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A mobile gamma ray spectrometer system for
nuclear hazard mapping: GAMMALOG v. 3.0

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REPORT

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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/cars. 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 carborne 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 or wireless network while surveying is underway.

The measuring system is unique in that it can utilise NaI (sodium-iodide) and HpGe (high purity germanium) detectors simultaneously from a single computer. This guarantees synchronisation between the instruments, GPS navigation and radar altimeter. The computer program that controls the measuring system runs under Microsoft Windows XP Service Pack 2 and Windows-2000 and utilises the LabView v.7.01 data acquisition tool developed by National Instruments.

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: Geophysics (Geofysikk)	Radiometrics (Radiometri)	Nuclear emergencies (Atomberedskap)
		Technical report (Fagrapport)

CONTENTS

1 INTRODUCTION

In most nuclear emergencies involving the release of radioactive materials it is important that data on the geographic distribution of potentially hazardous radioactive materials be quickly presented to the authorities in an easily assimilated form. This report describes a mobile gamma ray spectrometer system that carries out all necessary data logging and processing tasks in real-time so that radiation measurements and maps can be delivered to crisis managers shortly after each measuring mission. The software that controls the measurement and visualisation system is called "GAMMALOG" and is maintained by the Geological Survey of Norway (NGU) in co-operation with the Norwegian Radiation Protection Authority (NRPA).

The measuring system consists of two gamma ray spectrometers, one utilising a NaI (sodium-iodide) detector and the other a HpGe (high purity germanium) detector, a GPS/DGPS satellite navigation device, a radar altimeter, a portable computer running Windows XP™ or Windows 2000™ and electrical power transformers.

A variety of data displays are available to the system operator during surveying. These are updated every second after each new measurement is made and provide a clear view of spatial and temporal variations in contamination level and can be used to dynamically adjust mapping strategy. It is possible to send meaningful data to decision makers in real-time with a live telephone or wireless network connection to a remote computer.

2 TRANSPORTATION PLATFORM

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

3 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 according to changes in radiation level and other environmental conditions. It is therefore important that the operators of the measuring system are presented with a variety of displays of the incoming data in real-time. The measuring system described here provides that.

All measuring strategies, regardless of contamination scenario, have human safety as their central element. The primary and first objective will always be to map contamination where it has the greatest impact on human health. In Norway this means reviewing towns and cities first, and the large tracts of unpopulated ground between them afterwards. The safety of the mapping crews must be monitored at all times. Guidelines on dose limits for civilian and military crews are being prepared by the NRPA.

3.1 Orphan radioactive sources

If the purpose of a survey is to locate what is effectively a point source of radiation (an orphan source) lost somewhere in a large unpopulated region, airborne measurements are most appropriate, following search patterns similar to those developed for air sea rescue missions. The design of the survey will depend upon the severity of topography, the volumes and 'fields of view' of the gamma-ray detectors being used and the composition, activity and housing/shielding of the lost source/s. Surveys should be drape-flown, that is to say flown at a constant ground clearance, whenever the topography permits it. Flying elevations should be as low as possible and not exceed 150 m.

3.2 Radioactive fallout on the ground

Fallout is likely to be spread over a large geographic area and fixed-wing or helicopter surveying is most appropriate. Early flights should be dedicated to determining contamination levels in urban areas, food-producing regions, and the countryside between. These exploratory flights will probably have an irregular and widely spaced flight plan. If fallout covers a large part of the country, parallel lines can be flown starting at 30 km spacing and later additional flight lines can be planned to fill-in the wide gaps. At some point fill-in mapping can be restricted to the most contaminated regions. Although Chernobyl fallout was, and still is, widely spread across Norway, the most contaminated regions are rather small and flight line spacings down to 200 m are appropriate to determine their forms precisely.

It should be noted that radiation levels from fallout on the ground fall rapidly in the days and weeks following a nuclear accident. This depends on the distance to the source of the accident and composition of the fallout. Also, new fallout may arrive some time after the first episode so that measurements from early expeditions may need to be adjusted or replaced with new data. Again, drape-flying is appropriate at elevations of 150 m or less.

3.3 Radioactive clouds and plumes

Mobile mapping of radioactive clouds and plumes is usually inappropriate. The data are difficult to interpret, the transport platform and measuring system become permanently contaminated and the measuring crew are in danger of experiencing rapid changes in exposure to radiation.

3.4 A niche for carborne systems

Carborne measuring systems can play an important role under all mapping scenarios. The advantages of the carborne system are that the system can get close to the source, can map in urban landscapes where it is difficult or dangerous to fly, can readily stand still and measure the same thing for a long time and provide the crew with the opportunity to take samples for analysis, carry out additional in-situ measurements outside the vehicle and generally reconnaissance the scene. A natural partnership between airborne and carborne systems was well illustrated under the Barents Rescue exercise in Boden, Sweden in 2001 (NKS 2002). In that case airborne systems proved better at locating orphan sources. In several cases the approximate positions of sources from airborne reconnaissance measurements were communicated to companion carborne systems that drove to the locations to find the sources, perform more sophisticated measurements and describe the settings.

3.5 Post-survey data processing

Although data are processed in real-time it might be necessary to re-process data at the base of operations after a mission. 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 will 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. The Geological Survey of Norway use Geosoft's Oasis Montaj™ program package for post-processing.

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. The Geological Survey of Norway use Geosoft's Oasis Montaj™ and ESRI's Arc/GIS™ packages for map-making.

3.6 Post-survey delivery of results

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

4 HARDWARE

The measuring system can operate with two gamma ray spectrometers for gamma radiation measurements:

1. Exploranium 256 channel GR-820 gamma ray spectrometer with large volume sodium iodide (NaI) detector pack (the NGU operates with a GPX 256 NaI detector with a total crystal volume of 20.9; 16.7 l downward directed, 4.2 l up; APPENDIX G). This instrument produces one measurement each second.
2. Ortec DSPEC+ gamma ray spectrometer with ruggedised high purity germanium (HpGe) detector (APPENDIX H). This instrument produces a measurement at a user specified interval usually in the range 10 to 30 seconds

Instrument (1) is fast acting and lends itself to high-speed radiation mapping while (2) has a high photon energy resolution and is well suited to identifying anthropogenic radionuclides present in the radiation source. The measuring system can operate with both or only one of these instruments present.

The location of the measuring system is determined using a GPS navigation device at a rate of one positional fix per second. The Garmin GPS 16 device, and later models in the same series, are recommended for use with the measuring system.

Elevation above the ground, ground clearance, is determined using any altimeter that outputs a voltage between +10V and –10V that is proportional to elevation.

The above hardware is controlled by a PC running the purpose-written GAMMALOG program under Windows XP™ or Windows 2000™ (APPENDIX K). Figure 1 is a schematic diagram summarising the way in which the instruments are connected to the PC.

Detailed considerations on the operation of this hardware, hardware and software settings and cabling are given in:

APPENDIX G	Gamma ray spectrometer (NaI)
APPENDIX H	Gamma ray spectrometer (HpGe)
APPENDIX I	GPS navigation device
APPENDIX J	Altimeter
APPENDIX K	PC

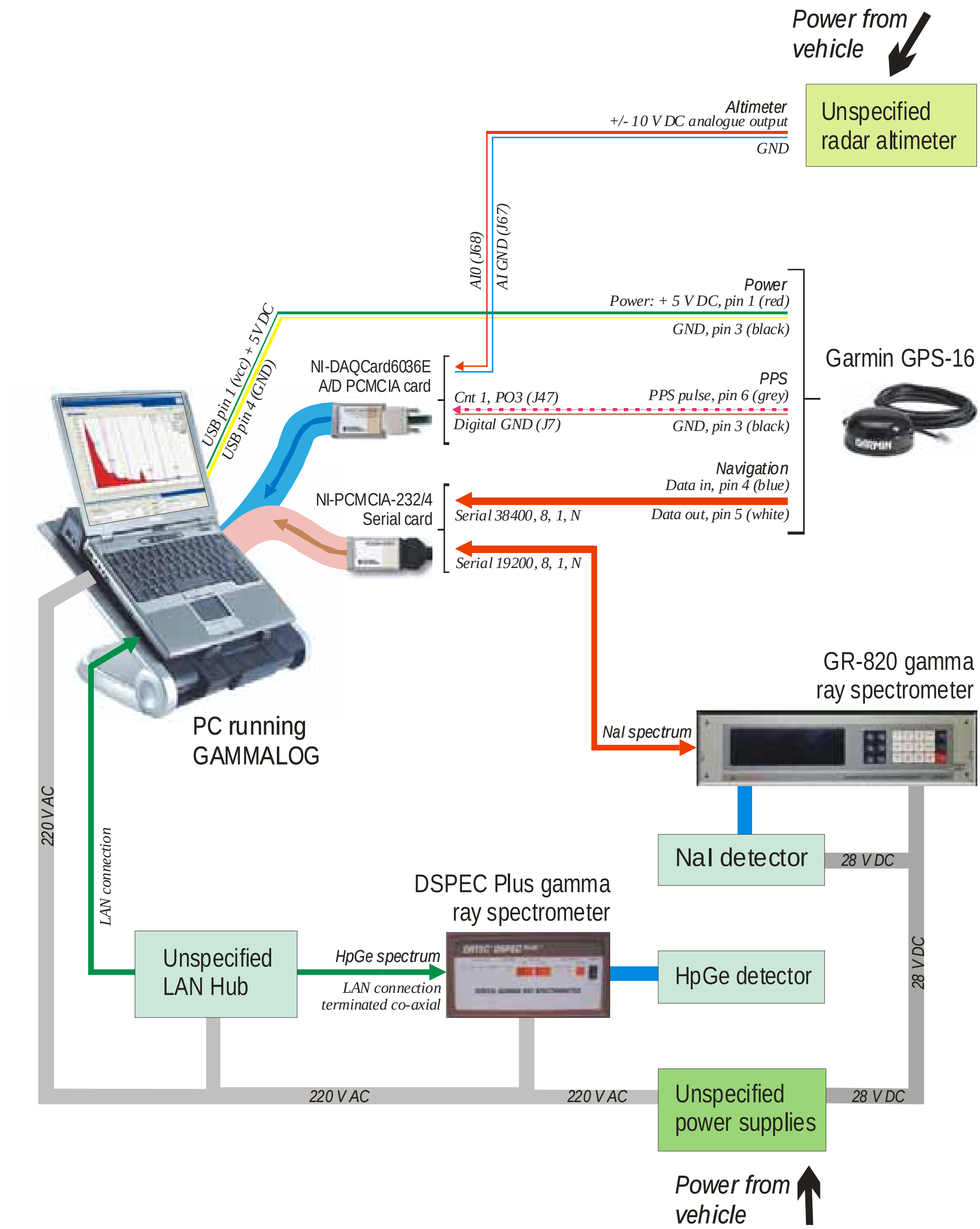


Figure 1. Schematic diagram showing how instruments are connected to the PC. Connection pin numbers and pin names are in accordance with the NGU's hardware configuration specified in APPENDIX B.

5 SOFTWARE

The program development application LabVIEW™ version 7.1 of National Instruments Corporation was used to develop program GAMMALOG that controls the measuring system. 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. The NGU and NRPA hold the source code for GAMMALOG. Otherwise the software is distributed in executable form.

6 INSTRUCTIONS FOR NORMAL OPERATION OF THE MEASURING SYSTEM

- Turn on the component parts of the measuring system as described in APPENDIX G, APPENDIX H, APPENDIX I, APPENDIX J and APPENDIX K.
- Run the GAMMALOG program from the "START" menu or by double clicking the program's icon on the computer desktop.
- Enter the name of a GAMMALOG '.STARTUP' file containing configuration information specific to the measuring system being used (APPENDIX A).
- The measuring system runs until the "STOP" button is pressed.
- Turn off the component parts of the measuring system as described in APPENDIX G APPENDIX H, APPENDIX I, APPENDIX J and APPENDIX K.

7 DATA PRODUCTS

It takes 1 second for the NaI-based instrument to produce a single radiation measurement (APPENDIX G). Measuring while travelling at 50 km/h in a car results in a reading every 14 m along the road. Measuring in an aeroplane travelling at 250 km/h produces a reading every 70 m travelled. Eight hours surveying can produce up to 30,000 readings over a region hundreds of kilometres across.

The HpGe-based instrument can be set to use between 1s and many hours to produce a single reading (APPENDIX H). This adjustment depends on the objective of the measurement programme. For mapping purposes the HpGe instrument is usually set to take 20 seconds for each reading, corresponding to 280 m travelled in a car or 1.4 km in a helicopter.

The logging program measures *continuously* and *all* successful measurements are saved to:

1. a BINARY log file, including full NaI and HpGe spectrum data (APPENDIX E)
2. an ASCII log file, including raw and processed nuclide data and estimated dose rates (APPENDIX F)

The binary file contains a complete record of all raw data produced during a mission so that the data can be re-analysed completely at a later time. The ASCII file contains derived values including estimated dose rates, that can be readily read into spread sheets and displayed on maps using, for example, Microsoft's EXCEL™, Geosoft's Oasis Montaj™ and ESRI's Arc/GIS™.

The operator of the measuring system can choose to create an ASCII *Snapshot* file at any time (8.3.3). This file contains raw and processed nuclide data and full spectrum data in ASCII form (APPENDIX D). It constitutes a complete description of a particular place and can be used to mark and record locations of special interest. This file can, for example, be opened in Microsoft's EXCEL™ spreadsheet program.

8 GAMMALOG PROGRAM OPERATION

Section 6 of this report describes how to start and stop the measuring system including the GAMMALOG program. APPENDIX K summarises adjustments to the PC settings *essential* for correct operation of the GAMMALOG program. This section describes how to use the GAMMALOG program once it is running.

8.1 Program startup

The logging program has a single computer screen display consisting of two sets of panels and a [STOP] button. (Figure 2). The upper series of panels is largely used for data display while the lower series is used for displaying navigational data and program settings.

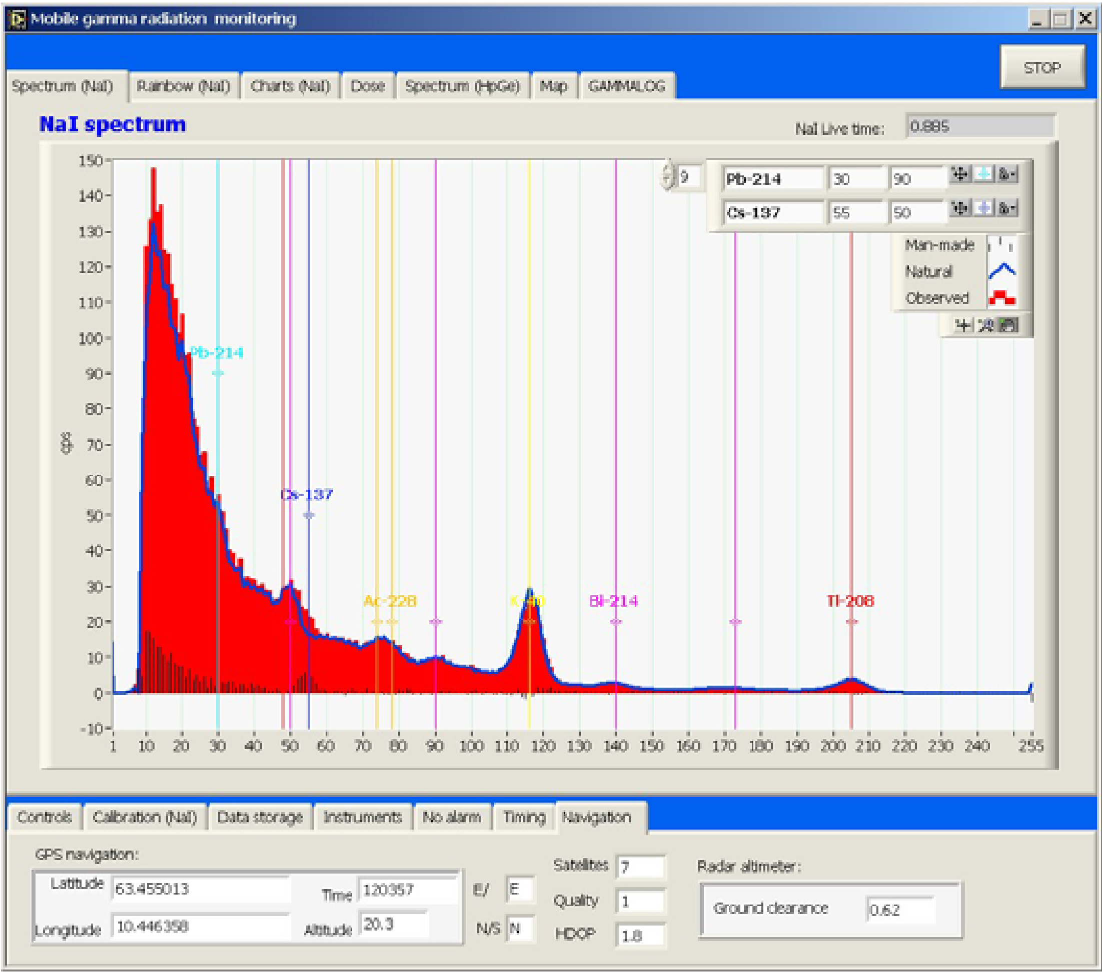


Figure 2. GAMMALOG display consisting of two sets of panels and a [STOP] button.

A dialog box appears at program startup requesting the name of a '.STARTUP' file (APPENDIX A) that will provide the program with all the configuration and calibration data it requires. The dialog box is shown in Figure 3.

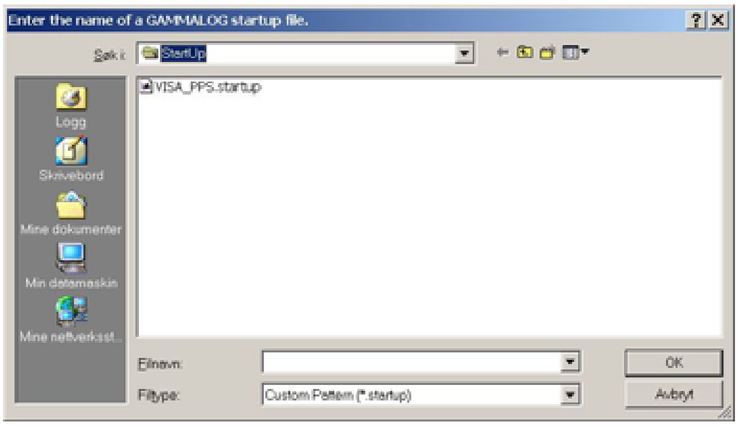


Figure 3. After program startup this dialog box is displayed requesting the name of a '.STARTUP' file containing program configuration and calibration data (APPENDIX A).

