Scottish Universities Research & Reactor Centre

Upgrade of Airborne Gamma Spectrometry Equipment

March 2002

D.C.W. Sanderson, A.J. Cresswell

Scottish Universities Research and Reactor Centre, East Kilbride

East Kilbride Glasgow G75 OQF Telephone: 01355 223332 Fax: 01355 229898

SUMMARY

The Airborne Gamma Spectrometry (AGS) system used by the SURRC team has been upgraded, with a new computer system, detector pack and electronics rack.

The computer and LCD use a dc power supply, simplifying the requirements of the power distribution unit, and it is significantly more powerful than the previous computer allowing greater flexibility in data acquisition and on-line analysis and data presentation. New code has been developed in the Borland C++ Builder environment to acquire and analyse data. At present, this is for a NaI(Tl) only spectrometry system with a text only interface; future developments of the code will probably include the use of additional Ge detector systems and a graphical display.

The new detector pack consists of four NaI(Tl) crystals, with a total volume of 16 litres, that had been purchased new or refurbished prior to the start of this project. At present, they use a single high voltage supply in the power distribution unit, with the gain on each detector adjusted manually using a potentiometer in series with the dynode chain of each photomultiplier tube. Future work will probably include the use of separate HV supplies adjusted by computer control using digital potentiometers.

A simplified power distribution unit has been designed that uses dc supply voltages throughout, with the exception of a single inverter to generate a 240V ac supply for the mini-NIM bin for the Ge electronics. The system has been verified for both Ge and NaI(Tl) spectrometry, operating as independent systems. Further work is, however, needed to establish the capability for simultaneous NaI(Tl) and Ge spectrometry.

The new components; the power distribution unit, computer and mini-NIM bin; are mounted inside a vibration damped 19” rack.

A series of laboratory, installation and flight tests have been conducted. These have resulted in several minor problems being identified and fixed. The last of these flight trials on the 27th and 28th February 2002 proved that the NaI(Tl) system is fully functional. It was noted that the new system operates with a much lower threshold on the MCA input than the old, and the spectral gain is constant when changing between power systems. Although environmental conditions, specifically standing water on the salt marshes of the Inner Solway, prevented quantitative comparison of the systems performance compared to the old system it is clear that the new system is functioning.

The work undertaken has significantly improved the computing systems and data transfer of the SURRC AGS system. New NaI(Tl) detectors have been commissioned. A programme of continuing implementation and flight trials is now required to bring the systems into full specification, including the use of combined NaI(Tl) and Ge systems and further software development. This should finish preparing the system for use in the forthcoming international intercomparison exercise.

ACKNOWLEDGEMENTS

The work presented here was funded by the Food Standards Agency (Scotland), project number S03001.

The aircraft used for installation and flight tests was supplied by PDG Helicopters Ltd.

CONTENTS

1. INTRODUCTION

Since the Chernobyl accident in 1986, significant developments have occurred in airborne radiometric systems in Europe, and there is growing recognition of their potential use in emergency response (Darwin and McColl, 2000). This is due to the high rates of data capture, fields of view, and the mobility of the airborne platform in airborne gamma spectrometry (AGS). Recent developments in systems suitable for rapid deployment in fixed and rotary wing aircraft, and of rapid data processing and presentation systems, have greatly enhanced the capability of AGS to deliver results on emergency timescales following accidental releases of radioactivity into the environment. The main early functions would be to locate areas of high radiation or deposition so that ground based resources were used more effectively, if necessary using a working calibration which would be improved by subsequent ground to air comparisons. With mobilisation timescales within one day and results available in digital and mapped form within the same day AGS systems could help justify early countermeasures. At later stages the emphasis would move towards more detailed mapping and quantification of deposition, particularly in areas of agricultural production where contamination could affect the food chain. Since AGS systems have the capacity for total area survey they can clearly show which areas are not affected, and together with the role of directing ground based work to areas of need, could have a major impact on the public that emergency response was correctly focused.

A number of AGS teams exist across Europe, and a consortium of 10 of these teams came together under a Concerted Action funded through the Nuclear Fission Safety Programme of the European Commission's Fourth Framework (Sanderson and McLeod, 1999). This project identified the European capability in AGS (Sanderson and Ferguson, 1997), showing a diverse range of methods and techniques, and showed the potential for future validation and possible standardisation of these methods. Currently, a Thematic Network funded under the Nuclear Fission Safety Programme of the European Commission's Fifth Framework, will facilitate an international intercomparison exercise to be held in SW Scotland between May 24th and June 3rd 2002 through which, it is expected, the draft protocols of the Concerted Action will be validated.

In preparation for this exercise, and to improve its capability for conducting environmental surveys and for potential emergency response situations, the radiometric systems employed by the SURRC AGS team have been upgraded. These system upgrades have focussed on hardware and software improvements based on on-going developmental work that will enhance the quality of data collected, the flexibility of the system and presentation of information to the detector operators. Flight trials of the upgraded system have been conducted in the Solway area.

