from the air or on the ground it is important that the route being followed can be adjusted dynamically with changing radiation levels and other environmental conditions. It is therefore important that the operator of the measuring system is presented with a variety of displays of the incoming data in real-time. If the purpose of a survey is, for example, to locate a local area of contamination from the air and then map it in detail during the same flight it is important that the operator can see both changing radiation levels and the aircraft's position on a map.

1.3 Data products

1.3.1 Spatial density of measuring positions

The measuring system can be adjusted to make measurements lasting between 1 s and 5 s. The spatial density of measuring positions depends on the duration of each measurement and the speed of travel of the measuring system. Measuring at 1s interval while travelling at 50 km/h in a car results in a measurement every 14 m along the road. Measuring with 1 s interval in an aeroplane travelling at 250 km/h produces a measurement for every 70 m travelled. Eight hours surveying can produce up to 30,000 measurements over a region hundreds of kilometres across.

1.3.2 Storage of data

Raw and processed data can either be stored directly to disk on the computer that controls the measuring device or can be sent to a remote computer via a modem and mobile telephone. Full gamma ray spectra and geographic location are stored in a binary file and raw and processed radioelement and dose-rate data are stored together with location in a simple text file. The text file is readily re-formatted to the Scandinavian standard 'NKS' format designed for mobile measurements by the Nordic Nuclear Safety Research organisation (Karlsson et al. 2000).

1.3.3 Post-survey processing

Although data are processed in real-time it might be necessary to re-process data at the base of operations. Such a need would arise if the vehicle carrying the measuring system should become contaminated during surveying. Also it is likely that different measuring systems employing different technologies would need to be calibrated against each other. If the instrument-to-instrument calibration factors are only known after surveying is complete then later adjustments will be required.

Map-making is an important post-survey task. This can be done on the return leg of a surveying mission or at the base of operations. Digital maps can be generated during travel but hard copies of maps must be made at the base of operations.

1.3.4 Post-survey delivery of results

Under usual operation it is anticipated that measurements can be made available in map or data table form within one hour of survey completion. Under ideal surveying conditions digital data can be made available in real-time.

2 HARDWARE

The measuring system is shown mounted in a car in Figure 1 to Figure 4. All of the photographs in the Figures were taken in the vicinity of Gävle in Sweden where the measuring system was test driven through the ‘Fixed Route’ part of the international RESUME99 mobile measurements exercise (Karlsson et al. 2000). The exercise was organised by the Swedish Radiation Protection Institute in cooperation with the Nordic Nuclear Safety Research organisation (NKS) and took place in September of 1999. The Geological Survey of Norway was not able to take part in the exercise in 1999 and instead measured the ‘Fixed Route’ (a 200 km stretch of road) 8 months later in May of 2000. The photographs in the Figures were taken at that later time. Smethurst (2000) compares the measurements made by the NGU with those made by the 9 vehicles participating in the exercise.

2.1 Radiation measurements

The measuring system is built around the 256-channel gamma-ray spectrometer model GR-820 of Exploranium Radiation Detection Systems. The GR-820 spectrometer controls a GPX 256 NaI detector with a total crystal volume of 20.9 l (16.7 l downward directed, 4.2 l up). The measuring system can be mounted inside a fixed wing aircraft, inside a van, or inside/beneath a helicopter. Figure 1 shows the measuring system mounted in a van with the detector next to the side door. The detector is tilted towards the roadside so that is picks up the largest possible signal from the area to the right of the road (Figure 1). Note that the side door is closed during normal operation. The attenuating effect of the door results in a reduction of some 8% in the number of gamma rays detected, but ensures that the interior of the vehicle remains uncontaminated by radiation. The instrument rack that supports much of the rest of the equipment is visible in the background facing the rear door of the vehicle. Figure 3 shows the front of the instrument rack though the back door of the van with the detector visible in the background. The gamma ray spectrometer is mounted in the centre of the rack, below an electrical power distributor.

Figure 1. The Geological Survey of Norway's car-borne gamma ray spectrometer system. The NaI gamma ray detector is visible through the side door.

Figure 2. A close-up view of the NaI detector and the frame that supports it. The tilt angle of the detector can be adjusted so that it registers more gamma rays from the roadside than from the road itself.

Figure 3. The instrument rack mounted at the rear of the car. The NaI detector is visible in the background next to the side door.

Figure 4. The laptop computer that controls the measuring system mounted in front of the passenger seat. This computer starts and stops the instruments, stores the data on disk, performs real-time processing and displays the data in various graphical forms. The software includes a visual and audio alarm warning of elevated radiation levels.

2.2 Navigation

Estimates of geographic position are obtained via the satellite-based Global Positioning System (GPS). The navigation system consists of an Ashtech G12 GPS receiver and a Seatex DFM-100 RDS-receiver connected to a dedicated laptop PC running Seatex Seadiff software v. 7.05 under MS-DOS (for increased speed). A new navigational fix with accuracy better than ± 10 m is obtained every second and converted to the desired coordinate system. The navigation PC is mounted on top of the instrument rack in Figure 3.

If the measuring system is being used in an aircraft height above ground is required in the processing of data. In this case the aircraft's own altimeter is used.

2.3 The principal computer for data storage, processing and display

Data from the gamma ray spectrometer, navigation PC and altimeter (airborne platforms) are channelled into a PC laptop computer running Windows 95 (or 98, 2000, ME, NT). This PC runs program RADLOG, the user interface for the operator of the measuring system. The program (1) controls the gamma ray spectrometer, (2) combines and records spectral and navigational data, (3) performs real-time processing of the gamma ray spectra and (4) displays incoming data in different forms. A moderately powerful computer is required, with a Pentium processor operating at 200 MHz of higher. This computer is shown in Figure 4 mounted on the dashboard of the van in front of the operator's seat.

The computer communicates with the spectrometer via a serial port and cable. Each radiation measurement is initiated and terminated by the computer. The measured spectral data are transferred to the computer via the serial connection in the form of a 577-byte string containing data in both ASCII and binary forms. The data from the spectrometer include date, time, measuring duration, spectrum window values (8, usually starting with Total Count, naturally occurring K, U, Th, and Cs-137), and the 256 spectrum channel values (0 - 3 MeV).

The laptop computer obtains navigational data from the navigation PC through a second serial port. The navigational information received is encoded in standard NMEA 0183 format.

For airborne platforms altimeter data are recorded via an analogue-to-digital I/O card where incoming voltages from the instrument are transformed into digital voltage values that in turn are converted to elevations in metres.

System dependent port settings and time-outs must be specified in a RADLOG configuration file. Some minor adjustments to the operating system settings are necessary to run the measuring system.

2.4 Power supplies

The measuring system includes electrical transformers that can draw power from 24V DC aircraft supplies and 12V DC car supplies. The transformers for the car system are in the base of the instrument rack and bolted to the floor in Figure 2.

3 SOFTWARE TOOLS

The program development application LabVIEW® of the National Instruments Corporation was used to develop the logging program RADLOG. LabVIEW uses a graphical programming language, G, to create programs in flow diagram form. LabVIEW has extensive libraries of functions and subroutines designed for instrument control, data acquisition, data analysis, data visualisation and data storage.

LabVIEW was also used in the development of the commercially available logging system by Exploranium Radiation Detection Systems. Development of a new logging system was favoured over purchase of the existing Exploranium system because

- The commercial system cannot be customised by users. The alternative logging system by the NGU can be freely customised to suit the special needs of the Norwegian Nuclear Preparedness organisation.
- It is undesirable in a nuclear preparedness situation to be dependent on an overseas commercial company for user support.