GAMMALOG immediately reads the configuration values and tries to establish communication with the measuring instruments. If it fails to do so one of the warnings in Figure 4 will be displayed. If an instrument is absent by intention, for example an HpGe spectrometer is not to be used and is therefore not connected, the warning can be ignored. The status of instrument connections is indicated by the instrument status lamps on the *Instruments* panel (8.3.4).

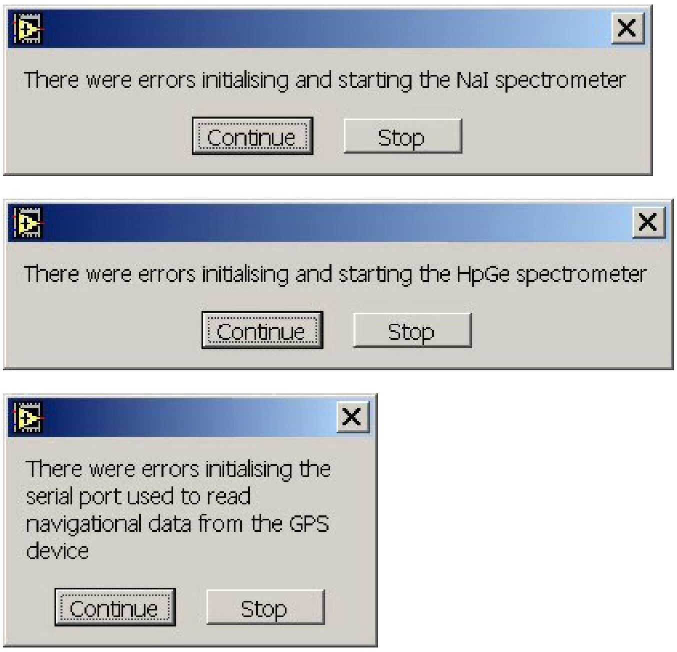
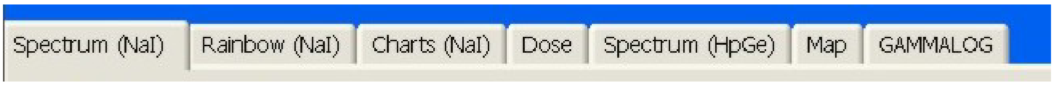


Figure 4. Warning messages at program startup.

GAMMALOG will settle into a regular measuring cycle after a few seconds. From this time on raw data will be stored automatically in a binary log file (APPENDIX E) and processed data in an ASCII text file (APPENDIX F).

8.2 Data display panels (upper series of panels)



8.2.1 Spectrum (NaI) panel

This display panel enables inspection of full 256 channel spectra from the gamma ray spectrometer with the NaI detector operating at one new measurement per second. Counts per second are plotted against channel number. Channel 255 is for photon energies of 3 MeV and above. Three derivatives of the measured NaI spectrum are plotted:

1. Red: the measured spectrum corrected for live time and background (9.3)
2. Blue: a model natural spectrum based on real-time processing of U-238, Th-232 and K-40 windows (9.6)
3. Green: The difference between (1) and (2), constituting an anthropogenic spectum (i.e. what cannot be readily explained by naturally occurring radionuclides).

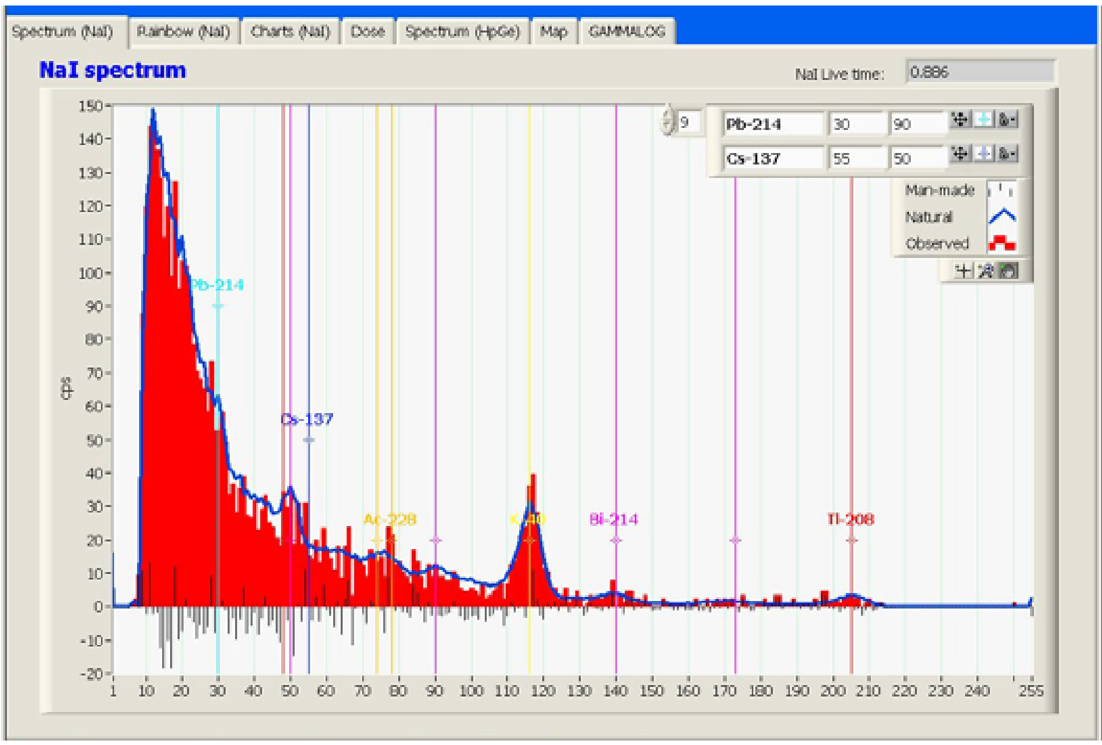


Figure 5. Full spectrum display for the NaI gamma ray spectrometer. The display is interactive and axes, colours and display modes can be altered.

All three spectra are affected by the states of the real-time processing controls (8.3.1) and calibration values (8.3.2 and APPENDIX C). See section 10.1 on how to use this display to detect anthropogenic sources.

8.2.2 Rainbow (NaI) panel

The 'rainbow' or 'waterfall' display mode (Figure 6) is suitable for locating orphan (local) radiation sources. Each NaI spectrum is represented by a vertical stripe. The low-energy (low channel number) 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 gamma ray count rate in each spectrum channel (red = high, purple/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 as in Figure 6. The horizontal stripes crossing the whole screen relate to K-40 with a peak in channel 116 (green stripe, 1.46 MeV), daughters of U-238 in channel 140 (Bi-214, weak blue stripe, 1.76 MeV) and daughters of Th-232 in channel 205 (Tl-280, strong blue stripe, 2.61 MeV).

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. If the system should pass a local source of gamma radiation it would appear on the plot as a short horizontal stripe first growing in intensity as the source is approached and then falling in intensity at it is left behind (10.2, Figure 24).

One of three alternative derivatives of the measured NaI spectrum is displayed, determined by the setting of the control in the lower right corner of the *Rainbow (NaI)* panel. The tree derivatives are the same as those displayed in the NaI spectrum plot on the *Spectrum (NaI*) panel (8.2.1) and are all affected real-time processing controls (8.3.1) and calibration values (8.3.2 and APPENDIX C):

1. "Original": the measured spectrum corrected for live time and background (9.3). These data are displayed in red on the *Spectrum (NaI)* panel (8.2.1)
2. "Natural": a model natural spectrum based on real-time processing of U-238, Th-232 and K-40 windows (9.6). These data are displayed in blue on the *Spectrum (NaI)* panel (8.2.1)
3. "Man-made": The difference between (1) and (2), constituting an anthropogenic spectum (i.e. what cannot be readily explained by naturally occurring radionuclides, 9.6). These data are displayed in green on the *Spectrum (NaI)* panel (8.2.1)

See section 10.2 on how to use this display to detect anthropogenic sources.

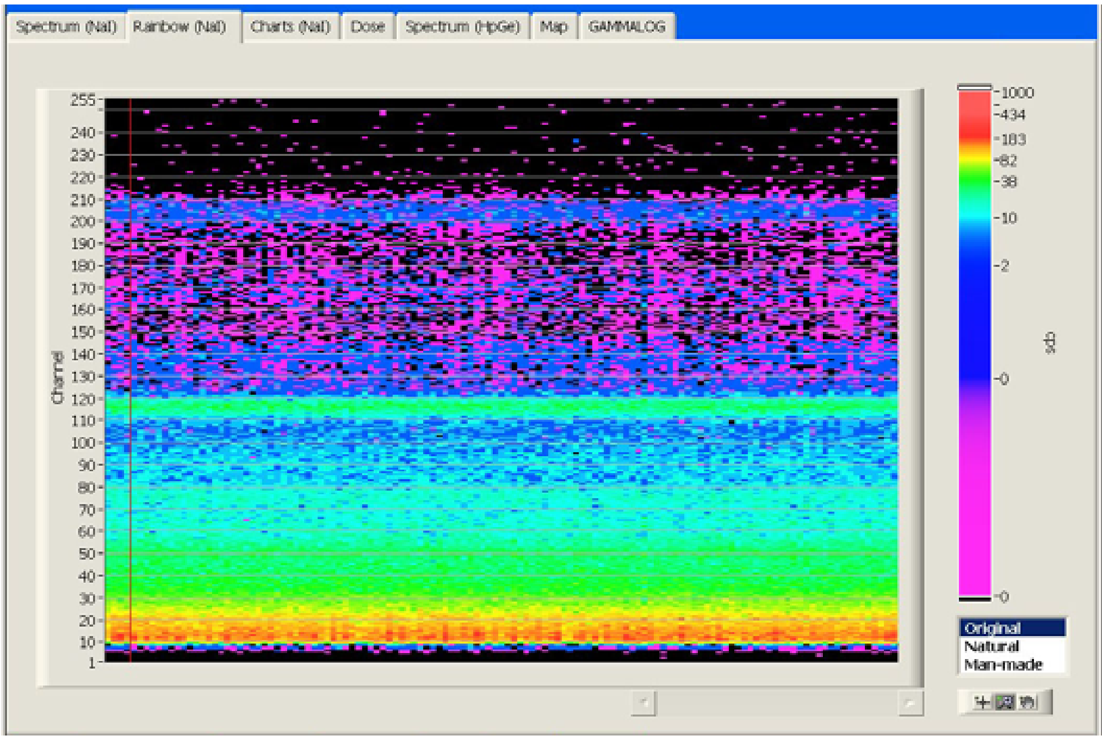


Figure 6. "Rainbow" or "waterfall" plot of full spectra from the NaI gamma ray spectrometer. The display is interactive and axes, colours and display modes can be altered.

8.2.3 *Charts (NaI)* panel

The Charts (NaI) display consists of four charts of processed data (Figure 7, see also section 9). The user selects the four data items to display via the drop-down lists to the left of the charts. Data values are affected by the real-time processing controls (8.3.1) and calibration values (8.3.2 and APPENDIX C).

The example display in Figure 7 shows the measuring system first passing a U-238 source, then a Cs-137 source, and finally a composite U-238 and Cs-137 source.

See section 10.3 on how to use this display to differentiate between natural and anthropogenic sources.

8.2.4 *Dose / ** Warning: Check Dose! *** panel

This display shows dose rate (air kerma rate) on the right-hand dial (Figure 8). Air kerma rates are calculated using the spectral dose index technique (9.8) and calibration values from a configuration file (APPENDIX C), displayed in panel *Dose rate factors* (8.3.2.3). These factors are adjustable in real-time to permit live dose rate tuning of the measuring system to any known reference value.

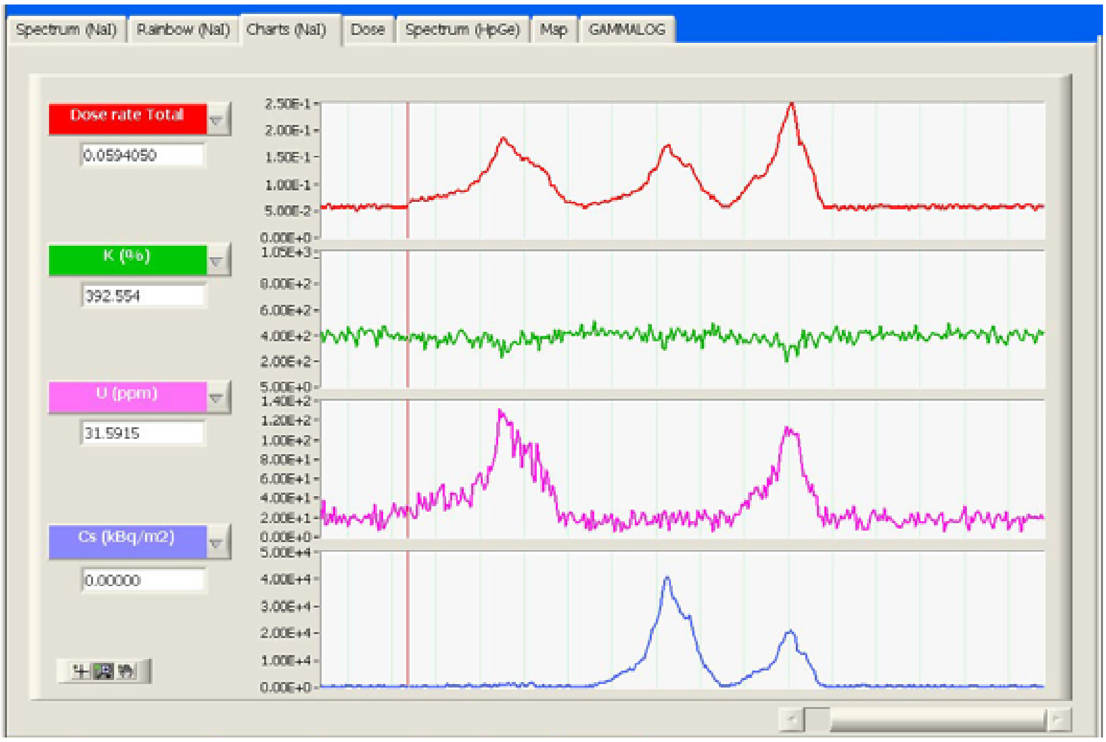


Figure 7. Chart plots of four selected quantities. The display is interactive and axes, colours and display modes can be altered.

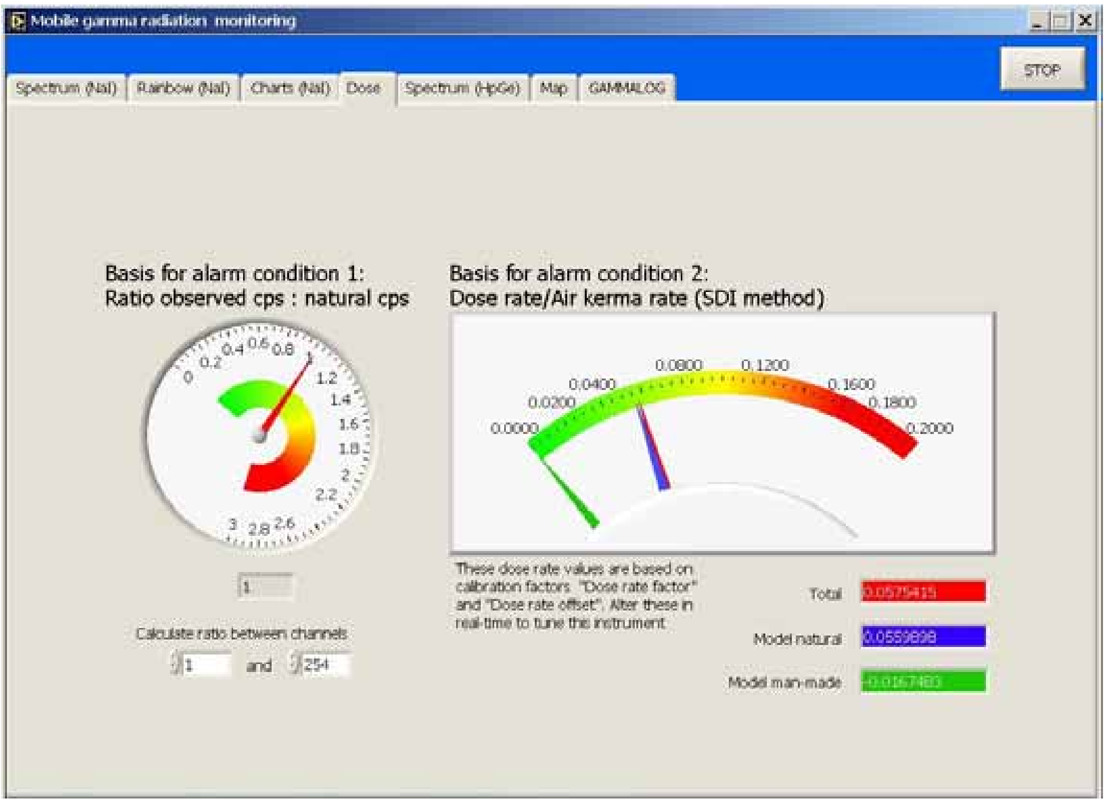


Figure 8. Dose rate (air kerma rate) indicators. The display is interactive and axes, colours and display modes can be altered.

Three dose rates are indicated in the display based on three derivatives of the measured NaI spectrum:

1. Red: Total dose rate derived from the measured spectrum corrected for live time and background (9.3)
2. Blue: Natural dose rate derived from a model natural spectrum based on real-time processing of U-238, Th-232 and K-40 windows (9.6)
3. Green: 'antropogenic' dose rate derived from the difference between (1) and (2).

These three dose rate parameters correspond to the three spectra displayed on the *Spectrum (NaI)* panel (8.2.1) and the *Rainbow (NaI)* panel (8.2.2).