Prior to this project SURRC had two radiometric systems developed in the early 1990's (Sanderson *et al*, 1994a), and last upgraded in 1996. Since then the state of the art in computer technology, GPS systems and nucleonics has progressed considerably. The benefits of upgrading SURRCs' AGS capability to state-of-the-art technology are considerable, particularly in potential emergency response situations where decision makers would require robust measured data in the early stages of a release of radioactivity as soon as safety permits.

Within the year prior to the start of this project several of the NaI(Tl) crystals used in the SURRC AGS systems had been refurbished, and some new crystals purchased. Part of the system upgrade would involve commissioning a new detector pack comprising these new crystals with consideration given to modifying the HV distribution and amplification circuits to allow for computer controlled gain adjustment of individual crystals and the logging of spectra from different crystal combinations. This should improve the gain stability of the system with minimal operator action, and allow for greater flexibility in the use of the system.

The use of a more modern computing system would allow modifications to the software to (for example) improve the visualisation of the data during surveys without affecting the efficiency of the front end data collection.

2. SYSTEM UPGRADES

2.1 Overview

The new Airborne Gamma Spectrometry (AGS) system was designed to use new or refurbished NaI(Tl) crystals, which had been purchased prior to the commencement of this project, with improved control of the high voltage on the photomultiplier tubes, and a new electronics rack and computer. The new system will incorporate several new features, and allow for future upgrading with minimal hardware modification. The system was designed such that the new electronics rack could use the old detector pack, or conversely the old electronics rack could use the new detector pack.

Two electronics racks, one capable of operating Ge semiconductor detectors in parallel with a pack of NaI(Tl) scintillators the other NaI(Tl) only, have been developed. The power distribution unit, computer and display are identical and fully interchangeable between the two systems. As far as possible, off-the-shelf components have been used, and the system kept as simple as possible. Figure 2.1 shows a schematic of the new combined NaI(Tl) and Ge system, the NaI(Tl) only system is identical except it doesn’t include the NIM electronics for the Ge detectors.

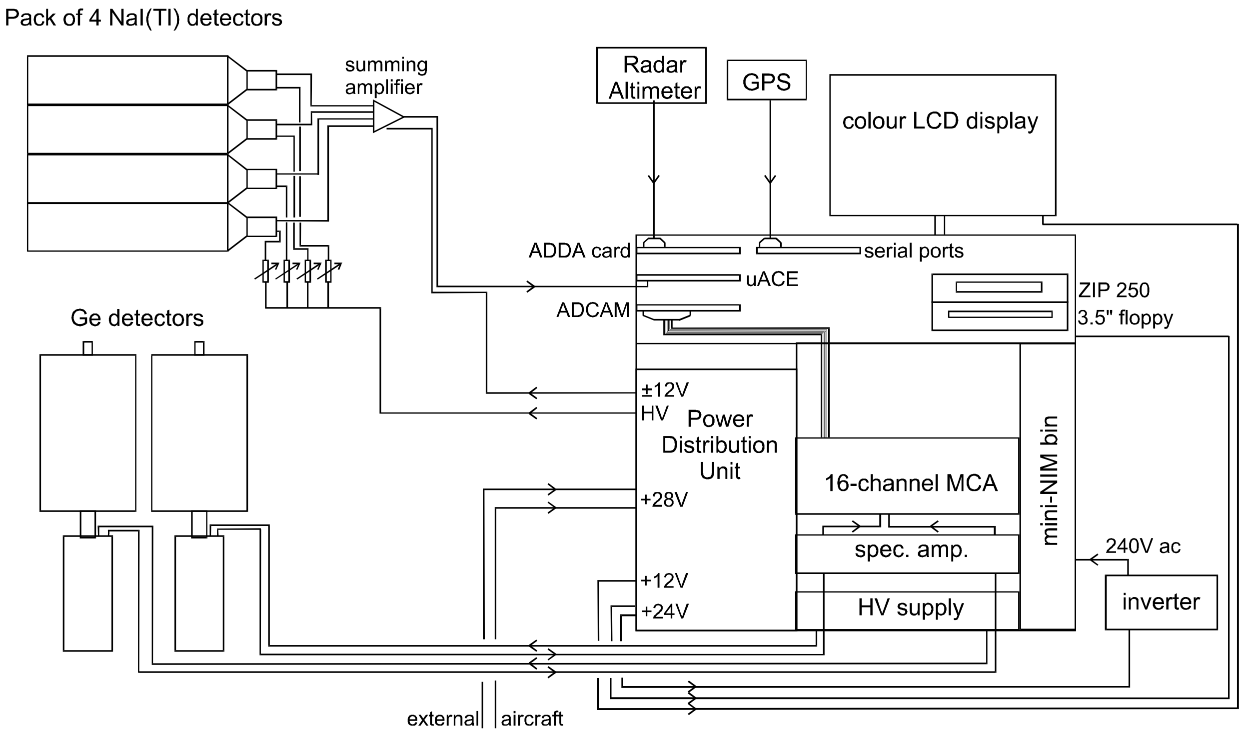

Figure 2.1: Schematic of the new combined NaI(Tl) and Ge detector system. The +28V external supply can be from either a 240V mains to 28V converter or an external battery pack. The internal battery is not shown