4 USER INTERFACE

4.1 Program start-up

4.1.1 Loading calibration values and unit spectra

4.1.1.1 Calibration values

At program start-up the user is required to supply the name of an ASCII file containing calibration values and parameters governing serial communication with the spectrometer and GPS navigation equipment. An example file is listed below:

```
0      /1  COM port number, spectrometer
19200  /2  Baud rate spectrometer
8      /3  Data bits spectrometer
1      /4  Stop bits spectrometer
0      /5  Parity spectrometer
576    /6  Bytes to read spectrometer (bytes)
0.5    /7  Read timeout spectrometer (seconds)
0.2500 /8  Alpha stripping ratio (Th pad: counts U per count Th)
0.4110 /9  Beta stripping ratio (Th pad: counts K per count Th)
0.7307 /10 Gamma stripping ratio (U pad: counts K per count U)
0.0523 /11 a stripping ratio (U pad: counts Th per count U)
0.0000 /12 b stripping ratio (K pad: counts Th per count K)
0.0000 /13 g stripping ratio (K pad: counts U per count K)
1.3060 /14 ThCs stripping ratio(Th pad: counts Cs per count Th)
2.1496 /15 UCs stripping ratio(U pad: counts Cs per count U)
0.1164 /16 KCs stripping ratio(K pad: counts Cs per count K)
0.0065 /17 K calibration factor K% = cps * factor
0.0774 /18 U calibration factor U ppm = cps * factor
0.1569 /19 Th calibration factor Th ppm = cps * factor
0.0172 /20 Cs calibration factor Cs kBq/m2 = cps * factor
5      /21 COM port number, navigation
9600   /22 Baud rate navigation
8      /23 Data bits navigation
1      /24 Stop bits navigation
0      /25 Parity navigation
82     /26 Bytes to read navigation (bytes)
1.1    /27 Read timeout navigation (seconds)
```

4.1.1.2 Unit spectra

The logging program performs full-spectrum modelling in real-time. Therefore unit spectra for K-40, the U-238 decay series, the Th-232 decay series and Cs-137 must be provided at program start-up.

The unit spectrum files are generated by the 'Save snapshot' switch in the logging program. An example K-40 unit spectrum file is listed below with annotations in curly brackets (not in the original file):

4897 {unique spectrum ID number}

```
 870665.5   7057858.5 {geographic location}
  387.9210    193.4478      0.0000      0.0000     22.5224
92.3594       156.3299      0.0648 {8 raw energy window values}
  387.9210    193.4478      0.0000      0.0000     22.5224
92.3594       156.3299      0.0648 {8 stripped energy window values}
{the 256 channel spectrum follows - cps}
7.1195          0.0025      0.0000      0.0000      0.0017
0.0202          0.0019      0.1532      0.0000      4.7988
19.1918        19.4503     18.8713     19.5794     17.8213
16.6830        16.2195     13.9383     14.0102     12.9302
14.3441        12.8508     12.8883     11.3357     10.5477
9.0435          8.8315      7.3370      7.1000      5.8796
5.8764          5.4795      6.2675      4.5988      5.0370
5.0251          4.1099      3.7958      3.5852      3.6545
3.2891          3.4217      3.7136      3.3854      3.5577
3.1951          2.9542      3.1205      3.2186      2.7846
2.5041          2.4832      3.0178      1.9574      2.6070
2.6803          2.3474      2.4295      2.5297      2.4701
2.5325          2.0882      2.6224      2.2422      2.1916
2.0782          2.3415      2.0998      2.4580      2.1634
2.1709          2.0842      2.3444      2.1498      2.3421
2.2313          2.2648      2.3341      2.6686      2.2380
2.2715          2.2602      2.2031      2.6810      2.4186
2.5028          2.6798      2.6289      2.8154      2.4959
2.6028          2.7383      2.6534      2.6154      2.6975
2.5429          2.4585      2.2057      2.3558      1.8082
2.1017          1.5830      1.4887      1.8104      1.5994
1.7355          1.8634      2.1834      2.4096      3.0271
4.8845          6.9325     10.5850     14.4068     19.0119
22.0133        24.9685 {peak at 1.46 MeV}
22.7140        21.3298     16.5268     11.8495      7.1821
4.2546          2.1830      1.0311      0.5472      0.3369
0.1650          0.1057      0.0087      0.0352      0.1104
0.0000          0.0405      0.0116      0.0000      0.0479
0.0644          0.0000      0.0650      0.0000      0.0000
0.0191          0.0000      0.0000      0.0181      0.0000
0.0616          0.0000      0.0481      0.0428      0.0102
0.0050          0.0025      0.0520      0.0000      0.0000
0.0000          0.0000      0.0413      0.0188      0.0137
0.0000          0.0164      0.0000      0.0000      0.0000
0.0000          0.0000      0.0034      0.0000      0.0476
0.0000          0.0000      0.0000      0.0000      0.0012
0.0256          0.0195      0.0070      0.0000      0.0000
0.0716          0.0047      0.0000      0.0000      0.0515
0.0000          0.0000      0.0796      0.0085      0.0000
0.0070          0.0000      0.0050      0.0000      0.0000
0.0000          0.0000      0.0000      0.0000      0.0757
0.0453          0.1075      0.0000      0.0459      0.0000
0.0000          0.0000      0.0000      0.0000      0.0000
0.0000          0.0000      0.0000      0.0000      0.0000
0.0000          0.0281      0.0000      0.0000      0.0286
0.0060          0.0000      0.0015      0.0001      0.0097
0.0148          0.0134      0.0000      0.0000      0.0045
0.0000          0.0000      0.0059      0.0008      0.0153
0.0010          0.0136      0.0000      0.0069      0.0147
0.0101          0.0048      0.0143      0.0000      0.0000
0.0070          0.0087      0.0000      0.0000      0.0000
0.0000          0.0019      0.0041      0.6013 {cosmic channel >=3
MeV}
```

4.1.2 ‘Invisible’ data storage

The logging program measures *continuously* and stores *all* successful measurements to disk. Two disk files are used in parallel:

1) a binary file containing *all* raw data and
2) an ASCII file containing raw and processed radionuclide and dose-rate data. The user is prompted for the names of these two files at program start-up. Existing or new files may be specified. The logging system measures and stores data at a rate of once a second to once every five seconds. This continues irrespective of operator interaction until the program is stopped. Even when the logging is set to compound successive measurements, the program will store the compounded measurement after each new measurement is added.

The ASCII file is intended for distribution and is in a simple table format with a header row indicating the nature of the data in each table column. The headings and a single example measurement are explained below:

Table heading (left to right)	**What**	**Units**	**Example value**
Spectrum_ID	Unique spectrum number	N/A	3
Snapshot	Status of real-time processing switches that determine the processing level for headings marked *	1/0 (on/off)	0
Accumulate		1/0 (on/off)	1
Record		1/0 (on/off)	0
Zero		1/0 (on/off)	0
Strip		1/0 (on/off)	1
Use		1/0 (on/off)	1
Conc		1/0 (on/off)	1
E	Navigation	Metres East	870659.3
N		Metres North	7057870.5
Time	Time for spectrometer measurement since 12:00 a.m., Friday, January 1, 1904, Universal Time.	Seconds	3041928687.13
Time_lag	Time difference between spectrometer measurement and closest navigational fix	Seconds	0.22
Total	Raw energy window values	cps total count window	614.2
K		cps K-40 win.	35.5
U		cps Bi-214 win.	2451.8
Th		cps Tl-208 win.	24.6
Cs		cps Cs-137 win.	850.4

W6	User defined energy windows	cps user defined win.	11.5
W7		cps user defined win.	8.9
W8		cps user defined win.	12.0
Total	Processed energy window values	cps total count win.	614.2
K*		cps or % K-40	7.5
U*		cps or ppm U-238	11.3
Th*		cps or ppm Th-232	4.7
Cs*		cps or kBq/m2 Cs-137	55.3
W6	User defined energy windows	cps user defined win.	11.5
W7		cps user defined win.	8.9
W8		cps user defined win.	12.0
SDI Obs*	Spectral dose index (Observed, Natural, Man-made)	Spectral Dose Index	512.7
SDI Nat*		SDI	408.1
SDI Man*		SDI	104.6

* Processed data values that depend on the setting of switches 'Strip', 'Use' and 'Conc'.

4.2 Program operation

The logging program has a single computer screen display comprising 7 parts (Figure 5):

1. A *main menu* that determines the kind of data displayed in part 7.
2. A panel of *switches* that controls real-time data processing.
3. Four *drop-down menus* controlling (a) the content of four numerical displays and (b) the four 'window charts' displayed in screen part 7.
4. A display of measuring *system location* in terms of North and East values.
5. Instrument *warning lamps*.
6. *Logging status* information.
7. A *data display region* controlled from the main menu (part 1).