The dial on the left the display shows the ratio between the sum of channel values in the measured spectrum and the sum of channel values in the natural spectrum (9.9). The first spectrum is displayed red in Figure 5 and the second blue in Figure 5. The channel range for calculating the sums is adjustable via the controls beneath the dial. A ratio of 1, as in Figure 8, suggests that the natural model is a good explanation of the observed spectrum and therefore that there is little or no gamma radiation from anthropogenic sources. A ratio greater than 1 implies radiation from anthropogenic sources (Figure 26). The ratio test becomes more sensitive when the channel range for the calculation is narrowed on the region of the spectrum where anthropogenic sources are anticipated to show themselves.

The dial on the left is designed to reveal anthropogenic sources whether they produce a lot of gamma radiation, or only a little. An alarm will sound ("alarm condition 1") if the value on this dial exceeds a critical threshold set on the No alarm / ** Warning: Alarm! ** panel (10.4.1). The dial on the right (red needle) indicates total dose rate (air kerma rate, 9.8) and an alarm will sound ("alarm condition 2") when this value exceeds a critical threshold set on the No alarm / ** Warning: Alarm! ** panel (10.4.2).

8.2.5 *Spectrum (HpGe)* panel

This display panel enables inspection of full 1024 channel spectra from the gamma ray spectrometer with HpGe detector operating at one new measurement every 20 seconds. While the number of channels and duration of measurements are set in the configuration file (APPENDIX B), the duration of measurements can also be adjusted interactively using a control labelled "HpGe sampling interval (s)"on panel *Controls* (8.3.1).

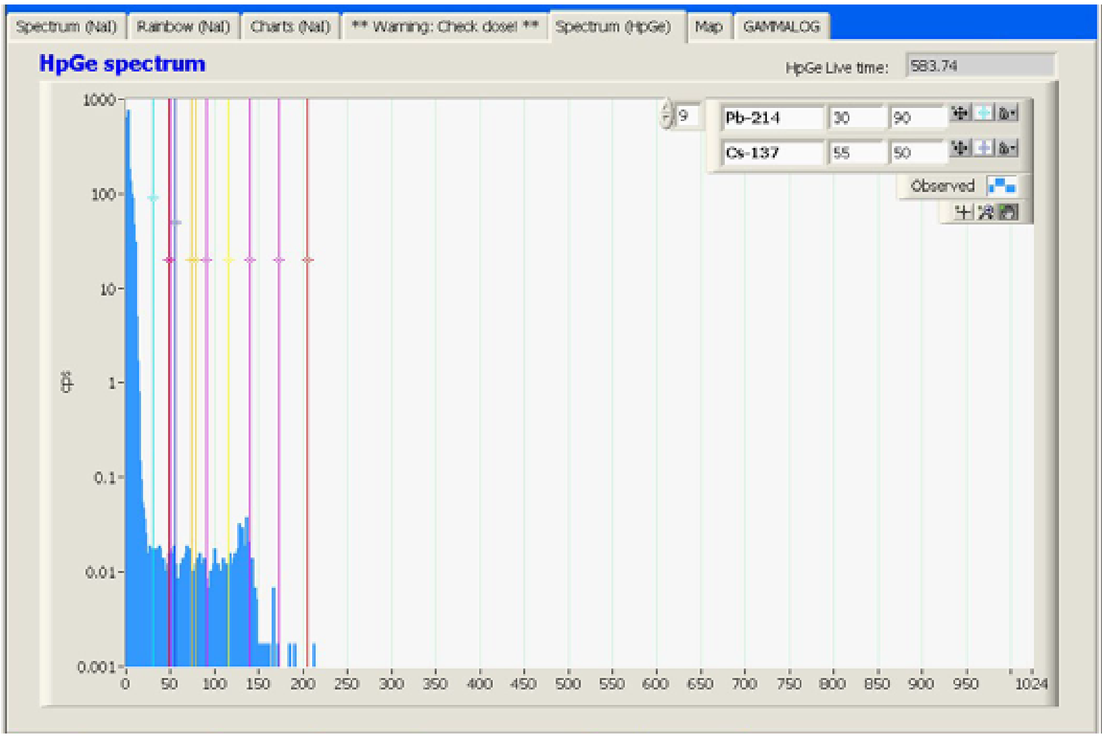


Figure 9. Full spectrum display for the HpGe gamma ray spectrometer. The display is interactive and axes, colours and display modes can be altered

8.2.6 *Map* panel

This panel displays the measuring system's position on a simple map (Figure 10). The user can adjust how many previous positions to remember (buffer) and can place reference crosses on the map to mark the positions of, say, orphan sources. It is *not* possible to display any themes like roads and rivers on the map.

8.2.7 *GAMMALOG* panel

The contents of the GAMMALOG configuration and calibration files are displayed on this panel (Figure 11, APPENDIX A13, APPENDIX B, APPENDIX C). Note that many of the values in these files can be modified in real time using panels *Controls* (8.3.1) and c*alibration (NaI)* (8.3.2).

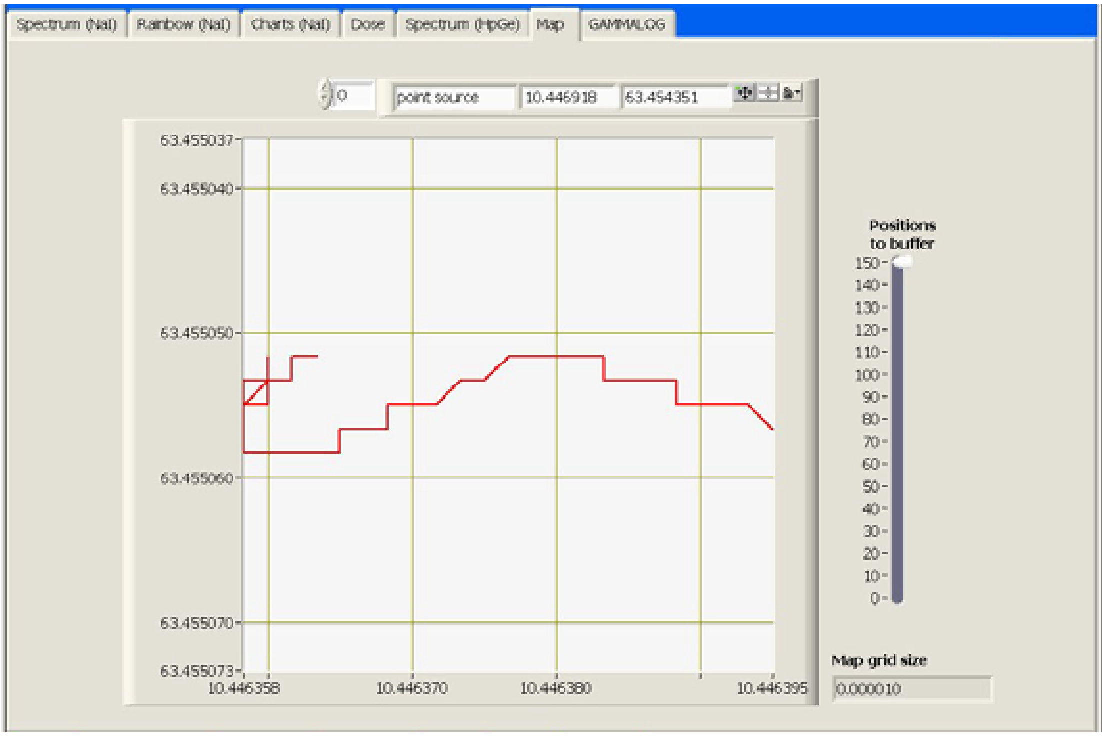


Figure 10. The route travelled of the measuring system. The "Positions to buffer" control determines how many GPS positions to remember and display.

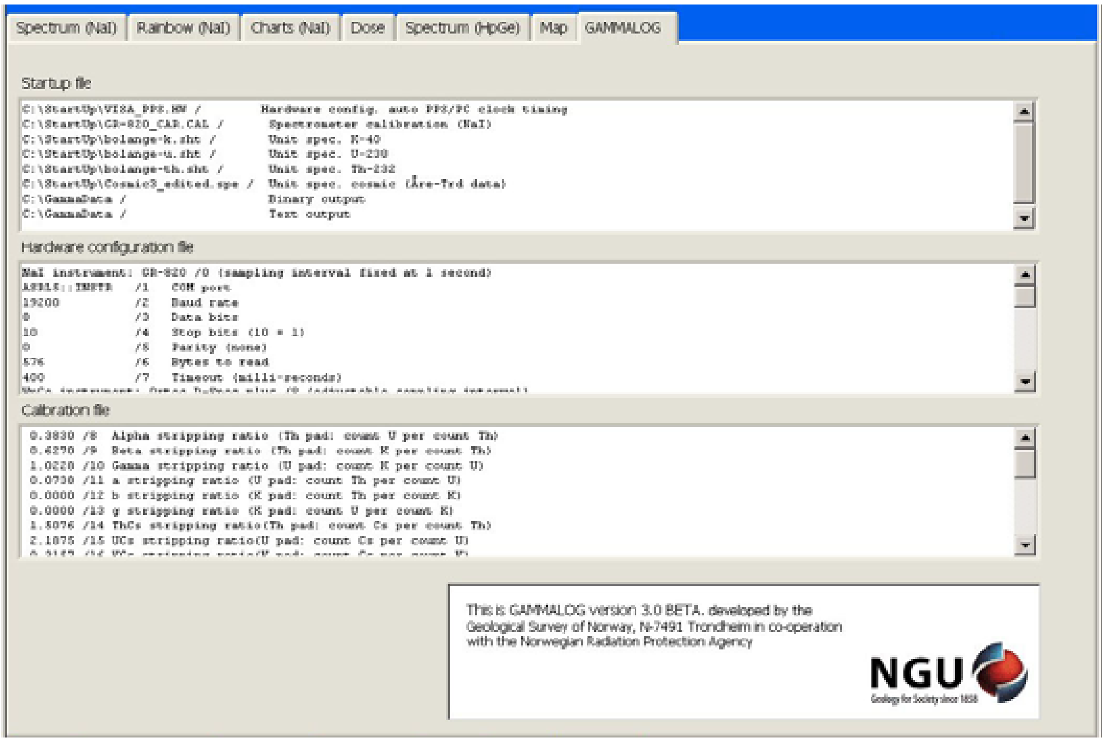


Figure 11. Display of initial configuration and calibration values.

Changed values will not be displayed on the *GAMMALOG* panel and will also not be written to the configuration files. Configuration files must be updated manually using a text editor.

8.3 Program settings and GPS navigation panels (lower series of panels)

8.3.1 *Controls* panel

The *Controls* panel (Figure 12) hosts the switches that determine which real-time processing steps are performed on NaI spectra (section 9), and the measurement duration for the HpGe instrument. In data processing order the [Cosmic] switch determines whether cosmic background is removed from the NaI spectrum (9.2). On the left, switches [Record], [Use] and [Zero] control the measuring of a background that can be removed from NaI measurements (9.3). In the middle, switches [Strip] and [Conc] determine whether window stripping and conversions to concentrations are performed for selected radionuclides (9.4, 9.5). On the right, the [NaI accumulate] switch activates and deactivates the compounding of successive NaI measurements (9.7).

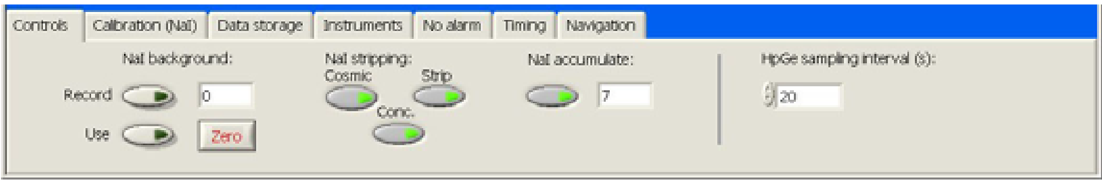


Figure 12. Controls that determine which real-time processing tasks are performed.

8.3.2 *Calibration (NaI)* panel

The *Calibration (NaI)* panel contains all of the calibration values read from the NaI calibration file at program startup (APPENDIX C) and used in real-time processing (section 9). All of the values can be changed in real time via this collection of sub-panels.

8.3.2.1 Stripping factors sub-panel

Calibration values used in real-time NaI window stripping (9.4). Use the [Strip] switch on the "Controls" panel (8.3.1) to turn window stripping on and off.

Figure 13. Factors for window stripping of U-238, Th-232, K-40 and Cs-137.

8.3.2.2 *Sensitivities* sub-panel

Calibration values used in the conversion of stripped NaI window values to ground concentrations (9.5). Use the [Conc] switch on the "Controls" panel (8.3.1) to turn this conversion on and off.

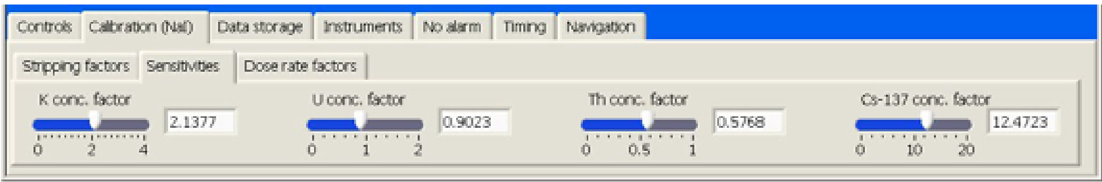


Figure 14. Factors for converting stripped U-238, Th-232, K-40 and Cs-137 values to concentrations.

8.3.2.3 Dose rate factors sub-panel

Parameters used in real-time NaI processing to calculate spectral dose index (SDI) and dose rate (air kerma rate) (9.8 below).

Figure 15. Parameters used in calculating spectral dose index (SDI) and converting SDI to air kerma rate.

8.3.3 *Data storage* panel

8.3.3.1 Binary and ASCII log files

The *Data storage* panel provides information on the state of data log files (Figure 16). Binary and ASCII log files are named and created automatically at program startup (sections 7, 8.1, APPENDIX E, APPENDIX F). The names of these files and file paths to them are indicated on the left of the panel.

8.3.3.2 Measurement ID numbers

One measurement is produced each second and given a unique ID number. The current ID number is displayed near the centre of the panel (e.g. 3542 in Figure 16). This number identifies the measurement in the binary and ASCII log files and also identifies which measurement is in a *Snapshot* file (e.g. in the Figure the last measurement to be saved in a *Snapshot* file was 3527).

8.3.3.3 Number of stored data

The operator is advised of the number of NaI spectra and HpGe spectra stored to the log files (e.g. 3105 and 175 in Figure 16). The number of HpGe spectra is lower than the number of NaI spectra because the HpGe instrument is operated with a longer measurement interval. If the system is working properly the number of stored NaI spectra should increment once a second. The HpGe number should increment at the specified measurement rate (8.3.1, APPENDIX B). Note that measurement ID will increment once every second whether a successful measurement is made or not. If it does not do so, the measuring system is failing and the user is advised to check for errors on the *Instruments* panel (8.3.4) or the *Timing* panel (8.3.6).

8.3.3.4 Creating *Snapshot* files

The right portion of the *Data storage* panel is dedicated to *Snapshot* files (Figure 16). A *Snapshot* file is an ASCII text file containing a single measurement for a particular place (section 7, APPENDIX D). The operator creates a *Snapshot* file at any time by pressing the [Save snapshot] button. The file is named automatically. The measurement ID and location (Latitude/Longitude) of the last *Snapshot* file are displayed to the right of and below the [Save snapshot] button.

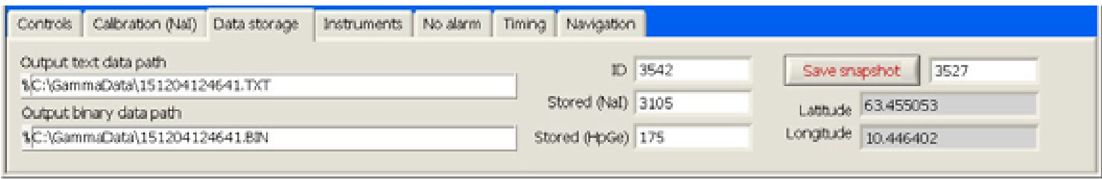


Figure 16. Information on data files and the number of data items stored in them.

8.3.4 *Instruments* panel

Figure 17 shows connection and communication status lamps on the *Instruments* panel. A red light indicates an error while a green light indicates normal instrument operation. GAMMALOG continues operating even when error lights indicate a problem and can recover from many error events, either on its own or with user intervention.

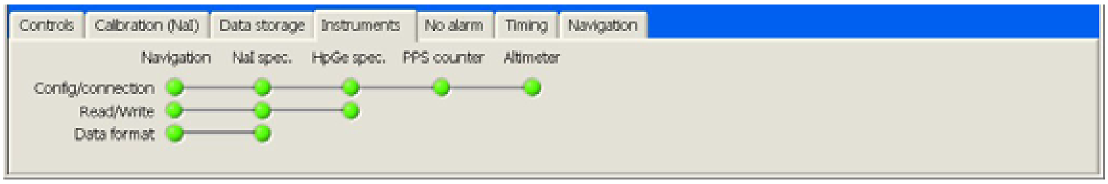


Figure 17. The status of instruments connected to the measuring system.

The status lights indicate when there are errors obtaining meaningful data from the following sources:

- "**Navigation**": GPS navigation device, APPENDIX I
- "**NaI spec.**": NaI gamma ray spectrometer, APPENDIX G
- "**HpGe spec.**": HpGe gamma ray spectrometer, APPENDIX H
- "**PPS counter**": PPS pulse from the GPS navigation device, APPENDIX I and APPENDIX K
- "**Altimeter**": Radar altimeter, APPENDIX J

The following error types are ordered by decreasing severity:

- "**Config/connection**"
  Diagnosis: GAMMALOG could not configure a hardware interface specified in the '.HW' configuration file (APPENDIX B). This error occurs when a serial port or the Analogue/Digital converter card is not working properly or when device settings are specified incorrectly (e.g. serial port number, baud rate or A/D device number). This type of error will seldom correct itself and if a solution to the problem is required GAMMALOG must be shut down and hardware and hardware settings checked.
- "**Read/Write**"
  Diagnosis: An error occurred when reading from or writing to a device. This error usually occurs when an instrument stops working, is turned off, becomes disconnected, or times out. These errors are usually recoverable without shutting down GAMMALOG. Turn the instrument on again, re-connect it, or find out why it has timed out. Time out settings for instruments connected to serial ports are specified in the '.HW' configuration file (APPENDIX B). It is usual for a GPS navigation device to time out in rough topography or urban landscapes; it will do so whenever satellite coverage is poor and a precise position cannot be sent to the computer. GAMMALOG will continue trying to communicate with an instrument in the event of a read/write error.