2.2 Electronics Rack

The current electronics rack runs off 240V ac mains or 28V dc supplies. When running from mains the computer, monitor and NIM rack are powered directly from the mains, with mains-dc converters to generate the low voltage supplies required for the detector electronics, when using a dc supply inverters are used to generate a 240V ac supply the components that require a mains supply. The upgraded electronics rack uses a 28V dc supply throughout; from either the aircraft, an external or internal battery pack or from a separate mains converter situated outside the aircraft. This results in a reduction in the number of voltage converters required and simplified system for switching between supplies. A computer and LCD monitor were procured that use +24V and +12V dc supplies respectively, the NIM bin for the Ge semiconductor detector electronics is the only component that requires a 240V ac supply that is supplied by a single inverter. A 19" vibration damped aluminium case was used to hold all these components, with the LCD screen fixed to the top of the case.

2.2.1 Power Distribution Unit

The power distribution unit takes a +28V dc supply from one of three locations; the aircraft battery, an internal battery or an external supply (usually a mains to +28V converter, although an external battery pack could be used). The unit supplies +24V for the computer and Navstar GPS unit, +12V for the LCD display, ±12V for the summing amplifier in the detector pack and other electronics, and a single HV supply for the NaI(Tl) detector photomultiplier tubes. A +24V to +24V regulator power converter is used to isolate the supplies for the computer and GPS systems from the detector electronics power supplies to reduce electrical noise in these critical supplies.

The source of the +28V supply (aircraft, external or none) is selected using a switch, and a second switch connects the battery. Connecting the battery while using a +28V input will charge the battery, alternatively a battery charger is included in the mains power unit to recharge the internal batteries. A leaded block filter is used to remove any noise on the input voltage, in particular generator noise on the aircrafts 28V auxiliary output.

The +28V supplied by either an external source, aircraft or batteries is used to power the computer and Navstar GPS system. It can also be used to power an inverter to generate a 240V ac supply for the NIM bin for the Ge detector electronics. The inverter generates considerable noise when used to power a device with a mains input filter, even when placed externally to the grounded enclosure containing the power distribution components some of this electrical noise affects the other components.

A +24V to +12V converter is used to generate a +12V supply for the LCD and any other device using +12V (eg: video camera, RDS differential receiver, handheld GPS systems). To remove electrical noise due to the inverter from power lines which require low electrical noise, a 24V to 24V converter was used. At present, the noise generated by the inverter is still transmitted, albeit at a much reduced level, through this unit generating unacceptable levels of electrical noise on the HV and amplifier outputs when the inverter is in use.

A HV unit is used to provide HV for the photomultiplier tubes on the NaI(Tl) detectors, this is controlled by a potentiometer and switch. The detector pack also contains four HV units, one for each detector, and to power these the clean +24V line is provided to the detector pack. A ±12V supply is generated for the summing amplifier and any other electronics required in the detector pack.

2.2.2 External Power Supply Unit

The external power supply unit consists of a 24V (12A) dc supply, with the output adjusted to give +28V, and a battery charger. A three pin plug (carrying +28V, the charger output and earth lines) connects the unit to the external supply input socket on the rear of the electronics rack. The sockets for the external and aircraft power supplies are functionally identical.

2.2.3 Computer System

An industrial PC system and 12.4” colour LCD display, both using a dc supply, were purchased. An internal IDE 250MB ZIP drive was installed for data back up. A 14bit analogue-to-digital/digital-to-analogue (ADDA) card was installed to measure the voltage output of the aircrafts’ radar altimeter, and potentially for measuring diagnostic data from the HV units and provide computer control for such units. For collection of spectra from the NaI(Tl) detector a multichannel buffer card was installed.

The computer is housed within a 2U 19” enclosure.

2.2.4 Ge Detector Electronics

To use Ge semiconductor detectors a stable HV supply, spectroscopy amplifier, preamp power supply and MCA are required. NIM modules were used to provide these, with an interface card to connect to the computer. Future developments could include using the computer network card to interface to the NIM based system (which would release an ISA slot in the PC for another card if needed), or the use of a NIM-less detector system such as the Ortec DigiDart which is a self contained module with HV, spectroscopy amplifier and preamplifier power supplies interfaced to a computer via a USB port.

2.3 Detector Pack

Four new or refurbished NaI(Tl) detectors were used to produce a new detector pack. A HDPE case with a high density thermal insulating foam interior was purchased to house these detectors and associated electronics. The case contains considerable amounts of aluminium for structural support, some of which may need to be removed in order to reduce absorption of gamma radiation. Since the new detectors do not have a gain control a potentiometer was place in series with the dynode chain of each detector to allow for the trimming of each detector to a common gain when using a single HV unit (in the power distribution unit). The summing amplifier from an old detector pack, using a single LF351N amplifier with 4 switches to select individual detectors, was used to produce a signal for analysis by the μACE.