4.2.1 <u>Main menu</u>

The main menu (Figure 6) determines the nature of the data displayed in region 7 of Figure 5.

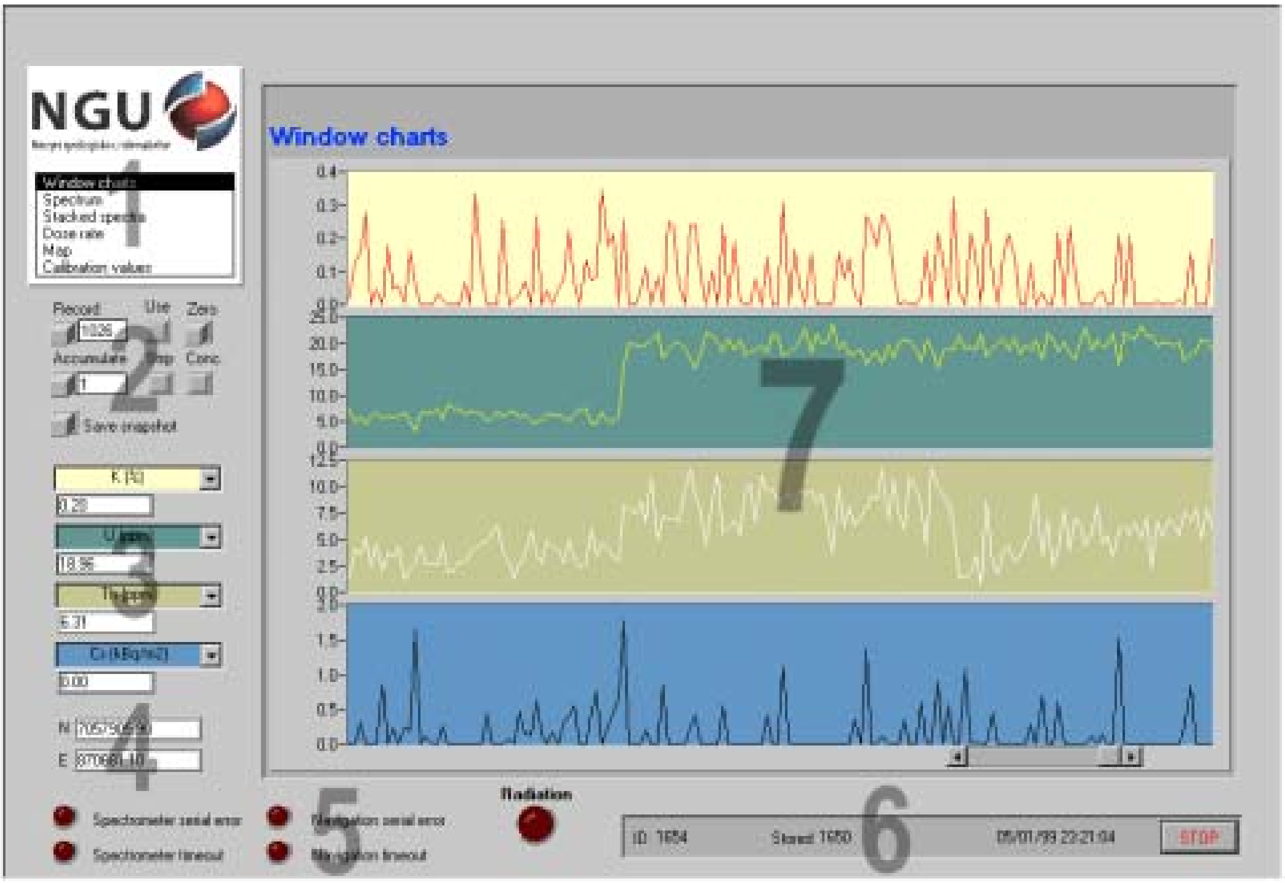

Figure 5. Initial screen display.

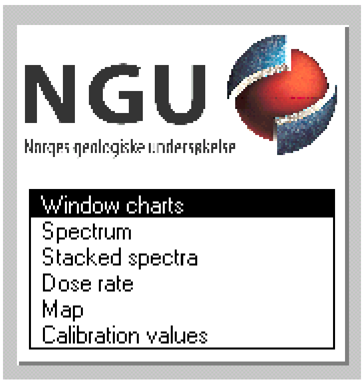

Figure 6. Main menu.

The following table summarizes the different ways of displaying data:

Display mode	Mapping objective	Displayed	Associated controls
Window charts	Radioelements known.	A set of 4 charts indicating changes in four user-defined data items.	*Drop-down menus* at position 3 in Figure 5 determine which 4 data items are displayed.
Spectrum	Radioelements not known.	• Measured gamma-ray spectrum • Model 'natural' spectrum • Model 'man-made' spectrum.	Plotting scales.
Stacked spectra	Searching for point sources – radioelements not known.	Successive spectra displayed side-by-side.	Plotting scales.
Dose rate	Early fallout mapping.	Spectral Dose Index (total, 'natural' and 'man-made').	Radiation alarm thresholds.
Map	All scenarios.	Map of route.	Buffer size for previous navigation points.
Calibration values	All scenarios.	Calibration values.	Adjustment of calibration values

4.2.2 Switches controlling real-time processing

The switches that control real-time data processing (at position 2 in Figure 5) are shown in Figure 7.

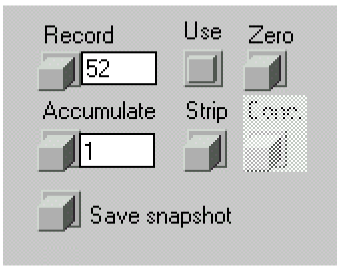

Figure 7. Real-time processing control panel. (The 'Concentrations' switch is inactive when 'Stripping' is switched off.)

4.2.2.1 Correction for background: the ‘Record’, ‘Use’ and ‘Zero’ switches

The ‘Record’, ‘Use’ and ‘Zero’ switches control the acquisition and use of background radiation measurements.

To record background radiation:

- Move the measuring system to a suitable geographic location
- Press the ‘Record’ switch. The digital display to the right of the switch indicates the number of repeat measurements incorporated into the background measurement
- When a sufficient number of repeat measurements have been made press ‘Record’ again to stop building the background measurement

To implement the background correction:

- Press ‘Use’ to toggle ON and OFF real-time background correction. The background spectrum is subtracted from the observed spectrum.
- Press ‘Zero’ to erase a background measurement (restore the digital display to zero).

4.2.2.2 Compounding successive measurements: the ‘Accumulate’ switch

It may be relevant to compound successive radiation measurements. Press the ‘Accumulate’ switch to start compounding; the digital display to the right of the switch indicates the number of repeat measurements incorporated into the combined measurement. Press ‘Accumulate’ a second time to stop compounding measurements.

The user is strongly advised against changing the status of other real-time processing switches while ‘Accumulate’ is active. This may lead to the compounding of measurements in incompatible processing states.

4.2.2.3 Stripping and spectrum modelling: the 'Strip' and 'Conc.' Switches

Stripping: Conventional window stripping is used to separate the contributions of the following sources of gamma radiation:

Source	**Radionuclide used in stripping**	**Energy window name**
Cs-137	Cs-137	Cesium
K-40	K-40	Potassium
Daughter products in the U-238 decay series	Bi-214	Uranium
Daughter products in the Th-232 decay series	Tl-208	Thorium

Press 'Strip' to obtain 'pure' data quantities (counts per second) for the radioelement energy windows associated with the above sources of gamma radiation. The units for displayed data values change from 'window cps' to 'stripped cps' (counts per second).

Press 'Conc.' to convert stripped counts per second to meaningful quantities (Cs-137 – kBq/m2; K-40 - %; U-238 – ppm; Th-232 – ppm).

Note that if a background measurement has been made and is being subtracted from the measured spectrum, correction is made for radiation emanating from the vehicle and for cosmic radiation. This constitutes a static correction in that the correction remains constant until a new background measurement is made and subtracted. Cosmic radiation varies continuously and the background radiation from the vehicle can also vary in an emergency situation through gradual contamination from fallout. Cosmic radiation can be stripped away dynamically in real-time using counts in the cosmic window (energies of 3 MeV or greater), however correction for increasing contamination of the vehicle during a survey must wait until the survey is over. Some measure of the contamination of the vehicle can be obtained by running the measuring system in an un- or lightly-contaminated enclosed space prior to and following mobile surveying.

