NUCLEAR GEOPHYSICS DIVISION
KVI.
ZERNIKELAAN 25
9744 AA GRONINGEN

EAGLE I&II

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DATA REPORT

J. LIMBURG[@], R. DE MEIJER[@], E.H. STETTLER[+], H. COETZEE[+], AND T. GRACE[*],

@ KERNFYSISCH VERSNELLER INSTITUUT, ZERNIKELAAN 25 9747 AA GRONINGEN, THE NETHERLANDS.

+GEOPHYSICS DIVISION, COUNCIL FOR GEOSCIENCE P. BAG X112, PRETORIA 0001

*SOUTHERN EXPLORATION SERVICES, P.O. BOX, SANDTON.

(@): Email:limburg@kvi.nl; tel xx310503633561/3541, fax: xx310503634003

INTRODUCTION

This data report present results from EAGLE (Eerste Afrikaans Gronings Luchtkarterings Experiment, i.e. First African-Groningen Airborne Survey Experiment). EAGLE comprised a feasibility study into the use of the NGD/KVI MEDUSA natural-radioactivity measurement system as tool in a microlight-based airborne radiometric survey platform.

From the need for cheaper and faster geophysical surveys, the Geophysics Division of the Southafrican Council for Geoscience (CGS) proposed the use of a microlight airplane as a survey platform (see table 1 and figure 1). However, the relatively small payload (~70 kg) of such a system imposed the need for lightweight, highly efficient gamma-ray detector technology – technology that cannot be found amongst present-day, commercially available logging systems. In such systems, typically large NaI(Ti) detector packs are used, amounting up to payloads of hundreds kg.

Figure 1: The "Streak Shadow" microlight plane.

In recent years, the Nuclear Geophysics Division at KVI in Groningen has been developing a lightweight gamma-ray measurement system. This system (called MEDUSA – Multi-Element Detector system for Underwater Sediment Activity) was designed to measure the natural radioactivity of the sea floor to map-out sediment distributions *in situ*. Besides a thermometer, a pressure sensor and a microphone, the system is equipped with a highly efficient 150x50 mm-sized BGO scintillation crystal. The high photopeak efficiency of the BGO crystal, combined with an in-house developed enhanced spectrum analysis method, yielded an order of magnitude sensitivity increase as compared to standard same-sized NaI(Ti) systems using traditional "windows" spectrum analysis methods [STA97].

Despite its initial purpose as a sea-floor radioactivity logging system, the MEDUSA technology was designed such that it could also be used in different settings, such as in bore-hole logging and car-borne surveys. And because of its relatively small weight and size (the detector weighs a mere 2.8 kg) it would be ideally suited to be used on the microlight platform described above.

To test this idea, a collaboration between NGD and CGS was started in 1997 and two test flights of the MEDUSA-equipped CGS "streak shadow" microlight plane, were carried out. The first flight took place in May 1997 near Petit airfield Pretoria and was simply intended to investigate the technical needs associated with the use of MEDUSA on the microlight. A second series of test flights was carried out in December near Carletonville of the same year. Aim of this test was to acquire a dataset that could be compared to data acquired using a commercial airborne system.

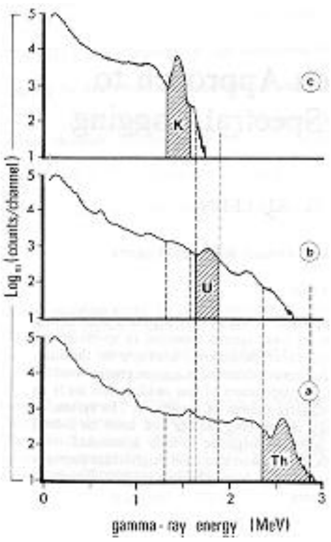
Table 1: Cost-efficiency comparison of different geophysical data-acquisition platforms. Note the 50% reduction in cost for the Microlight as compared to heli- and airplane systems

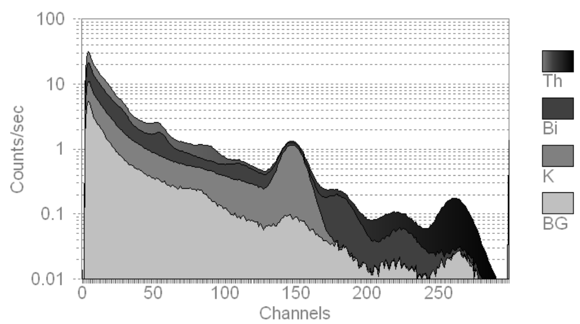
PLATFORMS/ PROPERTIES	Ground (sampling)	Vehicle	Helicopter	Airplane	Microlight
Detail	High	High	Medium	Low	Medium
Coverage	Poor	Very poor	Good	Good	Good
Speed	Very slow	Slow	Fast	Fast	Fast
Cost (R.S.A. 1997)	High	Low	Very high (typ. >12$/km)	High (typically ~12$/km)	Relatively low (~5$/km)
Methods	All	All	Mag, AGRS. EM	Mag, AGRS. EM	Mag, AGRS. EM
Typical applications (survey areas)	Small areas	Regional (road-based)	Large areas	Large/regional scale surveys	Large areas

This report describes results from the two test flights. This report gives a description of the MEDUSA system, test locations and technology involved, and data acquired during the test flights. Finally results will be discussed and some conclusions will be drawn.