The use of separate HV units for each crystal, with the voltage controlled by programmable resistors under computer control to allow automatic gain correction of separate detector elements to maintain overall detector resolution during survey in the event of a single element drifting in gain relative to the others, and the use of shaping amplifiers and gating electronics will be investigated at a later time.

2.4 Software

The software used on the old system was originally written under GWBasic, and later TurboBasic. This was modified to communicate with the μACE rather than the 916ACE card used in the old system. It was hoped to be able to compile the code under PowerBasic, which offers greater flexibility in potentially including a graphical display, however this code does not correctly access the μACE. The reason why the code will not work under PowerBasic have yet to be determined. A subroutine to read NMEA0183 strings output by handheld Garmin GPS systems was also written, though this only worked when compiled under PowerBasic rather than TurboBasic.

A problem was observed in reading data from the ADDA card. This was eventually identified as being due to the program issuing commands to the card faster than the card could process them. Introducing a short delay loop between issuing the commands provided a simple solution to this problem.

A version of the data acquisition code has been developed in C++ using the Borland C++ Builder 5 environment. The method of acquiring the data was identical to that in the Basic program, though some adjustments were made to the user interface. At present this code will only record spectra from the NaI(Tl) spectrometry system, though modification to record spectra from Ge detectors is planned. The code also records position (including spatial uncertainty and height above datum) from the NavStar XR4 unit used on the old rack and from the handheld Garmin GPS units. The program writes summary files (for gross, net, stripped and calibrated data) during acquisition, removing a step in the post-survey processing providing suitable background count rates, stripping matrix elements and calibration coefficients are known prior to survey. Post processing of the data is still possible. The code propagates the statistical uncertainties on the gross counts in each spectral window through the analysis procedure, though at present these are not included in the output files to maintain compatibility with older data analysis codes.

It is anticipated that the C++ code will form the basis of future data acquisition code. In addition to expanding the code to record data from Ge detectors, future upgrades of the code are planned. These could include graphical displays of the data (in the form of spectral colour plots or profiles) or the ability to replay data through the same program (which would enable the same code to do post-processing). The use of a Windows development environment, including DLLs to access the Ortec MCB, should make the addition of additional devices (for example a DigiDart) straight forward.

3. INSTALLATION AND FLIGHT TRIALS

3.1 Laboratory Tests

There was some concern that the presence of a 5mm thick aluminium sheet built into the bottom and side of the detector case for reinforcement purposes would significantly attenuate gamma radiation passing through it and hence reduce the efficiency of the detector pack. To check this, two ^{137}Cs spiked plywood sheets (used for detector calibration and performance testing) were placed below the detector pack (approximately 20cm below the middle of the detectors) and a spectrum recorded. This spectrum was compared with a similar spectrum recorded with the sheets above the pack at the same distance, there was no significant difference between these two spectra. For most purposes the presence of the aluminium structural support is not a problem, though it would render the detector almost incapable of measuring ^{241}Am activity.

A set of measurements of the detector response using concrete pads doped with enhanced natural series activity and calibration plywood sheets spiked with ^{137}Cs and a ^{60}Co point source were made. These involved placing the detector on top of seven sheets of Perspex, which has absorption characteristics equivalent to approximately 70m of air, with a further five Perspex sheets on top of the detector. Spectra were recorded for approximately 10 minutes on each of four pads (three doped in ^{40}K, ^{238}U series and ^{232}Th series activity, and one without any additional activity added), and the ^{137}Cs sheets and ^{60}Co source on the blank pad.

3.2 Installation and Flight Testing

An installation test was carried out at Cumbernauld Airport on the 19th December 2001. A number of small problems with the system were noted; poor electrical connections, the detector pack was situated to far back in the aircraft to fit properly, and the software was not correctly reading data from the Garmin GPS systems. These problems were all fixed with minor alterations to the system, except for the GPS readout, which required the writing of a new code in C++ (see section 2.4).

A further installation test, including a short flight trial, was carried out on the 1st January 2002. Data was collected using the NavStar GPS system to determine the position of the measurements. It was noted that the ADDA card was not recording the radar altimeter voltage correctly, so the ground clearance recorded was incorrect. Some data was, however, collected from the calibration sites in the Dumfries and Galloway area.

After correcting the problem with the ADDA card (see section 2.4), a flight trial was conducted on the 27th and 28th February 2002. A short survey was conducted in the vicinity of Cumbernauld airport on the 27th (the weather was unsuitable in the Inner Solway area). A longer survey covering a large part of Burgh and Rockcliffe Marsh was conducted on the 28th, along with a hover manoeuvre conducted over the calibration site at Caerlaverock. There was a substantial amount of standing water on the salt marshes during this flight trial.