Full spectrum modelling: The unit spectra for K-40, U-238 (daughters) and Th-232 (daughters) are multiplied by measured and then stripped K, U and Th window values to produce a set of model K, U and Th spectra. These are then added together to generate a model 'natural' spectrum. The 'natural' spectrum is then subtracted from the observed spectrum to isolate the 'man-made' component of the measured spectrum. As with window stripping it is possible to define a unit cosmic spectrum and account for that in the full spectrum modelling.

To apply full spectrum modelling to measurements made from airborne platforms the computer program must know how the shapes of the unit spectra for K, U and Th vary with height above the ground. This information can be obtained by placing plywood sheets between calibration pads and the gamma ray detector to simulate different flying elevations. Although the computer program can log flying elevation, the necessary calibration work is time consuming and remains to be done for the NGU system.

The original measured spectrum and its ‘natural’ and ‘man-made’ components are displayed when ‘Spectrum’ and ‘Stacked spectra’ modes are selected (4.2.1). The model spectra are also used in the ‘Dose rate’ display (4.2.1) where dose rate is separated into ‘natural’ and ‘man-made’ components.

4.2.2.4 Saving a single measurement: the ‘Save snapshot’ switch

Press ‘Save snapshot’ to write the current measurement to an ASCII data file. The ASCII file will contain the full spectrum, raw and processed window data values and geographic location.

The unit spectra loaded at program start-up were generated using the ‘Accumulate’ and ‘Save snapshot’ switches.

4.2.3 Drop-down menus

There are four drop-down menus at position 3 on the main screen display (Figure 5). The menus determine which four data parameters are to be shown in four digital displays (Figure 8) and which are to be shown in four charts when ’window charts’ mode is selected in the main menu (4.2.1). The units for the displayed data are determined by the status of the real-time processing switches (4.2.2.3).

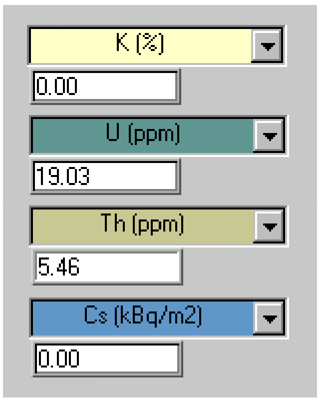

Figure 8. Four user-defined data values.

4.2.4 System location

The measuring system's location is displayed at position 4 on the main screen display (Figure 5 and Figure 9). 'N' represents metres in the projection north direction and 'E' represents metres in the east direction. The projection used is set in software running on the PC dedicated to controlling the navigation hardware (2.2).

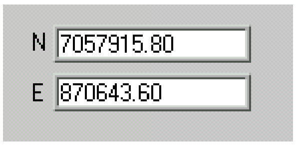

Figure 9. North and East projection co-ordinates.

4.2.5 Warning lamps

Lamps indicate 1) serial communication and timeout status of the gamma-ray spectrometer, 2) serial communication and timeout status of the navigation system and 3) status of the radiation alarm (

Figure *10*; position 5 in Figure 5).

The radiation alarm is activated when 1) Spectral Dose Index exceeds a critical user-defined value and/or 2) 'man-made' radiation exceeds a critical proportion of total radiation. The user can adjust the radiation alarm when 'Dose rate' is selected in the main menu (4.2.1).

Figure 10. Warning lights. Left - spectrometer communication; middle - navigation communication; right - radiation warning.

4.2.6 Logging status

The storage of data takes place automatically (4.1.2) and the user is advised of the number of spectra stored in the data files by way of the 'logging status' field (Figure 11). 'ID' is a unique identifier given to each spectrum. This enables the tracing of individual spectra through the series of data files created by the logging program (4.1.2, 4.2.2.4). 'Stored' is the number of spectra stored in the main data files (4.1.2) since logging began. From Figure 11 it is clear that fewer spectra have been stored than were assigned an 'ID'. This is because when logging begins, or when logging is interrupted, the storage of potentially incorrect spectra is temporarily suspended. Storage of spectra resumes after 1 second of normal instrument behaviour.

The 'Logging status' includes date and time obtained from the spectrometer and a 'STOP' button that stops program execution.

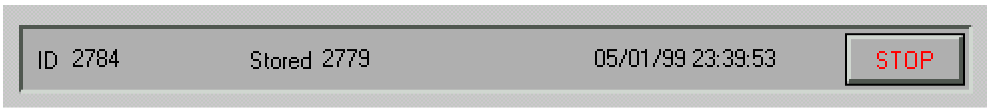

Figure 11. Logging status. From left to right: 'ID' - logging cycle number used as data record number in data files; 'Stored' - number of records written to data files; date and time from spectrometer; program 'stop' button (terminate logging).

4.2.7 Data display region

The data display region is at position 7 in Figure 5. The main menu (4.2.1) determines the kind of data displayed in this region.

4.2.7.1 'Window charts'

The 'window charts' display consists of four charts of processed data (Figure 12). The user selects the four data items to display via the drop-down menus in Figure 8. The real-time processing control panel in Figure 7 determines the level of processing of the data.

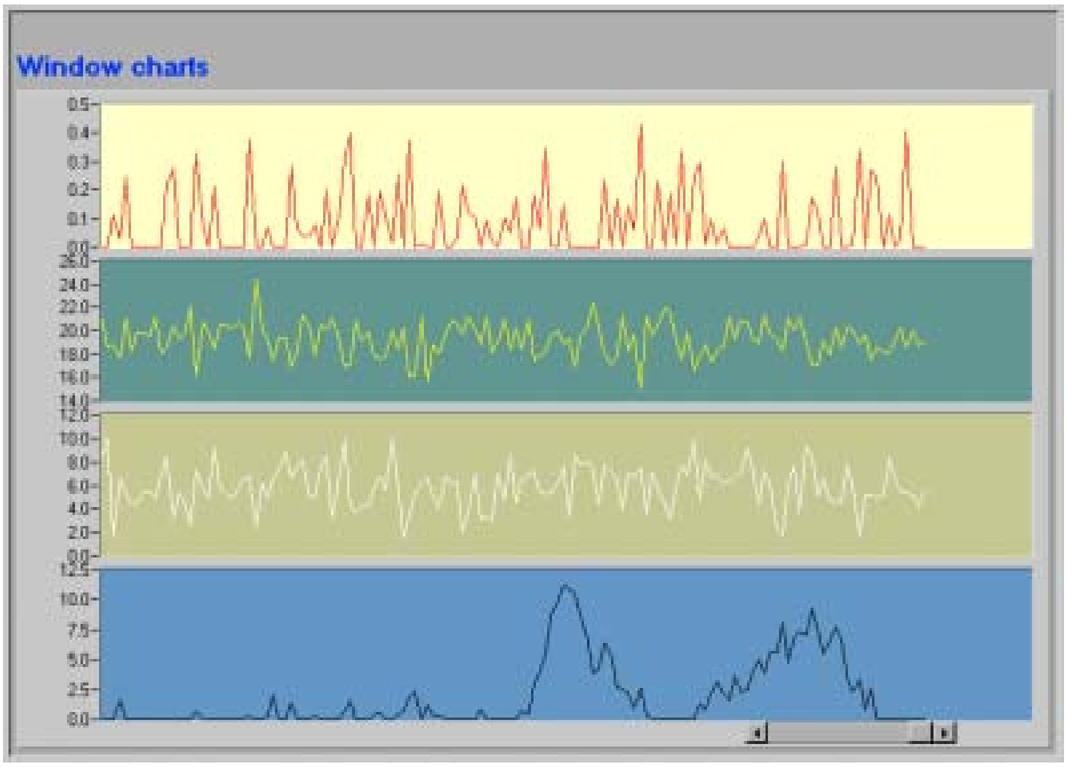

Figure 12 The 'window charts' display

4.2.7.2 'Spectrum'

The 'spectrum' display consists of a plot of the current gamma-ray spectrum (red line, Figure 13). The spectrum consists of gamma-ray counts in 256 consecutive energy windows/channels between 0 and 3 MeV (approximately 12 keV in each window/channel). Window/channel is plotted on the X-axis, count is plotted on the Y-axis. The vertical lines indicate the window/channels corresponding to peak gamma-ray energies for Cs-137 (0.66 MeV, blue), K-40 (1.46 MeV, green), Bi-214 (for U-238 mapping, 1.76 MeV, magneta) and Tl-208 (for Th-232 mapping, 2.62 MeV, yellow).