- "**Data Format**"
  Diagnosis: Data obtained from a device are not in the expected format. This error occurs when an instrument is not adjusted to output data in the format expected by GAMMALOG or when an instrument becomes disconnected and data transfer is interrupted. Changing settings on the instrument or improving the quality of the connection from the instrument usually solves the problem. GAMMALOG will continue trying to communicate with an instrument in the event of a data format error.

Navigation drop-out

If a meaningful navigational fix is not obtained within a specified timeout (APPENDIX B), the navigation time out warning lamp is lit (Figure 17). The last known geographic position is repeated until a new one is obtained.

8.3.5 *No alarm / ** Warning: Alarm! *** panel

The *No alarm / ** Warning: Alarm! *** panel (Figure 18) has the label *No alarm* when an alarm is not sounding and the label *** Warning: Alarm! *** when an alarm is sounding (see Figure 26). Use the panels in Figure 18 to fine-tune alarm settings for the anthropogenic radiation alarm (alarm condition 1) and dose rate alarm (alarm condition 2). See section 10.4 for an explanation of the alarm settings. Use the [Bell] switch on the right of the lower panel (Figure 18) to turn the bell "off".

8.3.6 *Timing* panel

The *Timing* panel (Figure 19) contains important diagnostic indicators that can be used in conjunction with the *Data storage* and *Instruments* panels (8.3.3, 8.3.4) to establish whether the measuring system is working properly. The triggering and timing of measurements is discussed in detail in section 11.

The lamps on the left of the *Timing* panel (Figure 19) change state when a new measurement is triggered. The top lamp "Satellite PPS signal" changes state when a new measurement is triggered by a 1-second satellite PPS pulse from the GPS navigation device (section 11). Depending on the timing mode set in the hardware configuration file (APPENDIX B), the PC's internal clock may be used as a backup triggering mechanism in the event of problems receiving a PPS pulse. The lamp "Internal PC clock" changes state when this time base is being used to trigger measurements. Figure 19 shows that 3906 PPS triggers and 89 PC clock triggers have occurred. This is because the measuring system was started 89 seconds before the GPS device detected its first satellite and the PPS pulse train began.

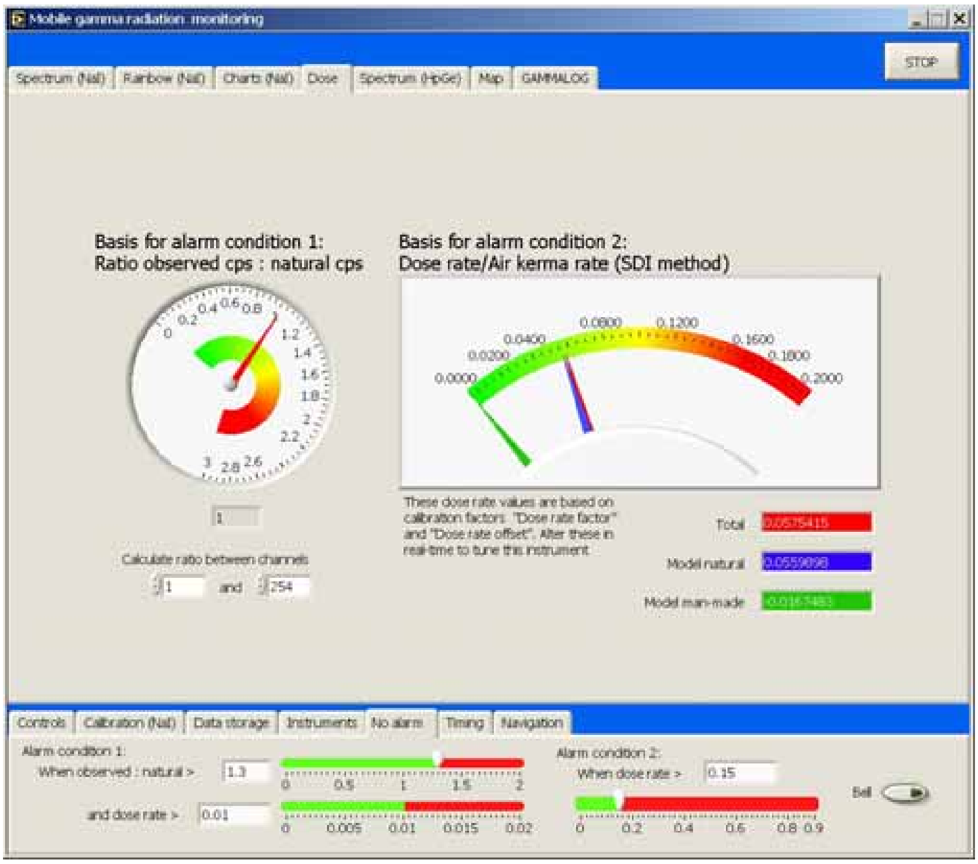


Figure 18. The* No alarm / ** Warning: Alarm! ** *panel (below) and the* Dose / ** Warning: Check Dose! ** *panel (above, 8.2.4). These panels are used to set the thresholds for two alarms (10.4).

Figure 19. Summary/diagnostic information on the triggering and timing of measuring events.

The two numerical indicators in the middle of the panel (Figure 19) show the "Trigger interval" and "Measured interval" in milliseconds. Both are estimates of the duration of each measurement cycle. These should be within 1 or 2 milliseconds of 1000 (the desired 1 second measuring interval). If one or both of these are significantly larger than 1000, the measurements are taking too long and an instrument may not be working or a timeout is set too high (APPENDIX B). Note that the displayed intervals will deviate significantly from 1000 when triggering changes from PPS pulse to PC clock and *vice versa*. This is due to a possible phase difference between the two time bases and is a rare event.

"Radar altimeter lag" (Figure 19) is the time difference between the start of a measuring cycle (the beginning of an NaI spectrometer measurement) and the start of an altimeter measurement. Settings in the hardware configuration file (APPENDIX B) determine how long an altimeter reading will take. The measuring system times this reading to be taken mid-way through a measuring cycle so that its lag is approximately half a second minus half the duration of the altimeter reading.

"Navigation lag" is the time difference between the reading of GPS navigational data and the end of a measurement cycle. This should be about 1 second under PPS triggering and be between 0 and 1 second under PC clock triggering (section 11). This number may drift under PC clock timing because of the significantly lower accuracy of the PC clock compared with the GPS satellite time base.

The set of four lamps on the right of the *Timing* panel labelled "Events" (Figure 19) switch on and off as critical events begin and end during a measuring cycle. Section 12 explains how these indicators can be used to evaluate the performance of the measuring system and check for errors.

8.3.7 *Navigation* panel

The *Navigation* panel (Figure 20) displays all GPS navigational and altimeter data. "Latitude" and "Longitude" are GPS latitude and longitude in degrees according to the WGS-1984 datum, "Time" is UTC time in format 'hhmmss' and "Altitude" is altitude above the WGS-1984 datum in metres. "Satellites" is the number of satellites in view (up to 12). "Quality" and "HDOP" reflect the accuracy of the GPS position. "Ground clearance" is the height above ground in metres from the radar altimeter calibrated according to values in the hardware configuration file (APPENDIX B).

This panel updates itself whenever a new GPS and radar altimeter reading is obtained. Should one or both of these data sources fail to deliver data, the last known GPS position and radar altimeter reading are used. GPS data often fall out for one or two seconds at a time during carborne measurements in urban and forested landscapes. These gaps in navigation can be interpolated over in post-processing.

Figure 20. Detailed GPS navigational information and altimeter reading.

9 REAL-TIME DATA PROCESSING

Real-time data processing is governed by the calibration values read at GAMMALOG program startup (APPENDIX C), any later changes to those values made on panel *Calibration (NaI)* (8.3.2), and the settings of switches on the *Controls* panel (Figure 12, 8.3.1). The following sections explain the real-time processing steps carried out by GAMMALOGn the relevant calibration values, and how to switch on and off processing steps using the controls (8.3.1).

There is a limited time available for the measuring system to carry out real-time processing of data. Few and simple processing steps are therefore carried out that generate useful data without overly burdening the measuring system's computer. In the following sections it is assumed that the reader is familiar with the commonly used terms in radiometric data processing. See IAEA (1991) for a full explanation of the processing steps referred to below.

Only raw data are stored in the binary log file (APPENDIX E). Therefore data values written to this file are not affected by the states of switches, calibration values, and data processing. Conversely, the ASCII log file (APPENDIX F) contains only processed data and the data values written to the file depend on the states of switches and calibration values at any given time during program operation. Pressing a switch that affects data processing, or altering a calibration value, will cause an immediate change in the data values displayed on the computer screen and written to the ASCII log file. Because of this, the states of the switches on the *Controls* panel are written to both the binary and ASCII log files every second along side each measurement so that the processing state of the data in the ASCII file is always known (APPENDIX E, APPENDIX F).

9.1 Correcting for instrument livetime/deadtime

Gamma ray spectra from the NaI and HpGe instruments are saved in the binary log file (APPENDIX E) in the form of raw channel counts together with their respective livetime values (necessary for making the livetime correction).

Both the NaI and HpGe spectra are corrected for livetime before they are displayed on the *Spectrum (NaI)* panel (in red, labelled "original", *Figure 5*, 8.2.1) and the *Spectrum (*HpGe) panel (in blue, *Figure 9*, 8.2.5). Channels in both spectra are then in the form 'counts per second' or 'cps' and form the basis for all later processing steps.

All NaI spectrum window values are likewise corrected for livetime and converted to 'cps' units. The windows relate to K-40, U-238, Th-232 and Cs-137 and have the spectrum channel ranges (ROIs) specified in the hardware configuration file (APPENDIX B). Corrected window values are displayed on the *Charts (NaI)* panel (8.2.3).

9.2 Removing Cosmic background

The state of the switch labelled [Cosmic] on the *Controls* panel (Figure 12, 8.3.1) determines whether cosmic background is removed from the livetime corrected NaI spectrum and window values. The cosmic background correction is based on the unit cosmic spectrum read at program startup (APPENDIX A) and the cosmic count rate in channel 255 of the livetime corrected NaI spectrum. If the cosmic correction is switched on, the resulting NaI spectrum is displayed on the *Spectrum (NaI)* panel (in red, labelled "original", Figure 5, 8.2.1) and resulting NaI window values displayed on the *Charts (NaI)* panel (8.2.3)

9.3 Removing measured background

It is possible to record many NaI spectra and use the mean spectrum in a background correction. This feature may be used to subtract gamma radiation emanating from a contaminated transportation platform or subtract gamma radiation measured at one geographic location from data obtained elsewhere.

The controls for recording and using a background measurement are [Record], [Use] and [Zero] on the *Controls* panel (Figure 12, 8.3.1). Pressing [Record] starts a background measurement and pressing it again stops the measurement. An indicator shows how many seconds the background measurement is based upon. A background can be based on data from a number of geographic locations, simply start, stop and re-start the building of a background measurement by pressing [Record] multiple times at different places.

The NaI spectra that go to make the background measurement are subject to the livetime correction and, if the [Cosmic] switch is 'on', the cosmic correction (therefore do not switch [Cosmic] on and off while building a background).

The switch [Use] determines whether or not the recorded background is subtracted from NaI spectra and NaI windows values (already processed to stage 9.2). If the background correction is switched on, the resulting NaI spectrum is displayed on the *Spectrum (NaI)* panel (in red, labelled "original", Figure 5, 8.2.1) and resulting NaI window values displayed on the *Charts (NaI)* panel (8.2.3).

Turn the [Use] switch off to stop subtracting the background. To reset the recorded background spectrum to zero press the [Zero] button. The system is then ready to begin recording a new background spectrum.

9.4 Stripping spectral overlap

The window stripping technique can be used to remove spectral overlap between gamma ray count rates in the K-40, U-238, Th-232 and Cs-137 NaI spectrum windows. The spectrum channel ranges of the windows are specified in the hardware configuration file (APPENDIX B) and the stripping ratios are specified in the NaI calibration file (APPENDIX C). Stripping ratios are displayed and can be adjusted in real-time on the *Calibration (NaI)/Stripping factors* panel (Figure 13, 8.3.2.1).

Stripping is turned on and off using the [Strip] switch on the *Controls* panel (Figure 12, 8.3.1). Stripping is carried out after processing stage 9.3 and the resulting stripped NaI window values are displayed on the *Charts (NaI)* panel (Figure 7, 8.2.3).

If stripping is switched off, conversion to ground level concentrations (9.5, the [Conc] switch) is unavailable.

Suggestions for new and better stripping ratios are displayed beneath the actual stripping ratios on the *Calibration (NaI)/Stripping factors* panel (Figure 13). These are only of interest when the measuring system is being calibrated (APPENDIX M).

Note that stripping ratios appropriate for the nominal survey elevation must be supplied. No real-time correction is made for deviations from this elevation.

9.5 Conversion to ground level concentrations

Stripped window values (9.4) can be converted to radionuclide concentrations at ground level using the [Conc] switch on the *Controls* panel (Figure 12, 8.3.1). This calculation is based on calibration factors/sensitivities for K-40, U-238, Th-232 and Cs-137 specified in the NaI calibration file (APPENDIX C). These sensitivities are displayed and can be adjusted in real-time on the *Calibration (NaI)/Sensitivities* panel (Figure 14, 8.3.2.2). Note that these sensitivities should apply to the nominal survey elevation. No adjustment is made for deviations from this elevation or for deviations from standard temperature and pressure. Units of concentration depend on the sensitivity values specified in the calibration file and on the *Calibration (NaI)/Sensitivities* panel. Labels on the user interface assume these units to be % (K-40), ppm (U-238 and Th-232) and Bq/m^2 (Cs-137). The uranium window values, for example, could just as well be converted to Bq/kg Ra-226 if the appropriate sensitivity for this conversion was specified.

Conversion to ground level concentrations is carried out after processing stage 9.4 and the resulting radionuclide concentrations are displayed on the *Charts (NaI)* panel (Figure 7, 8.2.3).

9.6 Derivation of natural and anthropogenic spectra

It is of interest to split NaI spectra into two parts, one associated with the naturally occurring radionuclides K-40, U-238 and Th-232, and the other associated with anthropogenic radionuclides. This is especially useful when gamma radiation from anthropogenic contamination is of a similar magnitude to or less than spatially variable gamma radiation from natural (geological) sources.

GAMMALOG makes this separation in real-time by taking unit spectra for K-40, U-238 and Th-232 read at program startup (APPENDIX A), multiplying them by corresponding stripped window count rates (processing stage 9.4), and adding them together to produce a model NaI spectrum for the naturally occurring radionuclides. This model is then subtracted from the observed NaI spectrum to produce a difference spectrum that is assumed to represent anthropogenic radionuclides. For best results the observed NaI spectrum should, at least, be corrected for cosmic background (9.2).

The 'original', natural and anthropogenic spectra are portrayed graphically in red, blue and green on the *Spectrum (NaI)* panel (Figure 5, 8.2.1). In Figure 5 the blue natural model matches the red observed spectrum extremely well. This indicates that:

- The calibration parameters are good and the measuring system is working well
- The observed spectrum reflects only natural sources of gamma radiation

In Figure 21 the natural (blue) curve fits the observed spectrum very well above channel 62, but very poorly below channel 62. This is because a strong C-137 source is near the NaI detector, creating a photo peak in channel 55 (662 keV). The anthropogenic (difference) spectrum contains this peak and associated Compton scattering tail and has the characteristic shape of a pure Cs-137 spectrum.

This illustrates very well how the measuring system can be used to differentiate between naturally occurring and anthropogenic sources of gamma radiation. This ability is utilised in the following displays:

- *Spectrum (NaI),* Figure 5, 8.2.1
- *Rainbow (NaI),* Figure 6, 8.2.2
- *Dose/**Warning: Check Dose!**,* Figure 8, 8.2.4

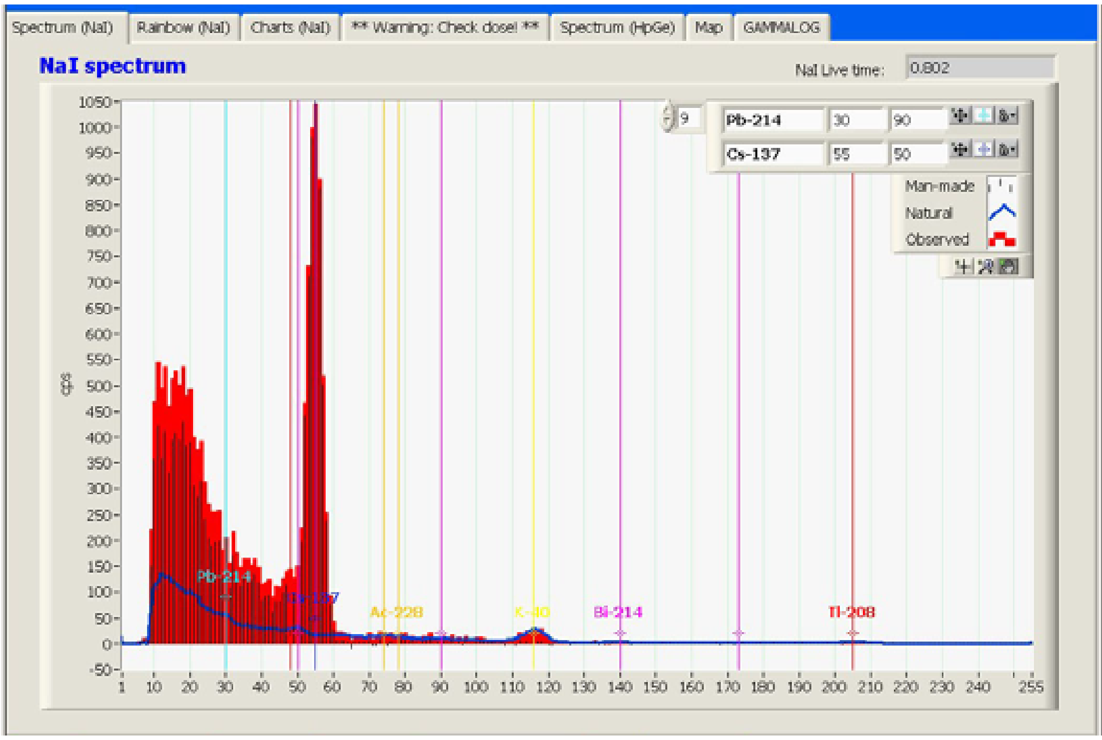


Figure 21. Observed (red), natural (blue) and anthropogenic (green) spectra with natural sources of gamma radiation in evidence as well as a strong Cs-137 source (peak in channel 55, 662 keV).