A single line between the calibration site at Caerlaverock and Carlisle airport was flown using the new C++ software with position given by the handheld Garmin unit. This showed that the new software works, and that the handheld GPS works with a small antenna mounted in the aircraft cabin. There was some concern that the satellite signals may be blocked by the aircraft engine which with older systems had required the antenna to be mounted in the tail boom of the aircraft, this short test indicated that this may not be a problem though further testing of this will be needed before confidence can be placed in the antenna mounted in the cabin.

The old rack exhibited a shift in detector gain when changing between mains and aircraft power supply, probably due to an earthing problem associated with that particular aircraft. In addition, the old rack required the lower threshold of the MCA input to be fairly high to reduce dead time to a reasonable level. Tests of the equipment on the ground, but under aircraft power, showed that the spectral shift does not occur with the new rack, and a much lower MCA input threshold can be used without introducing exceptionally high dead time to the system.

3.3 Caerlaverock Calibration Site

During the flight trial conducted on the 28th February 2002 a hover manoeuvre was conducted over the calibration site on Caerlaverock Merse. This site has been used for many years by the SURRC team for calibration of AGS systems, with soil cores collected from a spatially representative expanding hexagonal pattern in 1993 and 1999 (Sanderson *et al*, 1994b, 2000, 2001a,b). Figure 3.1 shows spectra recorded by the NaI(Tl) spectrometer at a range of heights over the calibration pattern. Data collected in June 2000 using the old AGS system are shown for comparison. While the two sets of spectra are very similar at higher energies around the ^{208}Tl peak at 2614keV, the new detector pack shows a significant reduction in count rate for lower energies. This is a result of the wetter conditions of the salt marsh in February 2002 compared with June 2000, with the extra moisture content attenuating the lower energy gamma radiation.

3.4 Rockcliffe Marsh Data

The Inner Solway area around Rockcliffe and Burgh Marshes has been surveyed by the SURRC AGS team in April 1999 at 50m (Sanderson *et al*, 2000, 2001b) line spacing, and again in June 2000 at 250m line spacing (Sanderson *et al*, 2001a,b). The southern two thirds of this area was surveyed again in the 28th February 2002 flight trial of the new equipment at 250m line spacing, time limitations not permitting the rest of the area to be surveyed. It was noted that the tide was fairly high during this survey, with substantial areas of standing water on Rockcliffe Marsh, particularly near the centre of the marsh.

Figure 3.2 shows the distribution of ^{137}Cs determined from this flight trial data. The stripping and calibration constants used for the June 2000 survey have been used. For comparison, figure 3.3 shows the ^{137}Cs distribution measured in June 2000. It can be seen that the new detector system does produce a reasonable distribution of ^{137}Cs activity in this area, with the major differences such as the substantially lower activity in the centre of the marsh and lower activities on the surrounding mud flats being due to the standing water present on the marsh and the higher tidal conditions.

Due to the significant differences in the environmental conditions of the June 2000 and February 2002 surveys a direct comparison between the two data sets to quantify the relative performance of the old and new detector systems is not possible.