THE MEDUSA SYSTEM

MEDUSA comprises a set of sensors (BGO-scintillation crystal, thermometer, microphone and pressure meter) plus a positioning system (DGPS). The philosophy of the system is to measure the distribution of the naturally occurring γ-emitting elements/series ^{40}K, ^{232}Th and ^{238}U *in situ*. Their respective concentrations vary significantly from one location to the other, due to geophysical processes such as mineralization and metamorphism. Though their presence is strongly coupled to the presence of certain (heavy) minerals (like monazite, zircon, and certain ores), in principle all materials in the earth's crust contain some amount of ^{40}K, ^{232}Th and ^{238}U. The degree to which these nuclides are present constitutes a "fingerprint" of these materials. Therefore, the spatial distribution of ^{40}K, ^{232}Th and ^{238}U, yields information both on the composition and the provenance of the measured materials.





These facts have been known for some tens of years and many systems have been devised to measure "natural radioactivity" *in situ*. Examples of these can be found in the oil- and gas industry (borehole logging devices) and the mining industry (air borne radiometry systems). However, these systems differ rather significantly from the MEDUSA system, both technologically as well as in the type of analysis methods used

Technological differences:

Virtually all known commercial logging systems are based on the use of NaI(Ti) detectors combined with the so-called "windows" spectrum analysis method. In this method certain energy windows are placed on the distinct peaks in the spectrum arising from ^{40}K, ^{232}Th and ^{238}U (see figure2). From the content of these peaks, the activity concentration of the nuclides are derived. This procedure involves among others correction for continuum contributions caused by other nuclides. MEDUSA uses a somewhat different approach: BGO is used as detector material, and the full spectrum is used in the analysis (fig. 3). This has two main advantages: firstly – despite its lesser resolution – BGO has a much higher photopeak efficiency, and secondly, full-spectrum analysis yields a much better statistics. These factors yield a much more efficient measurement system (typically an efficiency increase by a factor of 10 to 100 is obtained given the same detector volumes of NaI and BGO).

Analysis differences:

Apart from the inclusion of the total spectrum in the analysis, MEDUSA includes a second step in the analysis. In this (patented) second analysis stage, the nuclide concentrations obtained in stage 1 are translated into geologically relevant sediment or mineral fractions (see table 2). This stage incorporates the so-called "fingerprinting" of typical samples from the surveyed area. Using these fingerprints (i.e. the K, Th, U concentrations typical for a certain sediment/mineral type), the nuclide "map" of stage 1 can be translated into a sediment or mineral "map" of the survey area (see e.g. [Ven99]). This report, however, is restricted to the first stage – the nuclide concentration maps obtained in the EAGLE surveys were not translated into sediment/mineral maps. No corrections for flight altitude were performed in the present analysis.

Table 2: Overview of the MEDUSA *system and the steps in the data-analysis. To get to the sediment distributions, the γ-ray spectra measured by* MEDUSA *are translated into radionuclide distributions (step 1) and then into sediment distributions (step 2)*

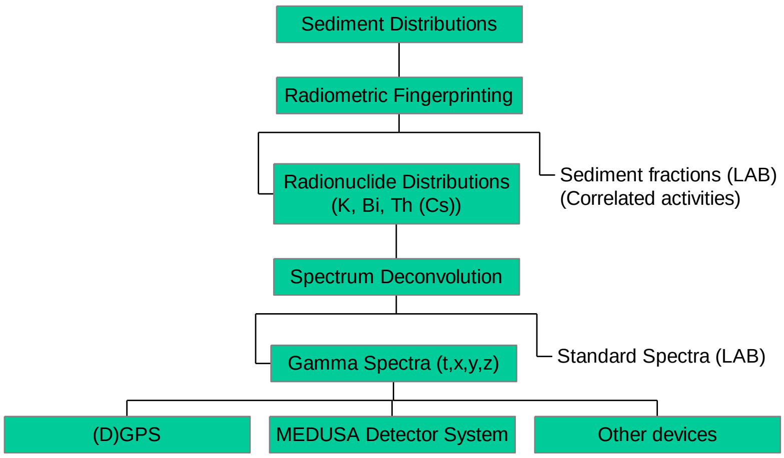


Figure 2: MEDUSA *Full Spectrum Analysis. A 512-channel spectrum is energy-calibrated and transferred into a 300-channel spectrum, and consecutively least-squares fitting is performed using so-called K, U and Th standard spectra.*