There are situation when this modelling of the NaI spectrum breaks down. The modelling works when window stripping works (9.4). If anthropogenic nuclides produce counts in the K-40, U-238 and/or Th-232 windows, the efficiency of the stripping process will be degraded by the degree to which the anthropogenic counts dominate over the natural counts. Co-60 produces a photo peak near that of K-40 and the stripping process breaks down in the presence of strong Co-60 sources. In this case the consequences are over estimates in the amounts of K-40 and Cs-137 and an underestimate in the amount of Co-60 (little or no effect on the estimated amounts of U-238 and Th-232).

Although untidy, this breakdown in stripping has no practical consequences for recognition of anthropogenic radiation. When anthropogenic radiation causes a significant breakdown in the modelling procedure, the natural model does not resemble the observed spectrum and anthropogenic sources are assumed to be the cause.

9.7 Accumulating or compounding successive NaI measurements

The gamma ray spectrometer with NaI detector makes measurements of 1 second duration. It is sometimes desirable to compound successive NaI measurements to produce a spectrum and window values based on many seconds of measurement.

The compounding of successive measurements is turned on and off using the [Accumulate] switch on the *Controls* panel (Figure 12, 8.3.1). It is likely that this function will be used when the measuring system is standing still and a more accurate NaI measurement is required, for example at a location of special interest or a calibration site. If the measuring system is in motion while compounding measurements is active, the resulting spectrum will be the average spectrum for the route travelled.

When [Accumulate] is switched on, all displays of the NaI spectrum and windows show the compounded values and are updated each second as every new 1-second measurement is incorporated into the mean spectrum. The indicator next to the [Accumulate] switch shows how many 1-second spectra have been incorporated into the mean spectrum (Figure 12).

Compare the spectra in Figure 5 and Figure 22 to see the effect of compounding data on the quality of NaI spectra. The same small Cs-137 source was present when both measurements were made, however the Cs-137 source is only detectable in the compounded spectrum in Figure 22.

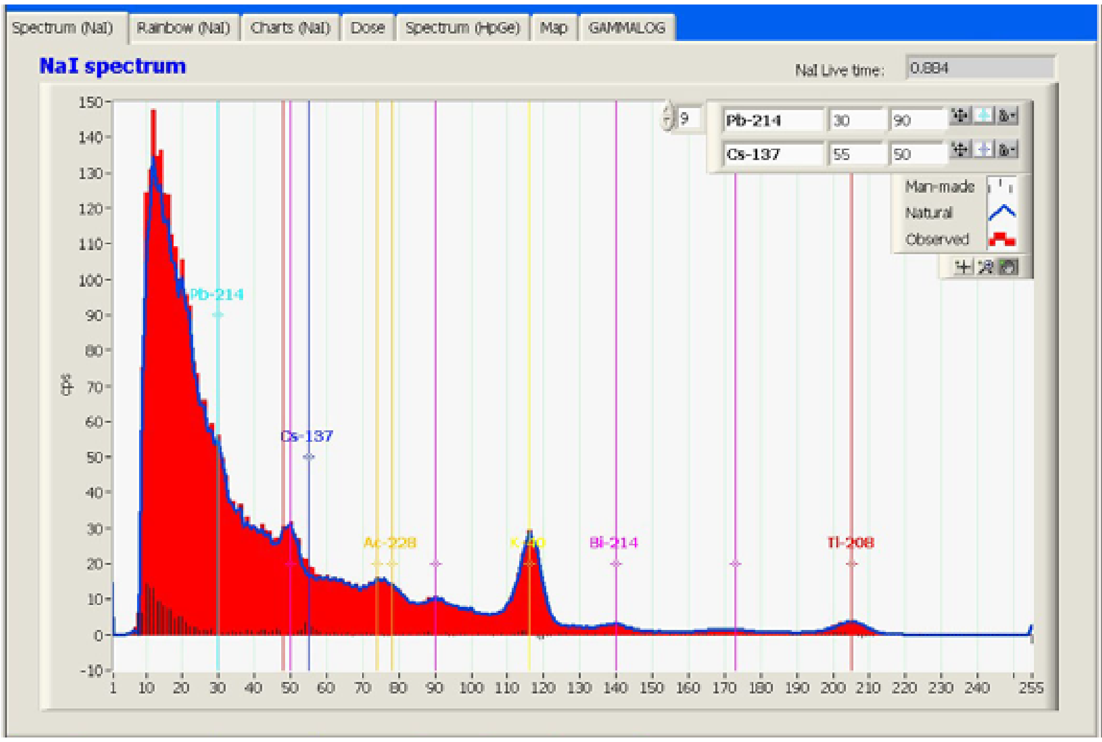


Figure 22. An NaI spectrum based on 300 1-second spectra using the [Accumulate] switch. Compounding spectra makes it easier to detect small anthropogenic sources like Cs-137 in this diagram (green 'difference' curve with peak at channel 55). Note the exceptional agreement between the model (blue) and observed (red) spectrum.

Raw 1-second NaI spectra are written to the binary log file every second, whether [Accumulate] is switched on or off (APPENDIX E). However, when [Accumulate] is switched on, compounded data are written to the ASCII log file each second (APPENDIX F), just as their display on the screen is updated every second.

Also, compounded data are written to the *Snapshot* file should the [Save snapshot] button on the *Data storage* panel be pressed while [Accumulate] is switched on (Figure 16, 8.3.3).

9.8 Conversion to ground level dose rate (air kerma rate)

Gamma ray spectra from the spectrometer with NaI detector are converted to ground level dose rates (air kerma rates). This calculation is based on calibration values read from the NaI calibration file (APPENDIX C). These values are displayed on the *Calibration (NaI)/Dose rate factors* panel (Figure 15, 8.3.2.3) and can be adjusted in real-time to permit live re-calibration for dose rate.

Determination of dose rate is based upon the work of Bargholz & Korsbech (1997). Dose rates are calculated for each of the observed, natural and anthropogenic NaI-spectra described in 9.6. Prior to the dose rate calculation the spectra are subjected to the cosmic correction (if [Cosmic] is switched on, 9.2), the background correction (if [Use] is switched on, 9.3) and the compounding of spectra (if [Accumulate] is switched on, 9.7). Be careful to note, therefore, that *if backgrounds are being subtracted from the NaI spectrum, the dose rates will also be reduced*.

First, the spectral dose index (SDI) is calculated for the observed, natural and anthropogenic NaI-spectra. Count rate in each spectrum channel is multiplied by channel number and then the weighted channel values are summed to produce an SDI.

Bargholz & Korsbech (1997) show that SDI is proportional to air kerma rate and that SDIs measured at different heights above the ground can be used to infer ground level air kerma rates. They notice that the best results are obtained by dropping low energy channels (below 350 keV) from the SDI calculation at higher elevations. Therefore the start and end channel numbers for the SDI calculation are present in the NaI calibration file and can be adjusted in real time.

It is assumed that SDI for the specified range of channels measured at the nominal survey elevation varies linearly with ground level air kerma rate and therefore SDI is multiplied by "Dose rate factor" and added to "Dose rate offset" to generate ground level air kerma rate values (Figure 15, 8.3.2.3, APPENDIX C). No account is taken for deviations from nominal survey elevation and standard temperature and pressure.

Observed, natural and anthropogenic dose rates are displayed on the *Dose / ** Warning: Check Dose! *** panel (Figure 8, 8.2.4) in the form of red, blue and green needles on a dial.

9.9 Anthropogenic radiation detection ratio

The ratio between the observed gamma ray count rate and natural gamma ray count rate (9.6) provides an indication of the presence of anthropogenic gamma radiation. This ratio is the sum of channel count rates in a user specified section of the observed spectrum divided by the sum of channel count rates in the same section of the natural spectrum. The spectra are processed to level 9.6. The ratio is displayed on a dial on the *Dose / ** Warning: Check Dose! *** panel (Figure 8, 8.2.4). The range of channels used in the calculation is set on the same panel just below the dial. A ratio of 1 implies no anthropogenic gamma radiation; a ratio greater than 1 implies anthropogenic radiation; a ratio less than 1 implies poor stripping of naturally occurring nuclides and/or interference between spectral peaks due to anthropogenic nuclides and windows for the naturally occurring nuclides.

10 DETECTION OF ANTHROPOGENIC RADIONUCLIDES AND ALARM CONDITIONS

The GAMMALOG program estimates dose rates (air kerma rates, 9.8) and attempts to separate gamma radiation from anthropogenic radionuclides from naturally occurring radionuclides (9.6). These data are displayed in ways that bring anthropogenic sources to the attention of the system operator, and two built in alarms are designed to do the same.

10.1 *Spectrum (NaI)* panel

Figure 21 shows how the *Spectrum (NaI)* panel (8.2.1) can be used to identify a powerful Cs-137 source. Figure 22 shows how the same display can be used in conjunction with the [Accumulate] switch (8.3.1, 9.7) to reveal much weaker Cs-137 and other anthropogenic sources.

10.2 *Rainbow (NaI)* panel

Figure 6 Shows a rainbow plot where only naturally occurring radionuclides are in evidence (8.2.2).

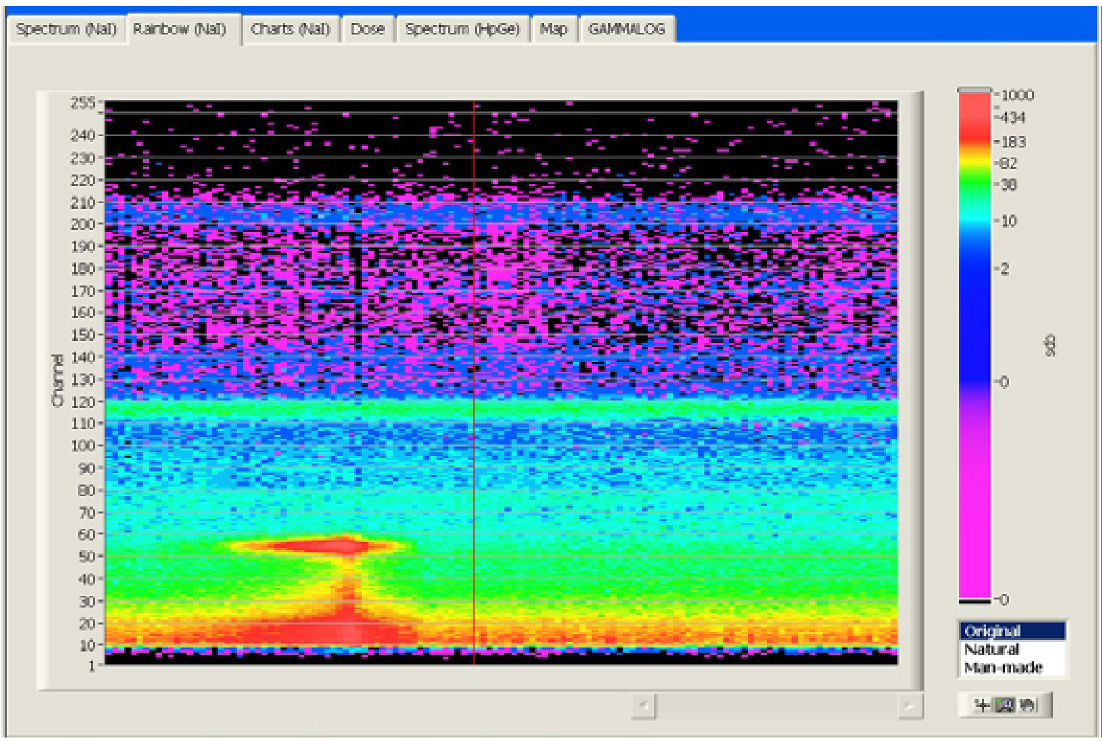


Figure 23. A rainbow plot showing naturally occurring nuclides (continuous stripes) and the passage of a Cs-137 point source (red oval centred on channel 55, 662 keV).

Figure 23 is a similar plot but the measuring system has moved past a Cs-137 point source (red oval). The response to the point source increases as it is approached and decreases, more quickly, as the measuring system moves away from it.

Figure 24 shows how the different component parts of the observed NaI spectrum, natural and anthropogenic (9.6), can be displayed in the rainbow diagram. Anthropogenic sources are easy to detect when what are modelled as natural sources are removed.

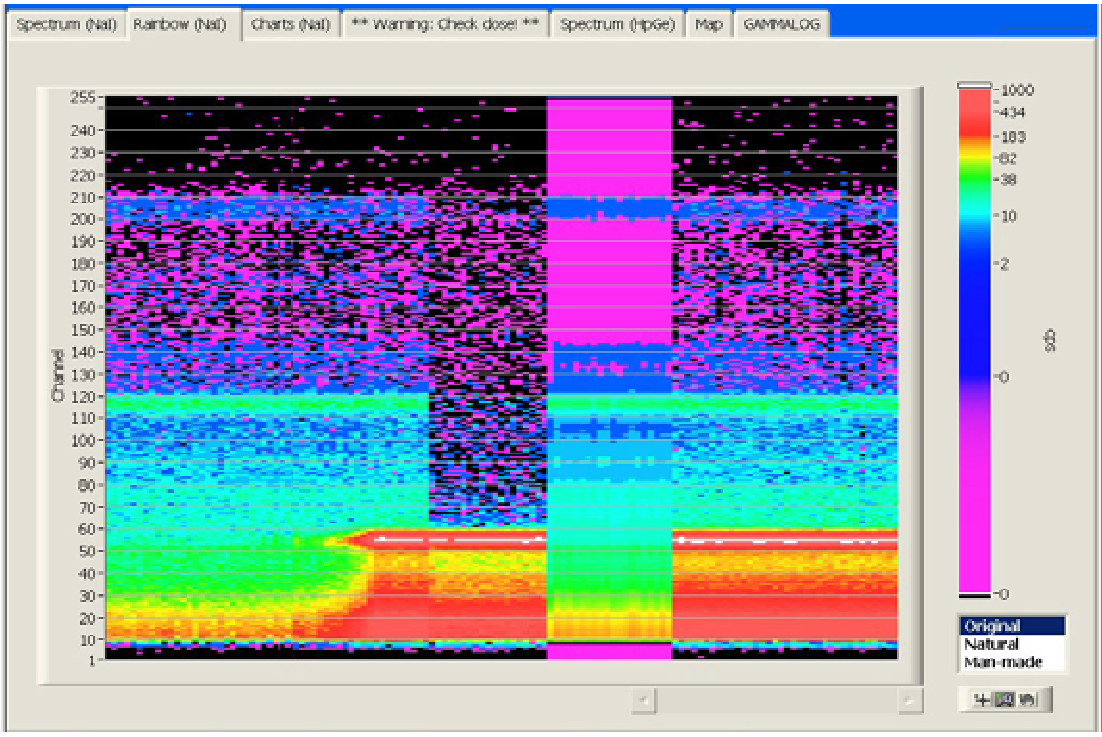


Figure 24. Rainbow plot showing the measuring system approaching a Cs-137 source while viewing the original (observed) NaI spectrum (left). Beginning at the left of the screen, the Cs-137 source becomes evident in the form of a widening red stripe (channel 55). Naturally occurring nuclides, that are not changing in concentration spatially, appear as continuous blue and green stripes. The display was then switched to show only anthropogenic sources for a few seconds. The red stripe due to Cs-137 continues unchanged but the stripes from natural sources disappear. Next, the model natural spectrum is displayed and the Cs-137 source is not visible. Finally the display is switched back to show the original (observed) spectrum containing both kinds of sources.

10.3 *Charts (NaI)* panel

Figure 7 shows how the *Charts (NaI)* panel (8.2.3) can be used to highlight anthropogenic sources of gamma radiation. The user has chosen charts for total observed dose rate (air kerma rate, 9.8), K-40 (%), U-238 (ppm) and Cs-137 (kBq/m^2) (9.5). Reading from left to right, dose rate increases because the measuring system is approaching a local, natural, U-238 source. The dose falls and increases for a second time, but this time because the measuring system is passing an anthropogenic (Cs-137) source. The dose rate then falls again only to rise as the system passes a second local and natural U-238 source and a second anthropogenic Cs-137 point source, both at the same geographic location.