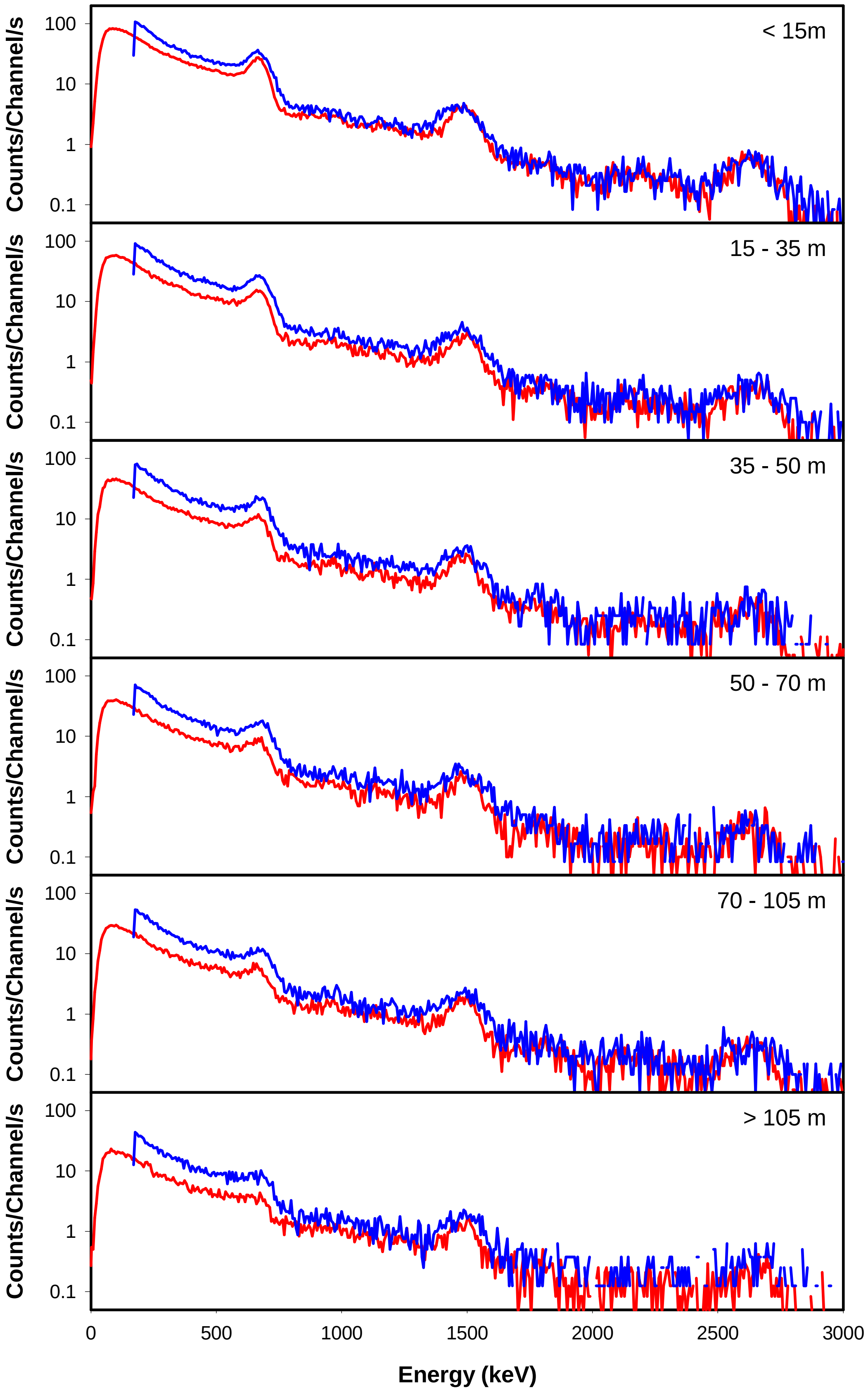

Figure 3.1: NaI(Tl) spectra recorded over the Caerlaverock calibration site using the new detector system in February 2002 (red) and the old system in June 2000 (blue).