The blue curve is a model 'natural' spectrum based on calculated quantities of K-40, U-238 (via daughter products), Th-232 (via daughter products) and known unit spectra for the three quantities (4.2.2.3). The green curve is the difference between the observed spectrum (red) and the model 'natural' spectrum (blue) that represents radiation sources not accounted for in the modelling. The green curve may indicate 'man-made' radionuclides (e.g. Cs-137, Figure 14), cosmic radiation not accounted for in the background correction (4.2.2.1), measurement inaccuracy or model error.

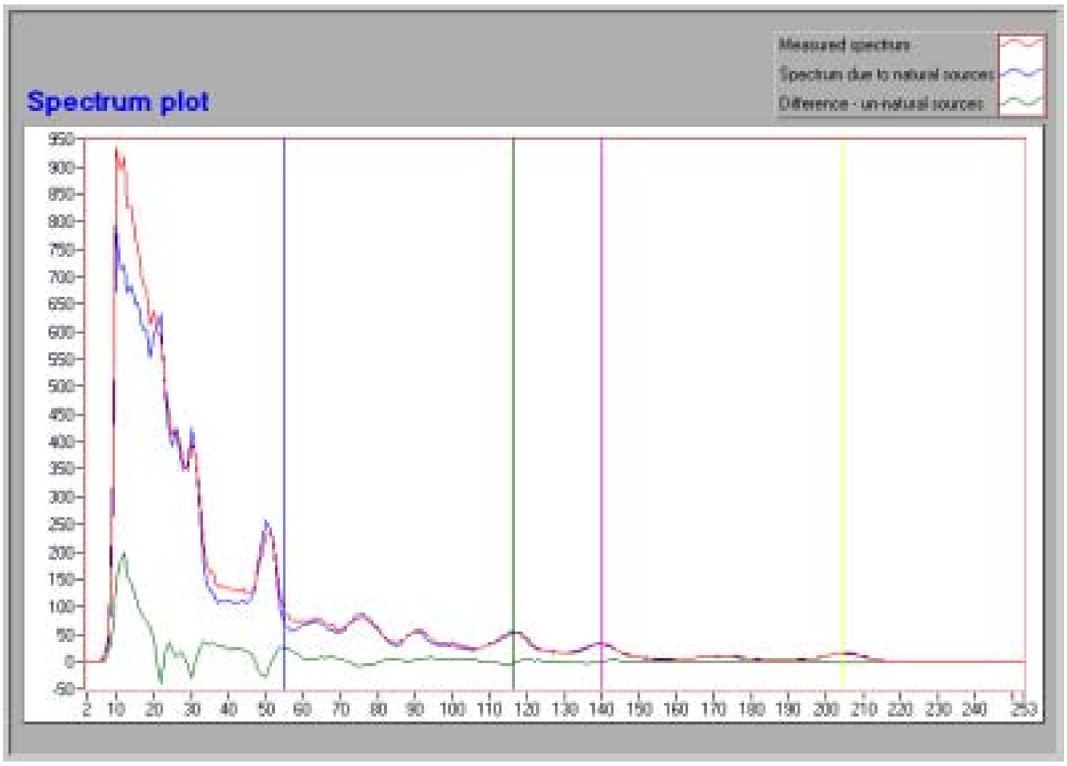

Figure 13. An example of the 'spectrum' display.

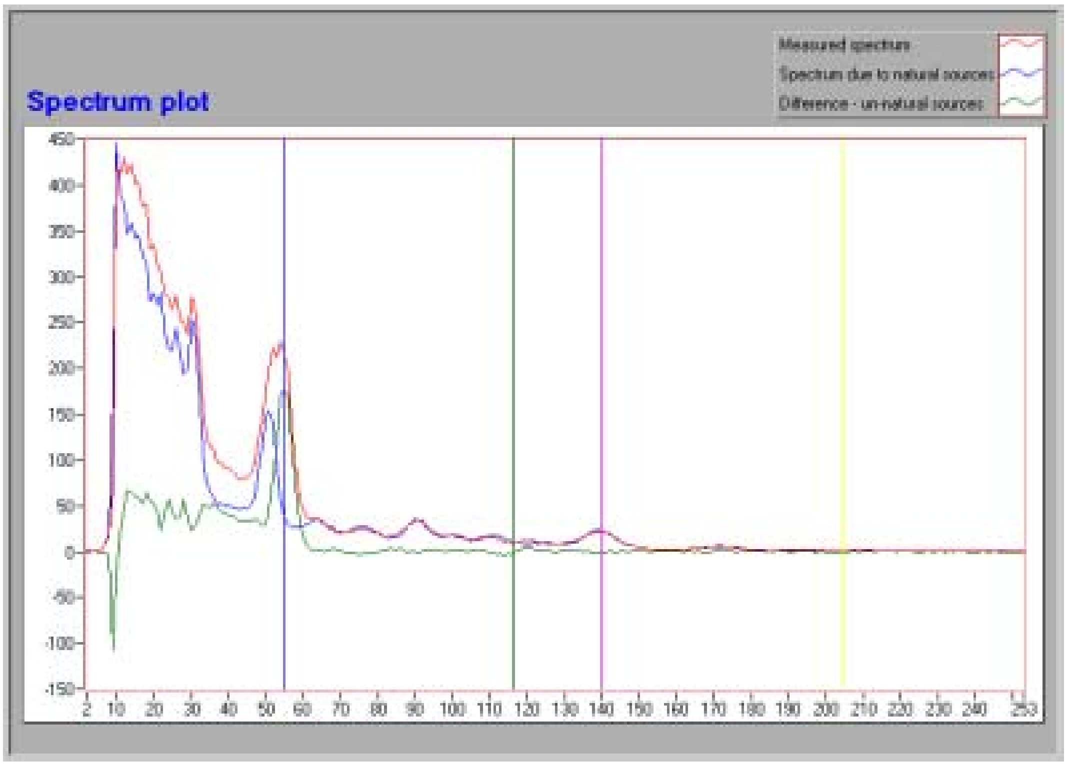

Figure 14. 'Spectrum' display indicating an observed spectrum (red), model 'natural' spectrum (blue, mainly daughters of U-238) and 'man-made' spectrum (green, Cs-137).

4.2.7.3 'Stacked spectra'

The 'stacked spectra' display mode (Figure 15) is suitable for locating point (local) radiation sources. Each measured spectrum is represented by a vertical stripe. The low energy end of the spectrum is at the bottom of the stripe, and the high energy end at the top. Spectrum channel numbers are shown on the left. Colour is used to indicate the number of gamma rays in each spectrum channel (white = high, black = low). As each new spectrum is obtained, previously measured spectra scroll left to accommodate the new measurement on the right side of the screen. Spectral peaks appear as distinct coloured patches in the vertical stripes. Horizontal coloured stripes are produced when the same spectral peaks are present in several consecutive spectra.

Given that the measuring system is moving while measuring, the X-axis of the plot, spectra stacked one after the other, is equivalent to distance along the route of travel. In Figure 15 the horizontal stripes crossing the whole screen relate to daughters of U-238 (the thin red stripe in channel 51 corresponds to a Bi-214 peak at 0.61 MeV). The Uranium is geological and spatially distributed. The middle 5 spectra have strong (white) peaks in channel 55 corresponding to Cs-137. During the acquisition of those 5 spectra (5 seconds) the measuring system passed a Cs-137 point source.