10.4 Two alarms

Two types of radiation alarms are built into the GAMMALOG program. The alarms are always active, but the sensitivity of the alarms can be adjusted interactively. The two alarms are:

1. *Anthropogenic radiation alarm*
   Warn when anthropogenic sources are detected, even when they are very weak. See real-time processing steps 9.6 and 9.9. For setting alarm thresholds see 10.4.1

2. *Dose rate (air kerma rate) alarm*
   Warn when dose rate exceeds a critical value. See real-time processing step 9.8. For setting alarm thresholds see 10.4.2

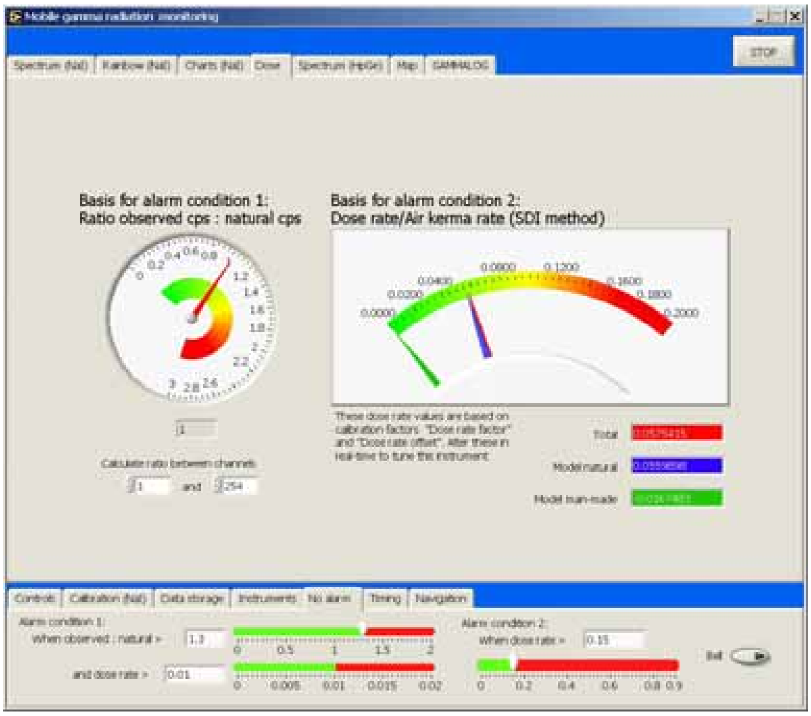


Figure 25. The alarm display consists of the* Dose/**Warning: Check Dose!** *panel and* No Alarm/**Warning: Alarm!** *panel. In this case the anthropogenic radiation alarm (alarm condition 1) shows no detectible anthropogenic radiation

and the dose rate (air kerma rate, alarm condition 2) shows dose rates within what has been specified on the lower panel as acceptable.

The alarm displays and alarm thresholds are placed on the *Dose/**Warning: Check Dose!*** panel and *No Alarm/**Warning: Alarm!*** panel respectively (Figure 25, Figure 26). The anthropogenic radiation alarm, alarm condition 1, is on the left of the screen and the dose rate alarm, alarm condition 2, is on the right of the screen.

When both alarms are inactive, i.e. there is no alarm; the top panel has the label Dose and the bottom panel No alarm (Figure 25). When one or both of the alarms is active the panel labels change to ***Warning: Check Dose!*** and ***Warning: Alarm!*** respectively (Figure 26). Also, the lower panel changes colour from grey to light blue and a bell sounds. The bell may be turned off and back on again using the switch on the right side of the ***Warning: Alarm!*** panel.

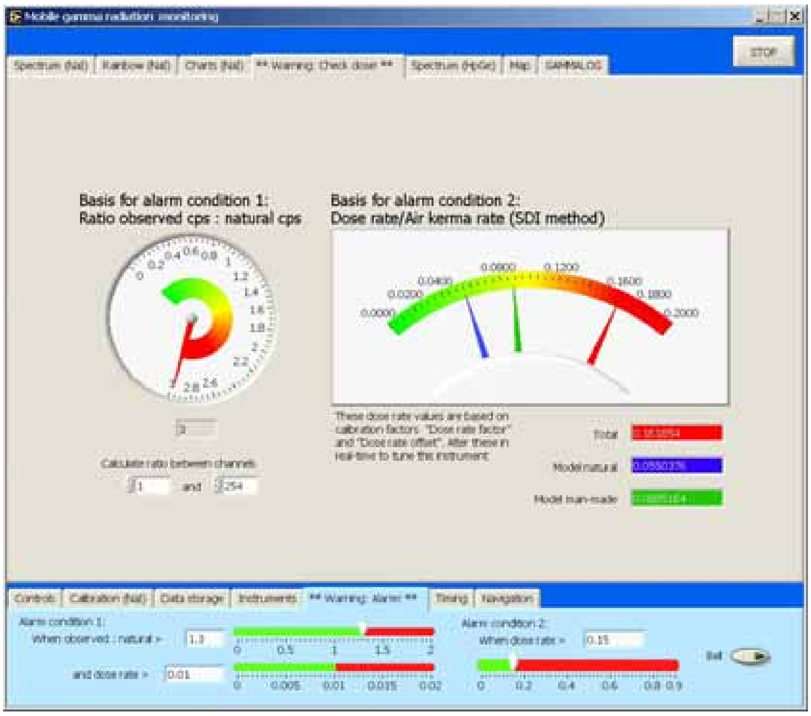


Figure 26. A similar display to Figure 25 but both the anthropogenic radiation and dose rate alarms (alarm conditions 1 and 2) are triggered. Note that the panel labels change from Dose (above) and No alarm (below) to **Warning: Check Dose!** (above) and **Warning: Alarm!** (below). The anthropogenic radiation alarm (left) shows a value of three (9.9). This means that the observed gamma count rate in the specified channel range is three times the amount that is presumed to be natural. The dose rate alarm (right) shows that the total dose rate (9.8) exceeds the critical value specified. Note that the dose due to anthropogenic sources (green needle) is higher than the dose due to natural sources (blue needle)(9.6).

10.4.1 Adjustment of the anthropogenic radiation alarm

The alarm depends on a good calibration of the measuring system and effective real-time processing (9.6 and 9.9). The alarm is based upon the ratio between observed and what is modelled to be natural gamma radiation. A value close to 1 implies no anthropogenic gamma radiation (left dial, Figure 25). A value above 1 implies anthropogenic radiation (left dial, Figure 26).

There are four parameters that can be adjusted to optimise the anthropogenic radiation alarm. Careful adjustment of these factors can improve the sensitivity of the alarm massively.

First, the user can adjust the width of the NaI spectrum window used in the calculation of the alarm value using the two controls beneath the left dial in Figure 26. The efficiency of the alarm increases massively if the user adjusts the window to include *only* the range of channels that contain photo-peaks for the anthropogenic nuclides being searched for.

Second, the user can adjust the critical ratio of observed to normal gamma radiation (9.9) above which the alarm will sound. The significance of the ratio calculation breaks down when gamma count rates are very low. Therefore, the alarm sounds when the calculated ratio exceeds the user specified critical value *and* total dose rate (9.8) exceeds a user specified critical value. These values are adjusted on the left side of the lower panel in Figure 26 under the heading "Alarm condition 1".

10.4.2 Adjustment of the dose rate (air kerma rate) alarm

The second alarm condition is when observed total dose (9.8, red needle on the right-hand dial of Figure 26) exceeds a value specified by the user on the right side of the lower panel in Figure 26 under the heading "Alarm condition 2".

11 TIMING OF MEASUREMENTS

Whenever possible the timing of gamma ray spectrometer measurements is co-ordinated with the arrival of GPS navigational fixes (one per second) heralded by the arrival of a pulse (PPS, pulse per second) from the GPS device (APPENDIX I; see the *Timing* display panel, 8.3.6). Timing modes are set in the hardware configuration file (APPENDIX B) and provide alternatives to PPS timing.

11.1 PPS pulse only

The most accurate timing of measurements is obtained when timing mode is set to 2 ("PPS pulse only"). This mode can be used when it is known that the navigation device will transmit PPS pulses to the computer at 1 second intervals during the entire mission, without fail.

As long as the recommended GPS device, the Garmin GPS 16 or later models (APPENDIX I), receives information from at least one satellite at or soon after system startup, it will continue to send PPS pulses thereafter whether satellites remain in sight or not. This mode is therefore suitable for use together with the GPS 16. Should PPS pulses fail while the system is in "PPS pulse only" mode, the measuring system will stop and wait for the next PPS pulse. This timing mode ensures that *each navigational fix corresponds to the start position for each 1-second spectrometer reading*.

11.2 PPS pulse with PC clock backup

"PPS pulse with PC clock backup", timing mode 1, performs like "PPS pulse only" but does not stop when PPS pulses fail. After a timeout of a little over 1 second the measuring system will start timing measurements using the PC's internal clock. Should PPS pulses resume, the system will return to PPS timing.

11.3 PC clock only

"PC clock only", timing mode 3, instructs the measuring system to use the internal PC clock for timing. This is the least accurate timing and should be avoided. It should only be used when the navigation device in use does not output PPS pulses. In this case the triggering of spectrometer measurements will not be coordinated with the arrival of GPS navigational fixes. Furthermore, the PC clock is so inaccurate that a phase shift will develop between 1-second spectrometer measurements controlled by the PC clock and the arrival of GPS navigation data governed by the satellite time base. This phase shift will vary between 0 and 1 second. The practical consequence of this is that at one time the navigation point may represent the start of a spectrometer reading, and at another time in the same mission, the end of a spectrometer reading.

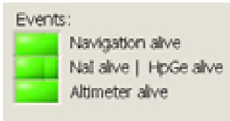
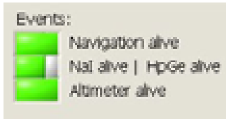
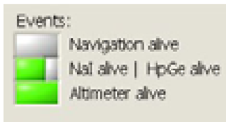
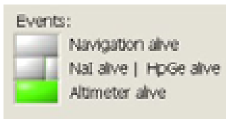
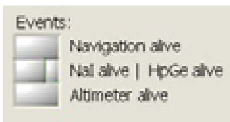
12 THE MEASUREMENT CYCLE AND DIAGNOSTIC INDICATORS

The GAMMALOG program co-ordinates measurement events in the manner described in Table 1. The sequence of events in a measuring cycle depends on which instruments are working and some user settings. For example, two alternative cycles are described in Table 1, one when both NaI and HpGe gamma ray spectrometers are connected to the system, and one where only the NaI spectrometer is present. The sequence of events in the short time after the GAMMALOG program startup is to some extent unpredictable because different instruments begin delivering data at different times. Therefore the description of events in Table 1 starts at the moment when the measuring system is waiting for a signal to start measurement number 5 (just less than 4 seconds after startup).

A group of 4 indicators/lamps labelled "Events" are placed on the *Timing* panel (8.3.6). These switch on and off to indicate the beginnings and ends of events that make up a measuring sequence. The changing states of these indicators as the measuring sequence progresses are given in Table 1.

Since the HpGe spectrometer measures for a longer time than the NaI instrument, the sequence of events during a measurement when data will be retrieved from both the NaI and HpGe instruments (cycle 5 in Table 1) will differ from the sequence of events when data will be retrieved from only the NaI instrument (cycle 6 in Table 1).

Table 1. Sequence of events during two successive measurement cycles. For the sake of simplicity the list shown only major events and starts at measurement number 5 and ends with measurement 6.

<table>
<tr><th></th><th>Event</th><th>Indicators (NaI & HpGe instruments)</th><th>Indicators (NaI instrument only)</th></tr>
<tr><td>5.1</td><td>All instruments waiting for trigger event #5
(5.1.1) If the navigation instrument is working and it generates a pulse once a second (PPS pulse), this is used as the trigger
(5.1.2) If the navigation instrument is not working or it does not provide a PPS pulse, the internal PC clock generates a trigger once a second</td><td></td><td></td></tr>
<tr><td>5.2</td><td>All instruments activated by trigger #5:
(5.2.1) Terminate NaI measurement #4 and start NaI #5
(5.2.2) Terminate HpGe measurement #4, read HpGe #4 from the instrument, and start HpGe #5
(5.2.3) Read Navigation #5 (associated with the PPS pulse in step 1 (i))
(5.2.4) Read NaI #4 from the instrument
(5.2.5)Wait to mid point of cycle #5 to begin altimeter measurement #5</td><td></td><td></td></tr>
<tr><td>5.3</td><td>Acquisition and display of Navigation #5 finished, navigation instrument waiting for trigger event #6
(5.3.1) The navigation indicator may not appear to light at all because all the navigation tasks are done very quickly
(5.3.2) The indicator will light longer if this instrument times out or some other abnormal event occurs</td><td></td><td></td></tr>
<tr><td>5.4</td><td>(5.4.1) Reading and displaying of NaI #4 finished
(5.4.2) Reading and displaying of HpGe #4 finished
(5.4.3) Save navigation #4, altimeter #4, NaI #4 and HpGe #4 to disk in binary and ASCII forms
(5.4.4) NaI and HpGe instruments waiting for trigger event #6</td><td></td><td></td></tr>
<tr><td>5.5</td><td>Acquisition and display of altimeter #5 finished, instrument waiting for trigger event #6</td><td></td><td></td></tr>
<tr><td>6.1</td><td>All instruments waiting for trigger event #6
Note that the HpGe indicator is lit all the time during a cycle where a HpGe measurement will be terminated and read (e.g. cycle #5). (The measurement duration for the HpGe instrument is usually set to last 20 measurement cycles.) The light remains off during the other cycles (e.g. #6).</td><td></td><td></td></tr>
</table>

6.2 **All instruments activated by trigger #6:**

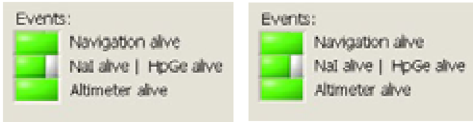
(6.2.1) Terminate NaI measurement #5 and start NaI #6

(6.2.2) If the measurement duration for the HpGe instrument is set to more than 1 second (it was triggered in cycle #5) do not interact with the instrument in this cycle and the indicator remains unlit

(6.2.3) Read Navigation #6 (associated with the PPS pulse in step 1)

(6.2.4) Read NaI #5 from the instrument

(6.2.5) Wait to mid point of cycle #6 to begin altimeter measurement #6



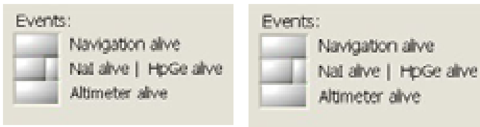
6.3 **Acquisition and display of Navigation #6 finished, navigation instrument waiting for trigger event #7**

6.4 (6.4.1) Reading and displaying of NaI #5 finished

(6.4.2) Save navigation #5, altimeter #5, NaI #5 and HpGe #5 (empty array) to disk in binary and ASCII forms

(6.4.3) NaI and HpGe instruments waiting for trigger event #7

6.5 **Acquisition and display of altimeter #6 finished, instrument waiting for trigger event #7**



Instrument settings, errors, time outs and other delays will be reflected in the behaviour of indicator lamps on the *Timing* panel (8.3.6). Therefore the indicators serve as a diagnostic/troubleshooting tool for experienced operators.

If, on a slow computer, delays mean that measuring, displaying and data storage tasks are not complete in time for the next measurement trigger event (occurring at 1 second intervals), the trigger event is registered anyway, albeit late, and a new measurement cycle will begin. If the cause of the delay disappears, the duration of measuring cycles will return to normal (1 second) within a few seconds. If not, the system will measure with an interval as close to 1 second as possible. Useful data will be produced as long as the essential instruments are working.

13 REFERENCES

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IAEA 1991: Airborne Gamma Ray Spectrometer Surveying. Technical reports series No. 323, International Atomic Energy Agency, Vienna.

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

Mellander, H., Helle, K.A., Karlsson, S., Korsbech, U., Lauritzen, B. & Smethurst, M.A. 2002: Mobile Gamma Spectrometry: Evaluation of the Resume 99 Exercise. Nordic Nuclear Safety Research, NKS-56, ISBN 87-7893-111-8.

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

Walker, P. & Smethurst, M.A. 1993: The distribution of Cs-137 in the Meråker and Grong/Snåsavatnet areas. NGU Report 93.045.

APPENDIX A STARTUP FILE ('.STARTUP')

At GAMMALOG program start-up the user is required to supply the name of an ASCII '.STARTUP' file (8.1). This file contains the names of configuration files that describe the characteristics of the measuring system. An example '.STARTUP' file is listed below:

```
C:\StartUp\VISA_PPS.HW /          Hardware configuration
C:\StartUp\GR-820_CAR.CAL /       Spectrometer calibration (NaI)
C:\StartUp\bolange-k.SPE /        K-40 unit spectrum (NaI)
C:\StartUp\bolange-u.SPE /        U-238 unit spectrum (NaI)
C:\StartUp\bolange-th.SPE /       Th-232 unit spectrum (NaI)
C:\StartUp\Cosmic3_edited.SPE /   Cosmic unit spectrum (NaI)
C:\GammaData /                    File path for binary data output
C:\GammaData /                    File path for text data output
```

File names are on the left and comments to the right of the "/" symbol. Any other text can be added to the file after the last line shown above. The configuration files listed are:

Hardware	Type '.HW'	(APPENDIX B)
NaI spectrometer calibration	Type '.CAL'	(APPENDIX C)
Snapshot (K-40 unit NaI spectrum)	Type '.SPE'	(APPENDIX D)
Snapshot (U-238 unit NaI spectrum)	Type '.SPE'	(APPENDIX D)
Snapshot (Th-232 unit NaI spectrum)	Type '.SPE'	(APPENDIX D)
Snapshot (cosmic unit NaI spectrum)	Type '.SPE'	(APPENDIX D)

The last two lines of the '.STARTUP' file determine where binary and ASCII data products (section 7) are generated. Binary log files (APPENDIX E) are written to the first file path. ASCII log files (APPENDIX F) and ASCII *Snapshot* files (APPENDIX D) are written to the second file path.

'.HW' and '.CAL' files are created using a text editor. *Snapshot* '.SPE' files are created using the GAMMALOG program's [Save snapshot] button (8.3.3.4) but can be edited in a text editor if necessary.

APPENDIX B   HARDWARE CONFIGURATION FILE ('.HW')

The GAMMALOG program reads this file by virtue of its name appearing in line 1 of the user specified '.STARTUP' file (APPENDIX A). The hardware file contains information required for communication with instruments. An example file is listed below:

```
NaI instrument: GR-820 /0 (sampling interval fixed at 1 second)
ASRL5::INSTR   /1   COM port
19200  /2   Baud rate
8      /3   Data bits
10     /4   Stop bits (10 = 1)
0      /5   Parity (none)
576    /6   Bytes to read
400    /7   Timeout (milli-seconds)
50 59 109 125 132 148 189 220 /8 ROIs for Cs-137, K-40, U-238, Th-232
HpGe instrument: Ortec D-Spec plus /9 (adjustable sampling interval)
#1     /10  Instrument ID
0      /11  GetData start
1024   /12  GetData length
20     /13  Sampling interval (whole seconds >= 1)
GPS, DGPS instrument (NMEA-183 data transfer) /14
ASRL4::INSTR   /15  COM port
38400  /16  Baud rate
8      /17  Data bits
10     /18  Stop bits (10 = 1)
0      /19  Parity (none)
100    /20  Bytes to read
500    /21  Timeout (milli-seconds)
1      /22  Switch: 1 = NMEA-183 Lat/Long, 0 = projected X/Y
A/D interface, Radar altimeter and PPS timing signal /23
Dev1/ai0  /24  Voltage device and channel number
Dev1/ctr1 /25  PPS counting device and counter number
10     /26  Voltage high limit
-10    /27  Voltage low limit
20     /28  Scans (number of samples to take at scan rate)
100    /29  Scan rate (Hz)
1      /30  Height factor (Height = Height factor * Volt + Height offset)
0      /31  Height offset (Height = Height factor * Volt + Height offset)
Measurement timing /32
1      /33  1=PPS with PC clock backup; 2=PPS only; 3=PC clock only
```

NaI spectrometer (APPENDIX G)

Lines 0 to 8 are serial communication settings for the NaI spectrometer. Note that the serial port (number 5 in this case) is referred to in an unconventional manner. Also, line 8 indicates the regions of interest (ROIs/windows) for the spectrometer.