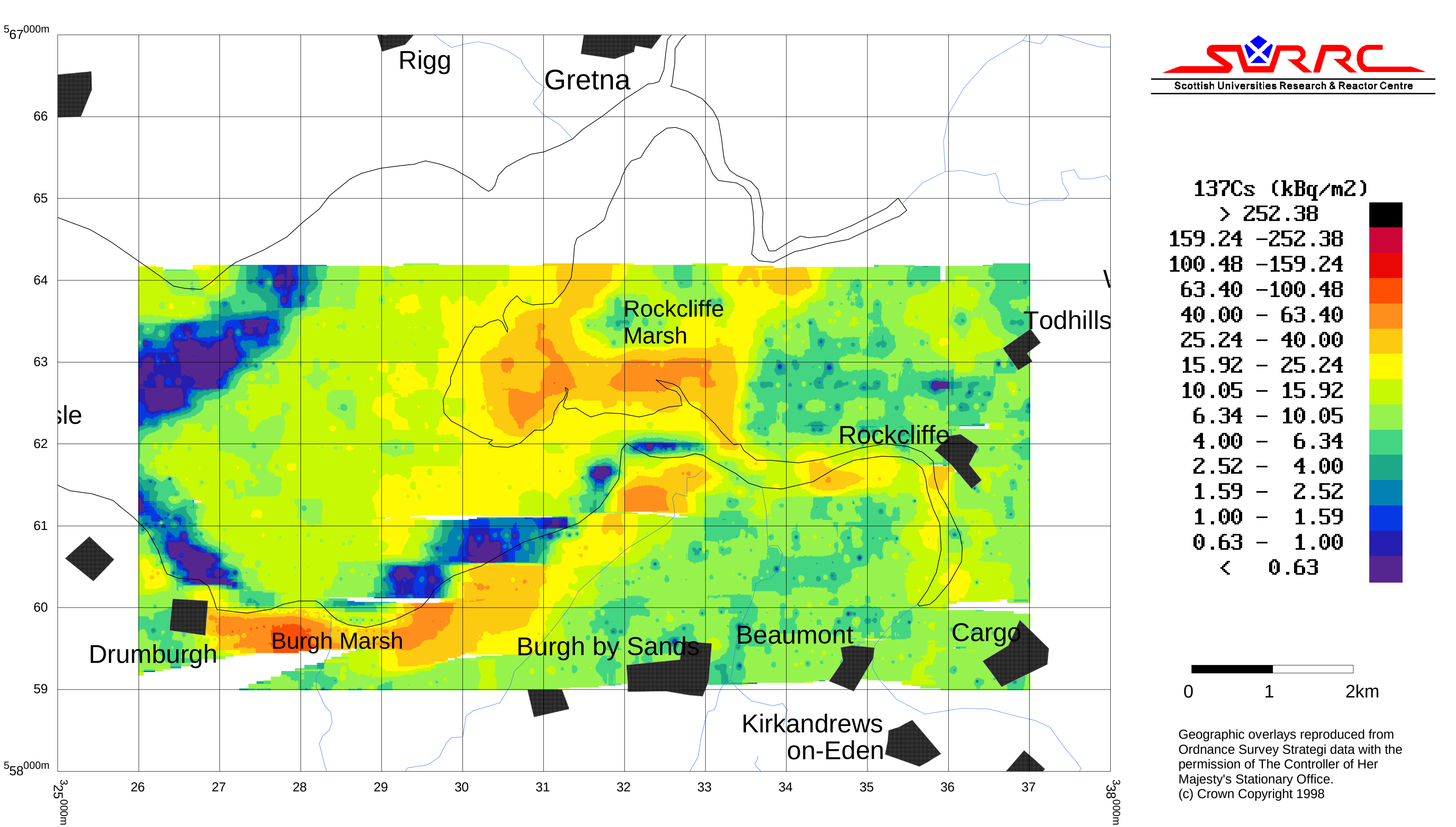

Figure 3.2: ^{137}Cs activity distribution in the Inner Solway measured in February 2002.

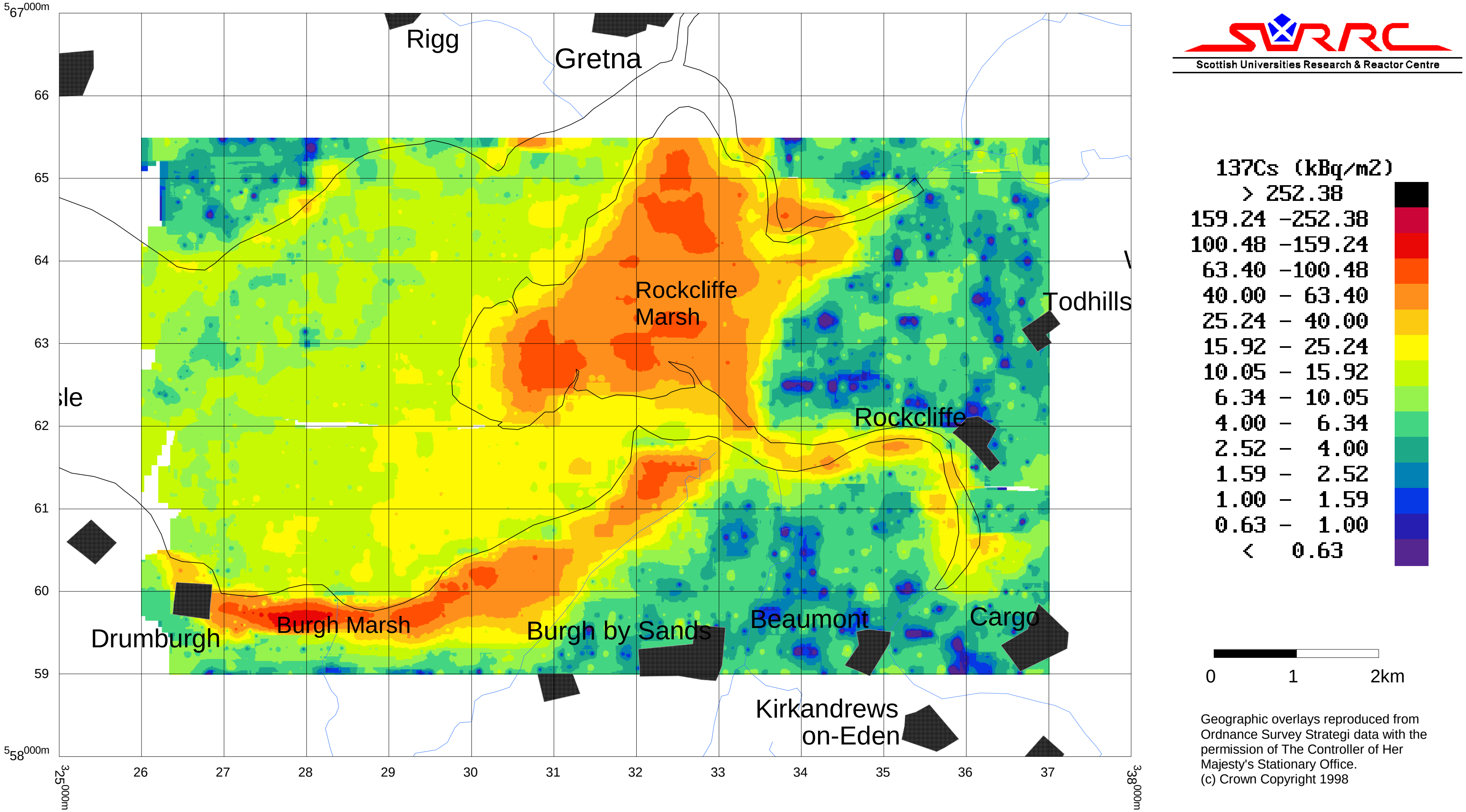

Figure 3.3: ^{137}Cs activity distribution in the Inner Solway measured in June 2000.