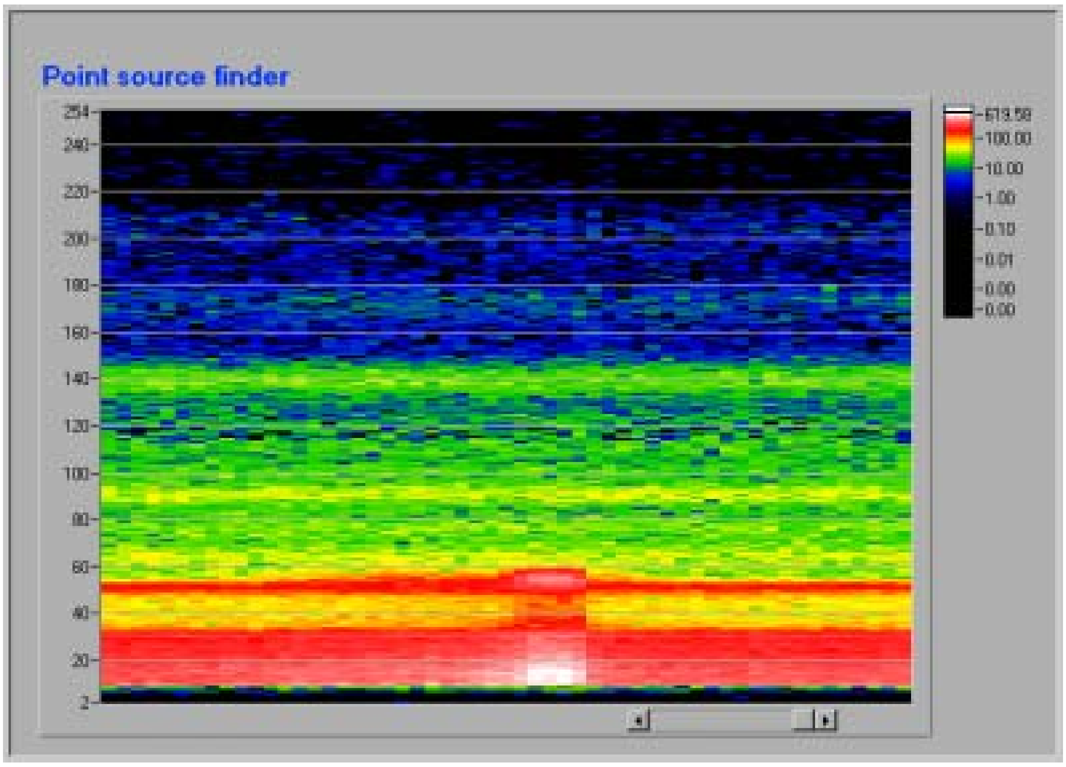

Figure 15. The 'stacked' spectrum display mode.

Although the point source in Figure 15 is quite easy to spot, the changing geological signal can make the identification of point sources of radiation difficult. (Figure 14)

In Figure 16 the background geological signal has been removed by recording it using the real-time processing switch ’Record’ and then subtracting it using the ’Use’ switch (4.2.2.1).

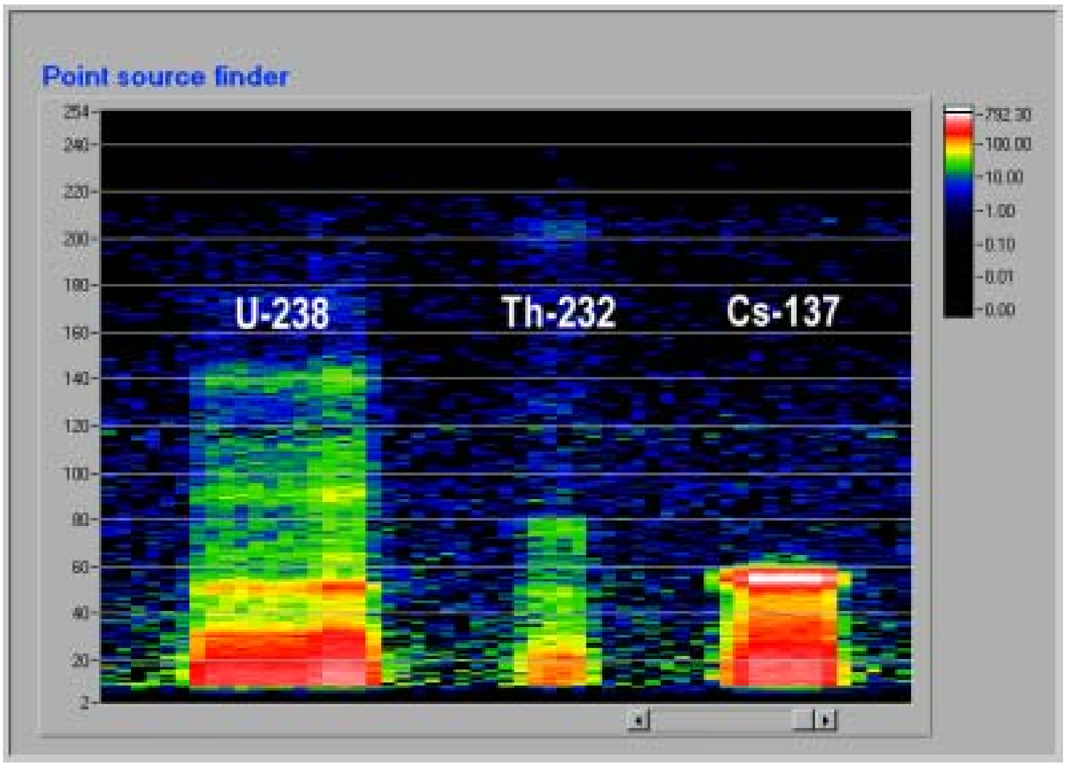

Figure 16. 'Stacked' spectra with geological background signal removed to enhance the signatures of point sources.

4.2.7.4 ’Dose rate’

The ’dose rate’ display is intended for initial fall-out mapping (Figure 17). On the left, a ’fallout alarm’ indicates the proportion between observed gamma-ray counts and ’natural’ counts (see 4.2.2.3). If the ’natural’ model equals (is a good explanation of) the observed counts, the ’fallout alarm reads ’1’ as in Figure 17. If the observed counts exceed the ’natural’ model by a factor of 2, the ’fallout alarm’ reads 2, indicating twice as many gamma-rays as can be explained by ’natural’ sources (daughters of U-238, daughters of Th-232, K-40). A radiation alarm sounds (4.2.5) when the ’fallout alarm’ exceeds a threshold value (e.g. 1.3, Figure 17). The value shown by the ’fallout alarm’ is unstable when counts are low. Therefore the alarm only sounds when observed counts exceed a user defined value (e.g. 450, Figure 17). The ’fallout alarm’ serves as a warning of ’man-made’ radiation even when contamination levels are very low.

A dial on the right of Figure 17 indicates observed, natural and ’man-made’ Spectral Dose Index. The data values are also given in digital indicators below the dial. The method of separating the contributions of ’natural’ and ’man-made’ sources is given in section 4.2.2.3. An alarm trigger based on observed Spectral Dose Index causes an alarm to sound when radiation levels exceed a threshold value. Unlike the ’fallout alarm’, this trigger is only concerned with high levels of radiation. The threshold value of this alarm is set to 800 in Figure 17.

Note that the ’Fallout alarm’ in Figure 17 indicates ’1’, showing that all of the observed radiation can be explained by natural sources. This can also be deduced from the Spectral Dose Index dial where the pointers for observed and ’natural’ radiation show the same values while the pointer for ’man-made’ radiation reads approximately zero. The ’dose rate’ display in Figure 17 corresponds to the display of a ’natural’ spectrum in Figure 13. The ’dose rate’ view of Figure 18 indicates a ’man-made’ source of radiation that, from the spectrum display of Figure 14, can be identified as Cs-137.