HpGe spectrometer (APPENDIX H)

Lines 9 to 13 determine how GAMMALOG will communicate with the HpGe spectrometer. The number of spectrum channels required is specified in line 12 (this should be the same as the instrument's own setting) and measurement duration is specified in line 13 in whole seconds (also adjustable in real-time, 8.3.1).

GPS navigation device (APPENDIX I)
Lines 14 to 22 are serial communication settings for the GPS navigation device. If the device terminates the GPGGA sentence with an *end of transmission* character, make sure the *bytes to read* value in line 20 is larger than the maximum anticipated length of the GPGGA sentences. If no *end of transmission* character is sent, the GPGGA sentence must be *exactly* the length specified in line 20. The switch in line 22 is for the NGU's use only. If set to 0, this switch enables use of the NGU's alternative GPS navigation device that delivers projected X/Y coordinates instead of latitude/longitude values (APPENDIX I; in this case *bytes to read* must be equal to the length of the GPGGA sentence).

Analoge/Digital interface (APPENDIX K) for the GPS PPS pulse (APPENDIX I) and radar altimeter (APPENDIX J)
The A/D interface specified in APPENDIX K is used to acquire PPS pulse signals from the GPS navigation device (APPENDIX I) and DC voltages from the radar altimeter (APPENDIX J). Lines 23 to 31 of the configuration file refer to the A/D device. Line 24 is the device name for the radar altimeter/voltage input. "Dev1/ai0" means National Instruments DAQ device "Dev1", analogue input connection "0". Line 25 is the device name for the GPS PPS pulse input. "Dev1/ctr1" means National Instruments DAQ device "Dev1", counter connection "1". Lines 26 to 31 relate to the input voltage from the radar altimeter. First, the voltage range from the device must be specified. "Scans" and "scan rate" determine how many samples of the input voltage will be taken and at what rate. The values specified in the example file constrain the voltage measurement to consists of 20 repeat voltage readings over 0.2 seconds (the median value is used and the others discarded, APPENDIX J). "Height factor" and "height offset" are used to convert the median voltage to height in metres. No conversion is made in the example file.

Measurement timing
The switch on line 33 determines how the measuring system will trigger and time measurements. See section 11 for a detailed explanation of the timing modes.

APPENDIX C NaI CALIBRATION FILE ('.CAL')

The GAMMALOG program reads this file by virtue of its name appearing in line 2 of the user specified '.STARTUP' file (APPENDIX A). The calibration file contains values used in real time processing of NaI spectra to produce dose rate estimates and radionuclide activities. All of the values in the calibration file can be adjusted in real-time using the *Calibration (NaI)* display panel (8.3.2). An example calibration file is listed below:

```
 0.3830     / Alpha  stripping ratio (Th pad: counts U  per count Th)
 0.6270     / Beta   stripping ratio (Th pad: counts K  per count Th)
 1.0228     / Gamma  stripping ratio (U  pad: counts K  per count U)
 0.0738     / a      stripping ratio (U  pad: counts Th per count U)
 0.0000     / b      stripping ratio (K  pad: counts Th per count K)
 0.0000     / g      stripping ratio (K  pad: counts U  per count K)
 1.5076     / Th/Cs  stripping ratio (Th pad: counts Cs per count Th)
 2.1875     / U/Cs   stripping ratio (U  pad: counts Cs per count U)
 0.3157     / K/Cs   stripping ratio (K  pad: counts Cs per count K)
 2.1377     / K-40   calibration factor (Unit = cps * factor)
 0.9023     / U-238  calibration factor (Unit = cps * factor)
 0.5768     / Th-232 calibration factor (Unit = cps * factor)
12.4723     / Cs-137 calibration factor (Unit = cps * factor)
 0.44960E-6 / Air kerma rate factor     (Unit = SDI * factor + offset)
-0.01830E+0 / Air kerma rate offset     (Unit = SDI * factor + offset)
 1          / Start channel for SDI calculation
 254        / End   channel for SDI calculation
```

Calibration values are to the left of the "/" character and comments to the right. Comments may follow the last line in the file.

Lines 1 to 9 are the stripping factors for determining pure quantities (in counts per second) of K-40, U-238 (or Ra-226), Th-232 and Cs-137 (IAEA, 1991). These factors should be for the nominal survey elevation (see real-time processing section 9.4).

Lines 10 to 15 are factors that convert pure quantities (in counts per second) of K-40, U-238 (or Ra-226), Th-232 and Cs-137 to standard units of activity/concentration at ground level assuming constant ground clearance and standard temperature and pressure (see real-time processing section 9.5).

Lines 16 and 17 determine the range of spectrum channels used to calculate spectral dose index (SDI). Lines 14 and 15 determine the conversion of SDI to air kerma rate at ground level assuming constant ground clearance and standard temperature and pressure (see real-time processing section 9.8).

See APPENDIX M for a discussion of calibration methods.

APPENDIX D SNAPSHOT FILES / UNIT SPECTRA FILES

The GAMMALOG program requires *Snapshot* files as input, specified by name in the '.STARTUP' file (APPENDIX A). *Snapshot* files are also created by GAMMALOG as one of its three data output files (section 7).

A *Snapshot* file contains full spectum data for a single measurement at a particular location and for that reason lends itself to being used as the source of pure nuclide spectra (unit spectra) for use in full NaI-spectrum modelling in real-time (9.6, APPENDIX M).

The system operator creates an ASCII *Snapshot* file at any time and place using the [Save snapshot] button on the *Data storage* display panel (8.3.3.4). The file can be made to contain an average spectrum produced over many seconds or hours by first pressing the [Accumulate] switch (8.3.1) to start averaging measurements and then some time later pressing the [Save snapshot] switch. The average spectrum is written to the *Snapshot* file. The *Snapshot* files containing unit spectra in APPENDIX A were produced using large calibration pads, background subtraction controls (8.3.1, 9.3) and [Accumulate] and [Save snapshot] switches.

GAMMALOG creates Snapshot files as follows:

File name: YYMMDDHHMMSS. (Year, Month, Day, Hour, Minute, Second)

File path: specified in the .STARTUP configuration file (APPENDIX A)

Data types:

- *Geographic position*
- *Ground clearance* from the radar altimeter
- *Raw and processed radionuclide and dose-rate data from the NaI device*
- *Three full gamma ray spectra from the NaI spectrometer* ('observed', 'natural' and 'man-made', processed to step 9.6) (The first spectrum is used when GAMMALOG reads a Snapshot file for unit spectrum data, APPENDIX A, 8.1)
- *A full gamma ray spectrum from the HpGe spectrometer* corrected for livetime/deadtime (9.1)

Format: Tab delimited text designed for Microsoft Excel™.

The layout of a *Snapshot* file is given below:

Line	Content (TAB delimited)
1	Unique spectrum ID (8.3.3.2), Number of NaI spectra accumulated (8.3.1, 9.7)
2	GPS latitude, GPS longitude, GPS altitude, Radar altimeter elevation (8.3.7)
3	8 live-time corrected NaI window values. Cosmic and background corrected if switches [Cosmic] and [Use] are "on" (9.2, 9.3). Compounded if switch [Accumulate] is "on" (9.7)
4	8 processed NaI window values. As above, but also processed according to switches [Strip] and [Conc] (9.4, 9.5). Units depend on calibration values (8.3.2). Some of the processed values may be in error in presence of anthropogenic sources. Also, total dose rate/air kerma rate (9.8), "Natural" dose and "Anthropogenic" dose (9.6).
5	256 channel NaI spectrum corrected for live time and background (9.3) coloured red in the *Spectrum (NaI)* display (8.2.1).
6	256 channel NaI model "natural" spectrum based on real-time processing of U-238, Th-232 and K-40 windows (9.6) coloured blue in the *Spectrum (NaI)* display (8.2.1).
7	The difference between the NaI spectra in lines 5 and 6, constituting an anthropogenic spectum (i.e. what cannot be readily explained by naturally occurring radionuclides) coloured green in the *Spectrum (NaI)* display (8.2.1).
8	1024 channel HpGe spectrum corrected for live time coloured blue in the *Spectrum (HpGe)* display (8.2.5)

When a *snapshot* file is used as the source of pure nuclide spectra, the first spectrum in the file, line 5, is taken to be the characteristic spectrum for the pure radionuclide. GAMMALOG translates this spectrum into a unit spectrum immediately after reading it by dividing the channel values by the window total appropriate for the radionuclide (line 8 of the hardware configuration file (APPENDIX B).

APPENDIX E BINARY LOG FILE (ONE FILE PER MISSION, GENERATED AUTOMATICALLY)

The binary log file is one of the three data products of the GAMMALOG program (section 7). The file contains all measurements made, including full spectrum data from the NaI and HpGe spectrometers. This means that the file can be used, if necessary, to retrieve the lowest level of data and re-process it.

GAMMALOG creates binary log files as follows:

One file per mission

File name: DDMMYYHHMMSS.BIN (Year, Month, Hour, Day, Minute, Second)

File path: specified in the '.STARTUP' configuration file (APPENDIX A)

Data types stored in the file:

- *Instrument settings*
- *Geographic positions*
- *Full gamma ray spectra* from the two spectrometers (NaI and HpGe)
- *Ground clearances* from the radar altimeter

Format: structured binary (Figure 27). Purpose written software is required to read this file.

Advanced considerations

Figure 27 shows the LabView™ (section 5) subroutine that writes measurements to the binary file. It is straightforward to design another LabView™ subroutine to read this file. The following section is for those who wish use some other program development environment to read the binary files.

A: Header bytes

The binary file has a header of exactly 354 bytes. Read past this header.

B: Binary items written to the file in a single measurement

Each measurement is written to the binary file in the format shown in Figure 27. The window in the Figure lists all of the items written to the file after each measurement is made. Ignore the fact that the items are shown grouped in "clusters".

B.1: The binary word labelled "16 booleans"

The word labelled "16 booleans" contains 16 flags. From least significant bit to most significant bit these represent:

1. State of [Snapshot] switch (0 = off 1 = on, 8.3.1)
2. State of [Record] switch (0 = off 1 = on, 8.3.1)
3. State of [Zero] switch (0 = off 1 = on, 8.3.1)
4. State of [Strip] switch (0 = off 1 = on, 8.3.1)
5. State of [Use] switch (0 = off 1 = on, 8.3.1)
6. State of [Conc] switch (0 = off 1 = on, 8.3.1)
7. State of [Cosmic] switch (0 = off 1 = on, 8.3.1)
8. Whether a NaI spectrum was obtained (0 = no 1 = yes)
9. Whether a HpGe spectrum was obtained (0 = no 1 = yes)
10. to 16 are not used

Flags 8 and 9 are used to indicate whether the current measurement includes a NaI and/or a HpGe spectrum and therefore how much space is occupied by the data structures "NaI spectrum" and "HpGe spectrum".

B.2: The data structure "NaI spectrum"

If a meaningful NaI spectrum was obtained (flag 8 = 1), the data structure "NaI spectrum" consists of a 4-byte word with value 256 indicating the number of elements in the following 1-D array of 2-byte words containing NaI spectrum channel counts.

If *no* meaningful NaI spectrum was obtained (flag 8 = 0), the data structure "NaI spectrum" consists of a 4-byte word with value 0 indicating that the following 1-D array of 2-byte words has 0 elements, i.e. that it does not occupy space in the binary file.

B.3: The data structure "HpGe spectrum"

If a meaningful HpGe spectrum was obtained (flag 9 = 1), the data structure "HpGe spectrum" consists of a 4-byte word with value 1024 indicating the number of elements in the following 1-D array of 4-byte words containing HpGe spectrum channel counts. If the number of HpGe spectrum channels is set to something other and 1024 in the hardware configuration file, the 4-byte word will have this other value and the following array will have this other number of elements.

If *no* meaningful HpGe spectrum was obtained (flag 9 = 0), the data structure "HpGe spectrum" consists of a 4-byte word with value 0 indicating that the following 1-D array of 4-byte words has 0 elements, i.e. that it does not occupy space in the binary file.

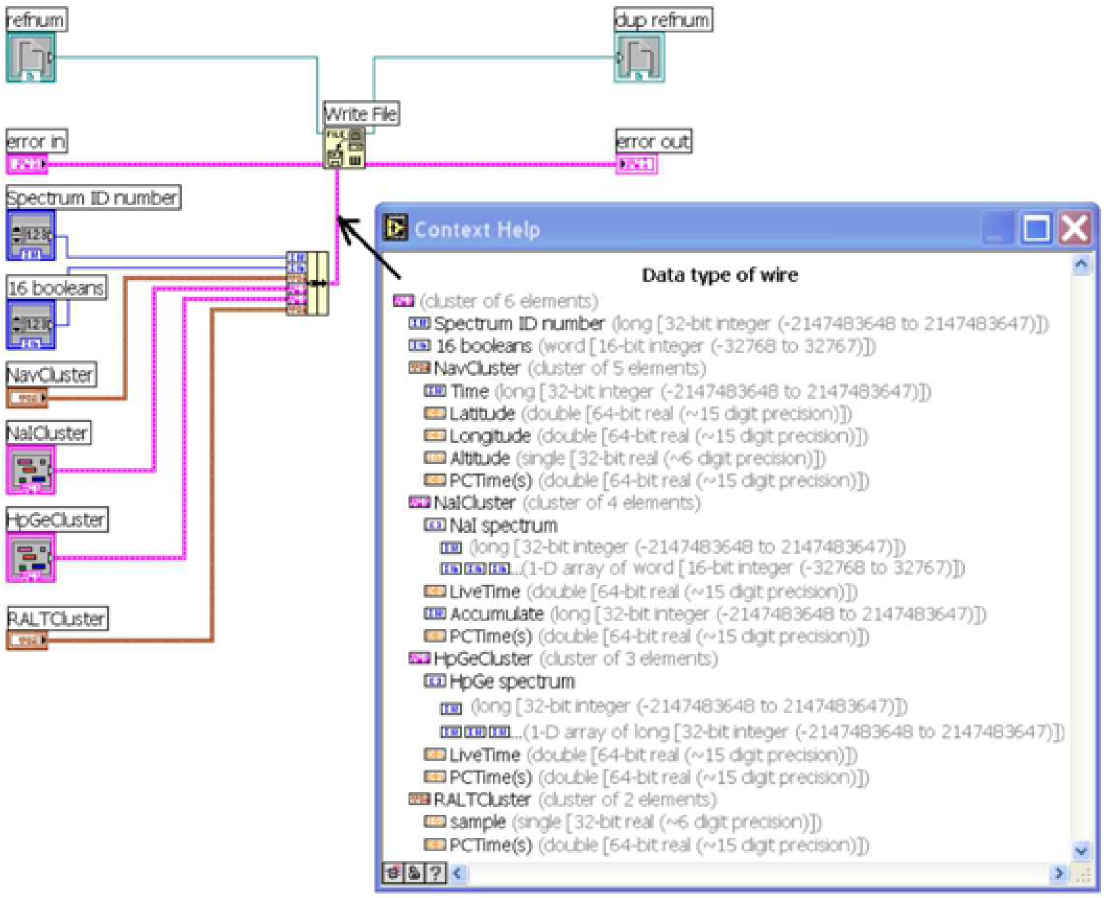

Figure 27. The LabView subroutine that writes each measurement to the binary file (see section 5). The window shows the order in which the data are written to the file and their data types. Note that flags encoded in "16 booleans" indicate whether the array parts of "NaI spectrum" and "HpGe spectrum" are present in the data.

APPENDIX F ASCII LOG FILE (ONE FILE PER MISSION, GENERATED AUTOMATICALLY)

The ASCII text log file is one of the three data products of the GAMMALOG program (section 7). The file contains all measurements made, in 'raw' and processed forms, but *without full spectrum data*.

GAMMALOG creates ASCII text log files as follows:

File name: YYMMDDHHMMSS.TXT (Year, Month, Day, Hour, Minute, Second)

File path: specified in the '.STARTUP' configuration file (APPENDIX A)

Data types stored in the file:

- *Instrument settings*
- *Geographic positions*
- *Ground clearance from the radar altimeter*
- *Raw and processed radionuclide and dose-rate data* from the NaI device

Format: Tab delimited text suitable for Microsoft EXCEL™, Access™, Geosoft Oasis Montaj™ and other software.