4. DISCUSSION AND CONCLUSIONS

An upgraded Airborne Gamma Spectrometry (AGS) system has been produced using a new set of NaI(Tl) detectors and a new electronics rack. The design of the system is largely based on the existing system, with some upgrades of the computer system, power distribution unit and software. The resulting system has shown a response comparable to the old system for NaI(Tl) only operation. An outstanding problem with electronic noise in the power distribution unit has still to be resolved before the use of Ge detectors in conjunction with the NaI(Tl) system can be tested.

A series of short flight trials, including a survey of part of the Inner Solway surveyed in April 1999 and June 2000, have been conducted. These have shown that the new system works well, though differences in the environmental conditions of the areas surveyed compared to previous surveys have made it impossible to quantify the relative performance of the old and new systems.

There is still some more work to be done to complete the upgrading of the AGS system. Most notably there is a problem with electronic noise in the power distribution unit that prevents the use of a combined NaI(Tl) and Ge detector system, although the two detector systems do work independently of each other. There are also minor outstanding problems with the LED indicators on the power distribution unit, which do not affect the functionality of the system.

It is also planned that it should be possible to monitor and adjust the gain of individual NaI(Tl) detectors under computer control. This will require the use of separate HV units for each detector, with a digital potentiometer to control the output on each of them. There will need to be some upgrading of software to control these. In addition, the new C++ code will need to be developed to record spectra from Ge detectors, the modified Basic program already does this though it doesn’t work with the hand held GPS systems. Modification to the user interface to give a graphical display is also a possibility for further work.

After completion of outstanding work further flight trials will be needed to prove the functionality of the upgrades, and to collect data over the Inner Solway under more favourable conditions for a comparison between the old system and the new.

GLOSSARY

Ge detector A semiconductor radiation detector. Radiation incident on the Ge crystal creates electrons in the conduction band that are accelerated by a high voltage to generate measurable electronic pulses. To reduce thermal noise they must be operated at liquid nitrogen temperatures (-196°C)

MCB MultiChannel Buffer. A device for measuring and recording spectra from radiation detectors. The height of each electronic pulse is converted to a channel number, and the number of counts in that channel incremented.

NaI(Tl) Thallium doped sodium iodide. A scintillator commonly used for radiation detection; radiation interacting with the crystal generates flashes of light which are measured using a **photomultiplier** tube.

NIM Nuclear Instrumentation Methods. A standard for interchangeable modules for use in nuclear and high energy physics. A NIM bin is used to hold several such modules, and provides the necessary power supplies to operate them.

NMEA-0183 National Marine Electronics Association standard for electrical interface and data protocol for communications between marine instruments. Often used for communication with a GPS unit.

Photomultiplier A very sensitive light detector. Light incident on a photocathode produces a free electron which is accelerated by a voltage onto a dynode which results in several more free electrons being produced. A series of dynodes amplifies the signal to produce a measurable electronic pulse.

REFERENCES

Darwin, S.A., McColl, N.P. (2000). *Airborne Gamma Spectrometry after a Nuclear Emergency*. NRPB-M1189.

Sanderson, D.C.W., Allyson, J.D., Tyler, A.N., Scott, E.M. (1994a). Environmental Applications of Airborne Gamma Spectrometry. *IAEA Technical Committee Meeting on the Use of Uranium Exploration Data and Techniques in Environmental Studies*. IAEA-TECDOC-827, 71-91.

Sanderson, D.C.W., Allyson, J.D., Tyler, A.N., Ni Riain, S., Murphy, S. (1994b). *An Airborne Gamma Ray Survey of parts of SW Scotland*. SURRC Report.

Sanderson, D.C.W., Ferguson, J.M. (1997). The European capability for environmental airborne gamma ray spectrometry. *Radiation Protection Dosimetry*, **73**(1-4), 213-218.

Sanderson, D.C.W., McLeod, J.J. (1999). *European Coordination of Environmental Airborne Gamma Ray Spectrometry, Final Report*. Report on European Concerted Action project F14P-CT95-0017.

Sanderson, D.C.W., Cresswell, A.J., McLeod, J., Murphy, S. (2000). *Investigation of Spatial and Temporal Aspects of Airborne Gamma Spectrometry. Report on Phase I Survey Conducted April 1999*. SURRC Report.

Sanderson, D.C.W., Cresswell, A.J., White, D.C., Murphy, S. (2001a). *Investigation of Spatial and Temporal Aspects of Airborne Gamma Spectrometry. Report on Phase III Survey of West Cumbria and Inner Solway Conducted in June 2000.* SURRC Report.

Sanderson, D.C.W., Cresswell, A.J., White, D.C., Murphy, S., McLeod, J. (2001b). *Investigation of Spatial and Temporal Aspects of Airborne Gamma Spectrometry. Final Report.* SURRC Report for DETR, DETR/RAS/01.001.