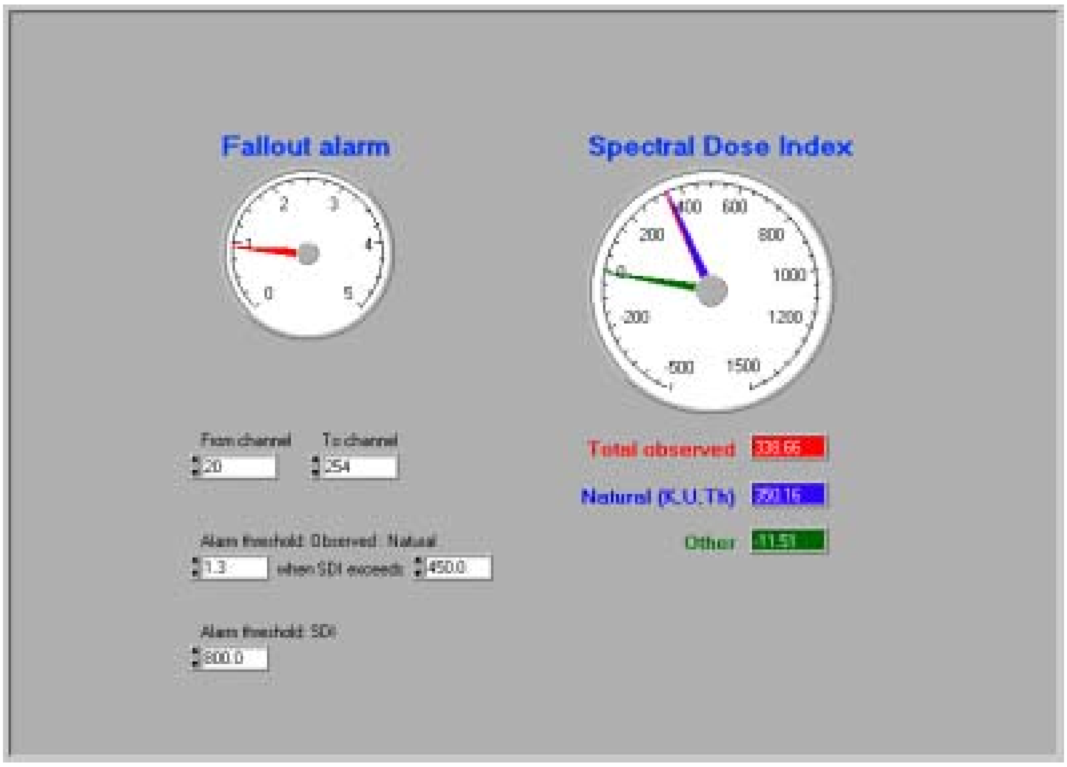

Figure 17. The 'dose rate' display. Spectral dose index values are displayed as well as the settings for the radiation alarm.

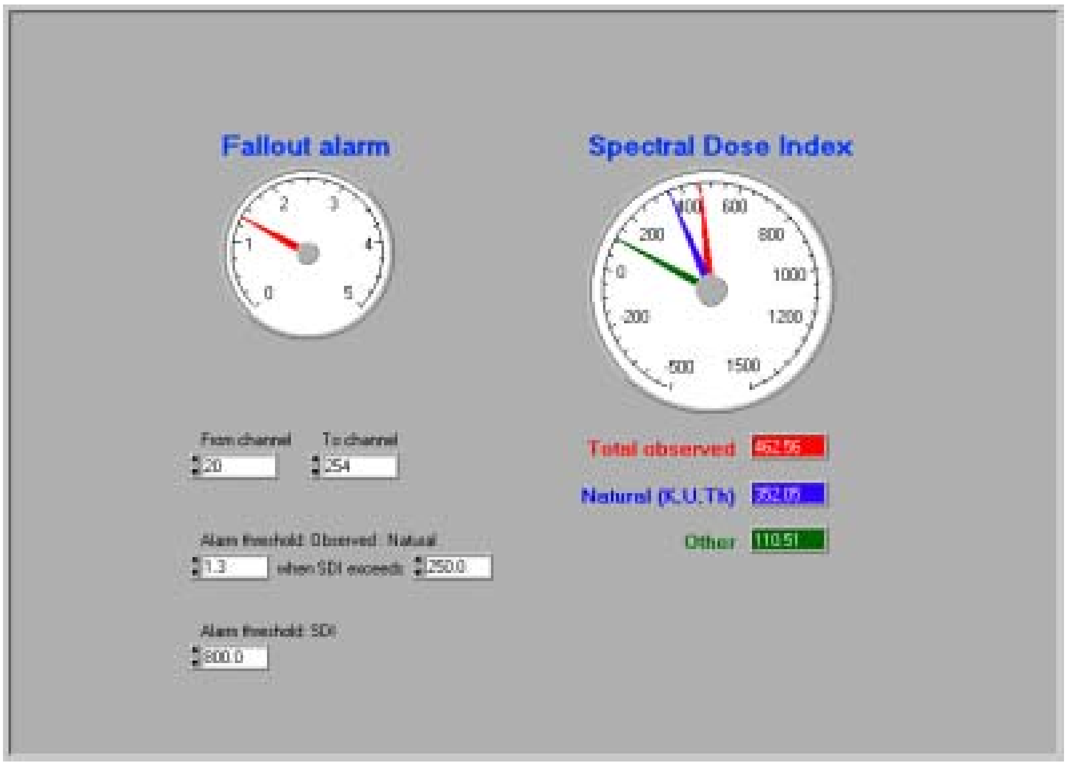

Figure 18. A 'dose rate' display registering both 'natural' and 'man-made' radiation.

4.2.7.5 'Map'

The 'map' display mode shows the route followed by the measuring vehicle (Figure 19). To save computer memory and to speed-up map drawing only the most recent navigation points are plotted. It has yet to be determined how many navigation points can be retained without compromising the data logging function of the program. At present the program can be set to retain up to 200 navigation points. This will increase in later versions of the program.

The coordinate system and distance units used in the map are determined by the user in software running on the laptop computer dedicated to the GPS equipment (2.2).

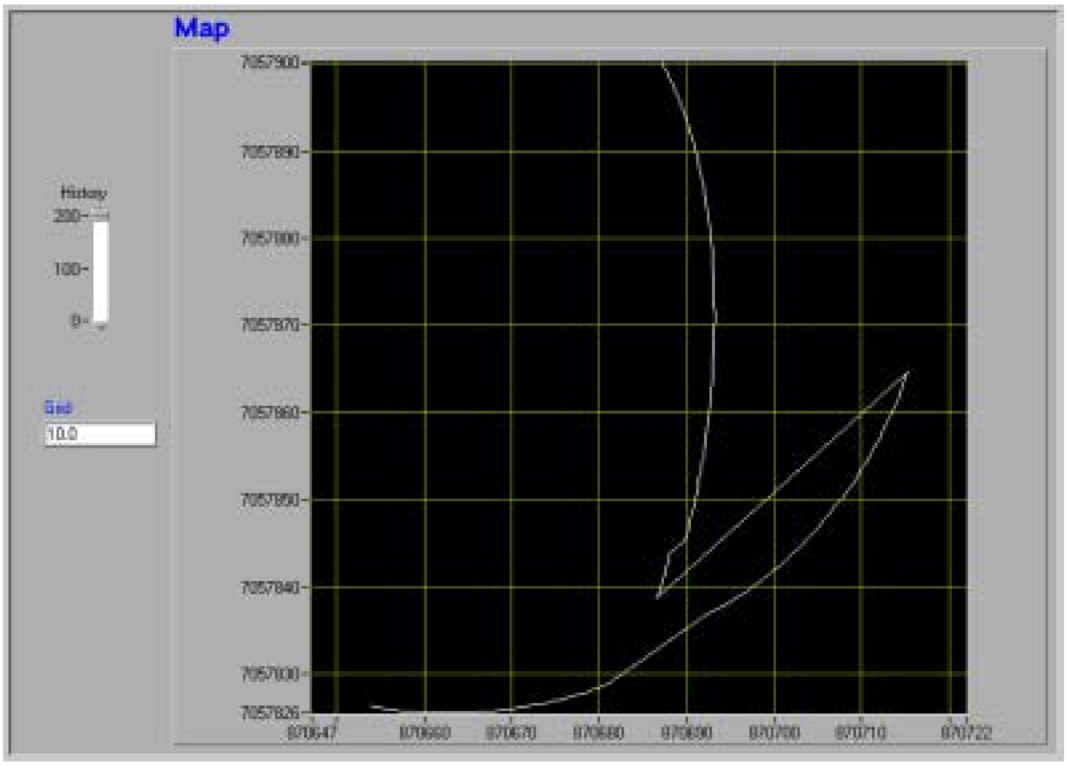

Figure 19. The 'map' display showing the route followed by the measurement vehicle. The 'history' slider determines the number of navigation points to be retained in memory. The 'grid' display indicates the side dimension of the grid cells in the display (in metres).