The ASCII file is intended for distribution and is in a simple table format with a header row. Column headings are explained below:

Heading	**What**	**Units**	**Example value**
ID	Unique spectrum ID (8.3.3.2)	N/A	1432
Snap [Save snapshot]	Status of real-time processing switches (8.3.1, 8.3.3.4) that determine the processing level (9) for headings marked *. The states of these are also stored in the binary log file in variable "16 switches" (APPENDIX E)	1/0 (on/off)	0
Rec [Record]		1/0 (on/off)	1
Zero [Zero]		1/0 (on/off)	0
Strip [Strip]		1/0 (on/off)	0
Use [Use]		1/0 (on/off)	1
Conc [Conc]		1/0 (on/off)	1
Cos [Cosmic]		1/0 (on/off)	1
Acc [Accumulate]	Number of NaI spectra accumulated (8.3.19.7)	N/A	200
UTCTime	Time for last navigational fix (8.3.7)	HHMMSS	102405
GPSLat	GPS navigation (8.3.7)	Degrees, WGS-1984	61.132814
GPSLong			123.649454
GPSAlt		Metres above WGS-1984	923.6
Ralt	Radar altimeter	Metres above ground	60.8
PCTime	Time, PC internal clock	HH:MM:SS	10:24:07
BTC	Live-time corrected NaI window values. Cosmic and background corrected if switches [Cosmic] and [Use] are on (9.2, 9.3). Compounded if switch [Accumulate] is on (9.7)	cps total count window	614.2
BK		K-40 cps	35.5
BU		U-238 cps	451.8
BTh		Th-232 cps	24.6
BCs		Cs-137 cps	850.4
B6		cps user defined window	11.5
B7		cps user defined window	8.9
B8		cps user defined window	12.0
PTC		cps total count window	614.2

PK*	Processed NaI window values. As above, but also processed according to switches [Strip] and [Conc] (9.4, 9.5). Units depend on calibration values (8.3.2). Some of the processed values may be in error in presence of anthropogenic sources.	e.g. K-40 cps or %	7.5
PU*		e.g. U-238 cps or ppm	11.3
PTh*		e.g. Th-232 cps or ppm	4.7
PCs*		e.g. Cs-137 cps or kBq/m^2	55.3
P6		cps user defined window	11.5
P7		cps user defined window	8.9
P8		cps user defined window	12.0
DT*	Total dose rate/air kerma rate (DT) (9.8). This is split into natural (DN) and anthropogenic (DM) doses (9.6). This allocation may be in error in the presence of some anthropogenic radionuclides.	air kerma rate, total. Units depend on calibration values	0.02708
DN*		air kerma rate, naturally occurring nuclides	0.00919
DM*		air kerma rate, anthropogenic nuclides	0.01024

* Processed data values (section 9) that depend on the setting of switches [Cosmic], [Use], [Strip], [Conc] and [Accumulate] (8.3.1) and on calibration values (APPENDIX C).

APPENDIX G GR820 GAMMA RAY SPECTROMETER AND NaI (SODIUM-IODIDE) DETECTOR

The principal radiation mapping device is an Exploranium 256 channel GR-820 gamma ray spectrometer with large volume sodium iodide (NaI) detector pack (the NGU operates with a GPX 256 NaI detector with a total crystal volume of 20.9; 16.7 l downward directed, 4.2 l up).

Figure 28 shows the front control panel of the GR-820 spectrometer. The settings of the spectrometer are adjusted using the keypad on the right. Figure 29 and Figure 30 show a NaI detector pack mounted next to the side door of a van. 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 28. Exploranium GR-820 gamma ray spectrometer, front view.

Figure 29. Exploranium GPX 256 NaI detector mounted in a van. A GPS antenna is mounted on the horizontal bar above the roof of the vehicle. Geological Survey of Norway's carborne system.

Figure 30. 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.

Instrument summary

Purpose: High-speed mapping of radionuclides

Interface with PC: Serial (19200, 8, 1, N, APPENDIX B, Figure 1)

Required instrument settings:

256 spectrometer channels
Data output set to ROIs plus spectrum from downward looking detectors
Dynamic energy stabilization on Th-232
Timing set to "External"
Serial data communication set to Baud 19200

Regions of interest (ROIs)/windows:

ROI 1	Total count (sum of all channels)
ROI 2	K-40 window
ROI 3	U-238 window
ROI 4	Th-232 window
ROI 5	Cs-137 window

ROI 6 Anything
ROI 7 Anything
ROI 8 Anything

Spectrum channel ranges in the hardware configuration file (APPENDIX B) must match the settings in the instrument.

Required settings in the hardware configuration file (APPENDIX B):

Relevant lines from the file:

```
ASRL5::INSTR   /1   COM port (e.g. 5)
19200  /2   Baud rate (Always this value must match instrument setting)
8      /3   Data bits
10     /4   Stop bits (10 = 1)
0      /5   Parity (none)
576    /6   Bytes to read
400    /7   Timeout (milli-seconds)
50 59 109 125 132 148 189 220 /8 ROIs for Cs-137, K-40, U-238, Th-232
```

"ROI" refers to spectrum region of interest/window in terms of start channel followed by end channel. These values must match the instrument settings.

Required calibration values in the NaI calibration file (APPENDIX C):

```
 0.3830     / Alpha stripping ratio (Th pad: counts U per count Th)
 0.6270     / Beta stripping ratio (Th pad: counts K per count Th)
 1.0228     / Gamma stripping ratio (U pad: counts K per count U)
 0.0738     / a stripping ratio (U pad: counts Th per count U)
 0.0000     / b stripping ratio (K pad: counts Th per count K)
 0.0000     / g stripping ratio (K pad: counts U per count K)
 1.5076     / Th/Cs stripping ratio (Th pad: counts Cs per count Th)
 2.1875     / U/Cs stripping ratio (U pad: counts Cs per count U)
 0.3157     / K/Cs stripping ratio (K pad: counts Cs per count K)
 2.1377     / K-40 calibration factor (Bq/kg = cps * factor
 0.9023     / Ra-226 calibration factor (Unit = cps * factor)
 0.5768     / Th-232 calibration factor (Unit = cps * factor)
12.4723     / Cs-137 calibration factor (Unit = cps * factor)
 0.44960E-6 / Air kerma rate factor (Unit = SDI * factor + offset)
-0.01830E+0 / Air kerma rate offset (Unit = SDI * factor + offset)
 1          / Start channel for SDI calculation
 254        / End channel for SDI calculation
```

Required pure nuclide Snapshot files (APPENDIX D):

```
K-40
U-238
Th-232
Cosmic
```

Instrument start:

Wait for the aircraft or car to start its engine
Turn on the appropriate transformer supplying the instrument with electrical power
Power up the spectrometer (Figure 28)
Let the detector warm up (powered up for 10 minutes)
Perform a system/gain test, usually using a Cs-127 point source
Place spectrometer in "Run" mode

The spectrometer will wait for external trigger signals from the GAMMALOG program

Start the GAMMALOG program when all instruments are running (APPENDIX K, section 8).

Instrument shutdown:
Shutdown the GAMMALOG program
Power down the spectrometer box

APPENDIX H ORTEC DSPEC+ GAMMA RAY SPECTROMETER WITH HIGH PURITY GERMANIUM (HpGe) DETECTOR

The Ortec DSPEC-plus gamma rays spectrometer (Figure 31) with ruggedised high purity germanium detector (HpGe) enables better resolution of photo-peaks from anthropogenic radionuclides. The instrument is less efficient than the NaI spectrometer (APPENDIX G) and is not effective during high-speed mapping. Use of this instrument is optional and the GAMMALOG program will function whether the instrument is connected or not.

Figure 31. Ortec DSPEC-plus gamma ray spectrometer, front view.

Instrument summary

Purpose: Identification of anthropogenic radionuclides, low speed mapping

Interface with PC: Local Area Network (LAN, Figure 1)

Required instrument settings:

1024 spectrometer channels (adjusted using Ortec's GammaVision program, must be as specified in the hardware configuration file, APPENDIX B)
High voltage power set to "ON" using Ortec's GammaVision program
Detector warmed up (powered up for 10 minutes)

Required settings in the hardware configuration file (APPENDIX B):

Relevant lines from the file:

```
HpGe instrument: Ortec D-Spec plus /9 (adjustable sampling interval)
#1     /10  Instrument ID
0      /11  GetData start
1024   /12  GetData length (number of spectrum channels)
20     /13  Sampling interval (whole seconds >= 1)
```

Instrument ID is assigned by Ortec's driver software. If one Ortec instrument is connected to the PC, its ID will probably be #1. If necessary use Ortec's GammaVision program to check this value. The number of spectrum channels must match the instrument setting.

Instrument start:

Wait for the aircraft or car to start its engine
Turn on the appropriate transformer supplying the instrument with electrical power
Power up the spectrometer box
Check instrument settings using Ortec's GammaVision program
Turn on High Voltage Power to the detector using Ortec's GammaVision program

The spectrometer will wait for external trigger signals from the GAMMALOG program

Start the GAMMALOG program when all instruments are running (APPENDIX K, section 8).

Instrument shutdown:
Shutdown the GAMMALOG program
Turn off High Voltage Power to the detector using Ortec's GammaVision program
Power down the spectrometer box

APPENDIX I GPS NAVIGATION DEVICE

Estimates of geographic position are obtained via the satellite-based Global Positioning System (GPS/DGPS). The standard GPS navigation device is the Garmin GPS-16 (Figure 32). Any GPS device that can be configured to deliver the NMEA 0183 format 'GPGGA' sentence on a serial output may be used. For best performance the device should generate and output a synchronising PPS pulse.

As long as the Garmin GPS 16 receives information from at least one satellite at or soon after system startup, it will continue to send PPS pulses thereafter, whether satellites remain in sight or not. This is a useful feature and supports use of instrument timing mode 1 (11.2).

Figure 32. The Garmin GPS 16 navigation device. The photograph does not show the custom cable connection of Figure 1.

Instrument summary

Interface with PC (APPENDIX B, Figure 1):

Navigational data: Serial (19200, 8, 1, N)
PPS pulse: counter on a PCMCIA A/D card (APPENDIX K)
Power supply: PC USB port

Required instrument settings:

Configure the GPS-17 using Garmin's sensor configuration software according to the configuration file 21_10_04.CFG located on the measuring system's PC in folder *c:\MobileMeasurements\GARMIN* (Figure 33). This procedure need only be carried out once. It sets the serial board rate for the device, configures it to output the PPS pulse and only the NMEA 0183 GPGGA sentence. The board rate value must match that specified for the device in the GAMMALOG configuration file (APPENDIX B).

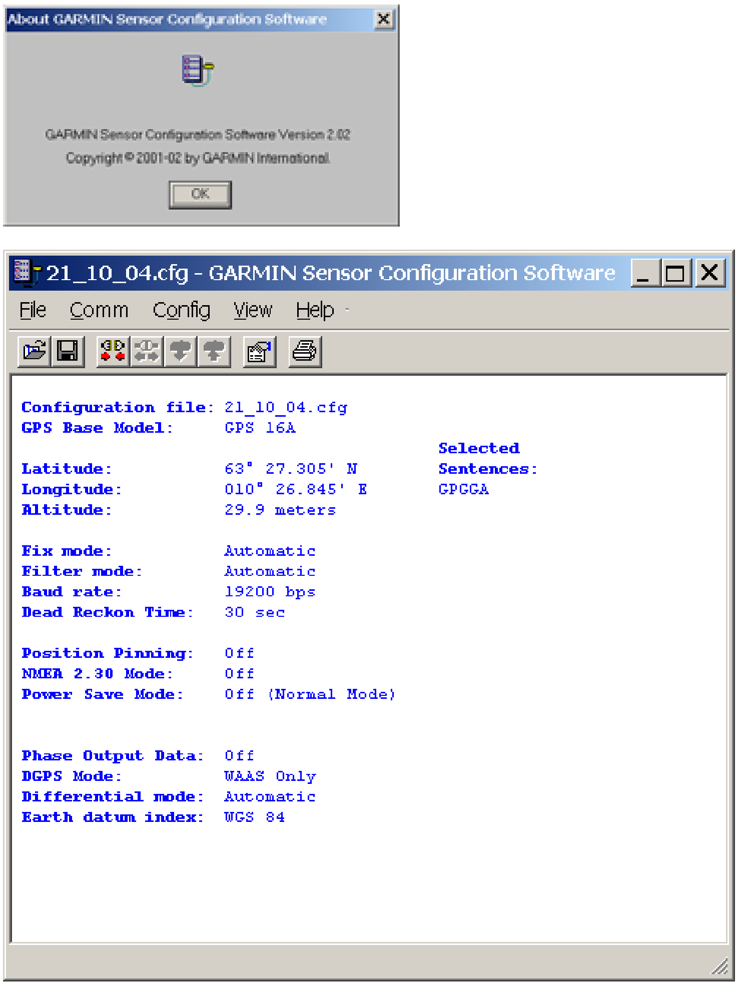

Figure 33. Configuration of the Garmin GPS 16 device using Garmin's sensor configuration software.

Required settings in the hardware configuration file (APPENDIX B):

```
GPS, DGPS instrument (NMEA-183 data transfer) /14
ASRL4::INSTR   /15  COM port (e.g. 4)
38400  /16  Baud rate (must match device setting)
8      /17  Data bits
10     /18  Stop bits (10 = 1)
0      /19  Parity (none)
100    /20  Bytes to read
500    /21  Timeout (milli-seconds)
1      /22  Switch: 1 = NMEA-183 Lat/Long, 0 = projected X/Y
```

The last parameter is set to 0 when the NGU's alternative Ashtech GPS device is used (see below).

Instrument start:

Under usual circumstances this device obtains power from the PC USB port. Therefore it is powered up whenever the PC is powered up.

Start the GAMMALOG program when all instruments are running (APPENDIX K, section 8).

Instrument shutdown:

Under usual circumstances this device obtains power from the PC USB port. Therefore it is powered down when the PC is powered down.

Alternative GPS device available to the NGU:

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. This alternative is selected using a switch in the hardware configuration file (APPENDIX B, also "bytes to read" must be set to the exact length of the GPGGA sentence).

APPENDIX J RADAR ALTIMETER (OPTIONAL, FOR AIRBORNE USE ONLY)

This device is not a fixed part of the measuring system and can be any altimeter that produces an output DC voltage between +10V and –10V that varies linearly with elevation above the ground.

Under most measuring scenarios that require airborne measurements, drape flying is appropriate. This means that the pilot should try to keep the aircraft at a constant ground clearance (nominal survey elevation). The real-time data processing described in section 9 assumes a constant ground clearance, and calibration values for the NaI spectrometer (APPENDIX C) are specified for a particular aircraft flying at a fixed ground clearance. Different calibration files are required for different aircraft flying at different ground clearances.

When airborne, an altimeter should be linked to the measuring system and ground clearance recorded so that significant deviations from the intended flying height can be corrected for in post-survey processing.

Instrument summary

Interface with PC (APPENDIX B, Figure 1):

DC voltage: Analogue input on a PCMCIA A/D card (APPENDIX K)

Required settings in the hardware configuration file (APPENDIX B):

Relevant lines from the file:

```
A/D interface, Radar altimeter and PPS timing signal /23
Dev1/ai0  /24  Voltage device and channel number
Dev1/ctr1 /25  PPS counting device and counter number
10      /26  Voltage high limit
-10     /27  Voltage low limit
20      /28  Scans (number of samples to take at scan rate)
100     /29  Scan rate (Hz)
1       /30  Height factor (Height = Height factor * Volt + Height offset)
0       /31  Height offset (Height = Height factor * Volt + Height offset)
```

Line 24 is the device name assigned to the PCMCIA card to which the altimeter is connected. The number of scans and scan rate determines how many voltage samples are collected to make a single measurement and at what rate. The final measurement is the median value of the samples taken. The samples are taken as close to mid-way through a NaI spectrometer measurement as possible. Conversion of voltage to elevation in metres is given by:

$$\text{Elevation(m)} = \text{Median voltage} * \text{Height factor} + \text{Height offset}$$

APPENDIX K PC COMPUTER FOR DATA STORAGE, PROCESSING AND DISPLAY AND PC INTERFACE CARDS

Data from the gamma ray spectrometers, GPS navigation device and altimeter (airborne platforms) are channelled into a PC laptop computer running Microsoft Windows XP or Windosws 2000 (Figure 34). The minimum recommended CPU clock rate is 1.7 G Hz. The PC runs the GAMMALOG program that controls the measuring system and displays and stores data (section 8).

Although only two serial ports are needed (NaI spectrometer and GPS navigation device, APPENDIX G, APPENDIX I), the number of ports is increased from 1 to 5 using a National Instruments PCMCIA 232/4 card (Figure 35). A counter is required for the GPS navigation device's PPS pulse (APPENDIX I) and an analogue input for the altimeter signal (APPENDIX J). These are provided by a National Instruments PCMCIA DAQ-card 6036E (Figure 35).

Figure 34. 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.

Figure 35. Left: PCMCIA card providing 4 extra serial ports (National Instruments PCMCIA 232/4). Right: PCMCIA Analogue/Digital card (National Instruments DAQ-card 6036E).

Some minor adjustments to the operating system settings are necessary to run the measuring system:

All power saving options must be disabled

1. Screen savers must be disabled

2. Decimal symbol must be set to "." (In XP do this via Settings/Control Panel/Regional and Language Options/Customize… In Norway the default decimal symbol is ",", this must be changed)

3. Device driver software for the PCMCIA A/D card (National Instruments DAQ-card 6036E) and PCMCIA serial ports (National Instruments PCMCIA 232/4) must be installed

4. The GAMMALOG program (including LabView runtime engine) must be installed

Required settings:

Configuration and calibration values are read when the GAMMALOG program is started (section 8). These are stored in files on the PC hard disk, usually in folder *C:\Startup*. The first file is of type '.STARTUP' (APPENDIX A) and consists of a list of the configuration files relevant to a particular measuring system mounted on a specific transportation platform. These files must exist. They include a hardware configuration file (type '.HW', APPENDIX B), a NaI spectrometer calibration file ('.CAL', APPENDIX C) and a series of NaI unit spectra ('.SPE', APPENDIX D).

Required settings in the hardware configuration file (APPENDIX B):

Relevant lines from the file:

```
Measurement timing /32
1      /33  1=PPS with PC clock backup; 2=PPS only; 3=PC clock only
```

See section 11.

PC start:

Check all electrical connections
Wait for the aircraft or car to start its engine
Turn on the appropriate transformer supplying the PC with electrical power
Power up the PC
Start the GPS navigation device (APPENDIX I)
Start the NaI spectrometer and detector (APPENDIX G)
Start the HpGe spectrometer and detector (APPENDIX H)

GAMMALOG startup:

Run the GAMMALOG program from the desktop icon or *Start* menu
Specify the name of a '.STARTUP' file designed for the measuring system as mounted in the transportation platform (section 8)

GAMMALOG shutdown:

Close the GAMMALOG program by pressing the [Stop] button (section 8)

PC shutdown:

Shut down Windows
Shut down the instruments
Turn off electrical power supplies
Turn of the engine on the transportation platform

APPENDIX L POWER SUPPLIES

The measuring system includes electrical transformers that can draw power from 24V DC aircraft supplies and 12V DC car supplies.

APPENDIX M 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 radionuclides into meaningful units of concentration, radioactivity and dose rate. 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 vary with distance of the detector above the ground.

Much of the calibration procedure required for the 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 and system sensitivity for Cs-137.

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.