4.2.7.6 'Calibration values'

The 'calibration values' display consists of a series of digital displays indicating the current values of calibration factors. These include 6 conventional window stripping factors for K-40, U-238 and Th-232 (alpha, beta, gamma, a, b, g), 3 stripping factors for K-40, U-238 and Th-232 into the Cs-137 window, and 4 coefficients for converting stripped counts K-40, U-238, Th-232 and Cs-137 into meaningful units. These calibration values are used in the 'Strip' and 'Conc.' real-time processing functions (4.2.2.3 above).

The logging program outputs suggested new stripping factors beneath each of the stripping factor displays. Under normal logging these suggested values will be inappropriate. To obtain appropriate suggested stripping values for K-40 into U-238, Th-232 and Cs-137, make a background measurement on a background calibration pad ('Record' switch ON, wait, and then OFF, see 4.2.2) and then correct for background ('Use' switch ON). Then place the detector on a K-40 calibration pad and measure. Make sure 'Strip' and 'Conc.' are OFF. Press 'Accumulate' and watch the suggested stripping values stabilize as 'pure' K-40 spectra are compounded. Substitute the existing stripping factors with the suggested new factors.

Observe the stripped K-40 counts per second (4.2.3) while the detector is still on the K-40 calibration pad (switches 'Strip' and 'Conc.' OFF). Then determine a calibration factor that converts the observed counts per second to the known K-40 concentration (ppm) of the calibration pad (taking account of geometric factors for the pad). Substitute the old calibration factor for the new. The same procedure can be followed for the U-238 and Th-232 calibration pads and a Cs-137 point source except that a more complicated procedure is required to determine the conversion factor to concentration/activity for Cs-137 using a Cs-137 point source.

5 THE MEASUREMENT CYCLE

The principal logging computer running RADLOG determines the timing of the measurement cycle. Measuring duration can be set at 1 (default) to 5 seconds. The logging PC initiates the measurement cycle when it sends a trigger signal to the serial port on the gamma ray spectrometer. The time at which the measurement begins is recorded by the PC. The logging program waits for 1 second (default) before sending another signal that instructs the spectrometer to terminate the measurement, output the spectrum data to the PC, and start a new measurement. In the meantime the PC has registered all of the navigation fixes outputted by the navigation PC and recorded a time for each one. The navigation point closest in time to the mid-point of the spectrometer measurement is chosen as representing the best estimate of the vehicle position for the measurement in question. The measurement and position are saved to disk in raw form, then processed, displayed, and saved in processed form. The time for the spectrometer measurement is recorded in the data files as is the time difference between the spectrometer measurement and the navigational fix. This time difference never exceeds 0.5 seconds during normal operation.

Warning lamps are lit when a serial communication error with the gamma ray spectrometer or the navigation PC occurs. The measuring system will continue trying to communicate the instruments after this time and measuring will automatically resume when the instrument fault is corrected.

If a meaningful spectrum is not obtained from the serial port within a specified timeout (usually 0.5 seconds, 4.1.1), the logging system reports an instrument error by lighting a timeout warning lamp (4.2.5), and the measuring cycle returns without delay to the beginning of the cycle. No data are stored and data displays are not updated. If a meaningful spectrum is obtained within the timeout time the data are saved to disk and then displayed. The measurement cycle begins again.

If a meaningful navigational fix is not obtained within a specified timeout (usually 0.5 seconds, 4.1.1), the logging system assumes an instrument error and a timeout warning lamp is lit (4.2.5). The measuring cycle does not stop due to a navigational error. The last known position is repeated until a new one is obtained.

6 CALIBRATION

The calibration of the measuring system differs in accordance with the nature of the mobile platform in which it is mounted. The real-time processing of data requires enough information to 1) correct for vehicle background and cosmic radiation, 2) perform conventional window stripping for K-40, daughters of U-238 and Th-232 and Cs-137, 3) adjust for the attenuation of gamma rays in the air between the ground and the detector (airborne surveys), and 4) convert the counted gamma rays associated with different radioelements into meaningful units of concentration, radioactivity and dose rate. The full spectrum analysis requires a knowledge of the shapes of the unit ('pure') spectra for K-40, U-238 (daughters), Th-232 (daughters), Cs-137 and cosmic radiation, and how these (excluding cosmic) are affected by attenuation in the air between the ground and the detector.

Much of the calibration procedure required for the present measuring system is based closely on the methods described in the guidelines for airborne gamma ray spectrometer surveying issued by the International Atomic Energy Agency (IAEA 1991). Nevertheless, some general remarks on calibration are made below.

Count rates due to cosmic radiation increase exponentially with height above sea level and a test flight can be flown to determine the shape of the unit gamma ray spectrum for cosmic radiation. The stripping ratios required to strip out gamma rays due to cosmic radiation from the K-40, U-238, Th-232 and Cs-137 spectral energy windows can be determined from the 'cosmic' unit spectrum. The same test flight can be used to determine aircraft background radiation.

Large cement calibration pads can be used to determine the shapes of the unit spectra for K-40 and the daughters of U-238 and Th-232. These spectra provide the window stripping ratios needed to separate overlapping gamma ray contributions from K, U and Th. The spectra are also used to determine stripping ratios that strip away gamma rays due to K, U, Th from the Cs-137 spectral window in order to obtain 'pure' Cs-137 counts. There are no large pads containing Cs-137 and therefore a point source of Cs-137 must be used to determine the unit spectrum for Cs-137.

The calibration pads contain known quantities of K, U and Th and therefore calibration coefficients can be obtained that convert 'stripped' energy window counts to meaningful units. Such a coefficient can be determined for Cs-137 using a point source but the procedure for a point source is more complicated and is described by Walker & Smethurst 1993)

Determination of a dose rate, or air kerma rate, is based on a weighted total count rate as described by Bargholz & Korsbech (1997). In essence the gamma ray counts registered in spectral channels are weighted according to their energy and summed to produce a spectral dose index that can be equated with air kerma rate. Bargholz & Korsbech (1997) claim that this method can be used to produce reliable air kerma rates for gamma rays with energies above 350 keV.

Most of the calibration parameters mentioned above vary according the height of the measuring system above the ground. Test flights for determining the necessary corrections for the attenuation of gamma rays in the air are described by the IAEA (1991). Alternatively, measurements at different altitudes can be simulated on the ground by placing plywood sheets between calibration pads and the detector.

The user interface for the measuring system allows calibration values to be changed at any time. This means that the calibration of the mobile measuring system can be quickly adjusted to match other instruments employing other measuring technologies. For example, in an emergency situation it might prove appropriate to mount the measuring system in an unfamiliar aeroplane for which there are no previously determined calibration values. It is desirable that useful dose rate data are forthcoming immediately. In this case the measuring system could take to the air immediately and comparisons could be made by radio between spectral dose index registered in the aircraft and actual dose rates measured using hand held instruments on the ground. Calibration values could then be adjusted so that the airborne system reproduces the ground measurements as closely as possible and surveying can begin. Improved results may be obtained later in a post-survey processing session.

7 OUTSTANDING TECHNICAL DEVELOPMENTS

Additional calibration work is required for airborne transportation platforms. This consists primarily of defining the change in shapes of the unit spectra for K-40, daughters of U-238 and Th232 and Cs-137 with increasing elevation above the ground.

Calibration work is also required to establish the relation between Spectral Dose Index and air kerma rate.

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Karlsson, S., Mellander, H., Lindgren, J., Finck, R. & Lauritzen, B. 2000: RESUME-99: Rapid Environmental Surveying Using Mobile Equipment, NKS, ISBN 87-7893-065-0.

Smethurst, M.A.: Rapid environmental surveying using mobile gamma ray spectrometry: processing of results from the RESUME99 exercise, Gävle, Sweden. NGU Report 2000.087.

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