Figure 3: Gamma spectra for ^{40}K, ^{238}U and ^{232}Th. Dashed areas indicate the intervals ("windows") used in the windows analysis method. Taken from: Desbarats and Killeen, 1990 [DES90]

SURVEYS I AND II: LOCATION AND TECHNICAL DETAILS

The first EAGLE survey took place in the week of 18/05/1997 to 24/05/1997, near Petit Airfield close to Pretoria (RSA). During this week, a set of standard spectra was measured on the pads at Lanceria and attempts were made to mount the MEDUSA system on the microlight in a safe way. A first attempt to fly the microlight with two MEDUSA probes mounted on the wing-carrier bars of the plane was unsuccessful; due to the drag imposed by the probe, the plane became quite unstable while flying. It was then decided to place the probe inside the cockpit which – though not being very comfortable for the pilot and being undesirable in view of the absorption of gamma signal by the plane materials – proved to be the safest solution within the limits of the circumstances.

The MEDUSA probe was hooked up to a standard PC mounted inside the co-pilot seating. Power was supplied by a 12V DC – 220V AC converter typically supplying 200W power. Power for the probe electronics was derived from a 40V, 1A-power supply unit. System power was provided by a engine-driven battery. No serious interference effects of engine sparks etc were recorded.

The second survey took place in the week from 30/11/1997 until 05/12/1997, in the vicinity of Carletonville, near Potchefstroom (RSA). Initially, this survey comprised the test of a double BGO-detector system inside the microlight plane. However, just before take-off of the first flight, one of the detector systems gave trouble. Despite severe efforts to repair the system on the spot, the detector-signal could not be revived. It was then decided to run with a single system, as in the first survey. Due to very windy weather conditions, flying was not possible until the very last morning of the testing period. In this single flight, an area of about 5x15 km containing tailings of old gold-mines, was covered with a line spacing of about 200 m. Unfortunately this area fell just outside the region covered before with a commercial system. Therefore a sound data-comparison could not be made. However, a tentative comparison is justified – as will be shown further.

The mounting of the probe was somewhat different from the previous survey. Firstly, the detector was spatially separated from the read-out electronics by placing it inside a small container. The detector was mounted on the landing gear of the plane, which proved to be a spot inducing no excessive drag. The same PC system was used as a readout, and again a converter was used to supply the system. A notebook was used as a "monitor" of the PC. Thereby the use of a monitor and a keyboard could be avoided. The read-out and analysis software was adapted such that it could run a double-detector system and – secondly – that it could run without user-interference. A signaling device was added to the system to notify the pilot of system failure.

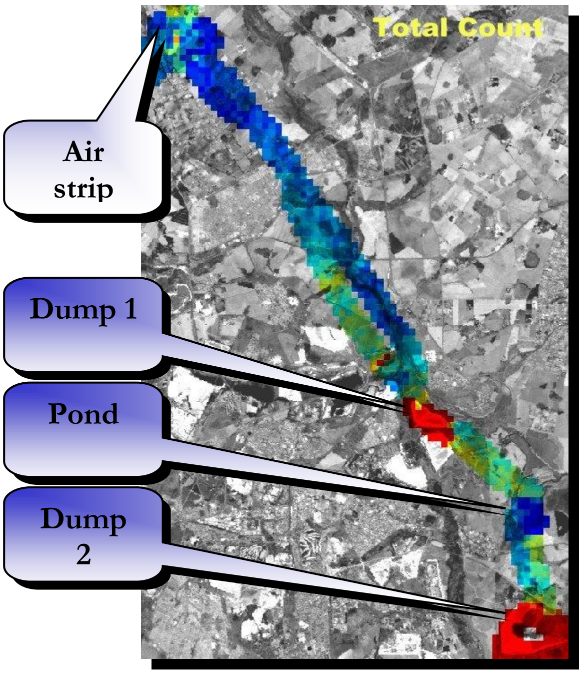


Figure 4: track flown during EAGLE 1. Colors indicate the total γ-activity (blue representing inactive regions, red active regions). Indicated are also the locations of the air strip, two dump locations and a small pond. The dump locations contain material from former gold mines

Figure 4 plots the track as it was flown during the first testflight in May 1997. During this flight, every single second a full spectrum was measured, analyzed and stored. The plane flew at about 30 m/s and at altitudes varying between 30 m and several hundred meters.

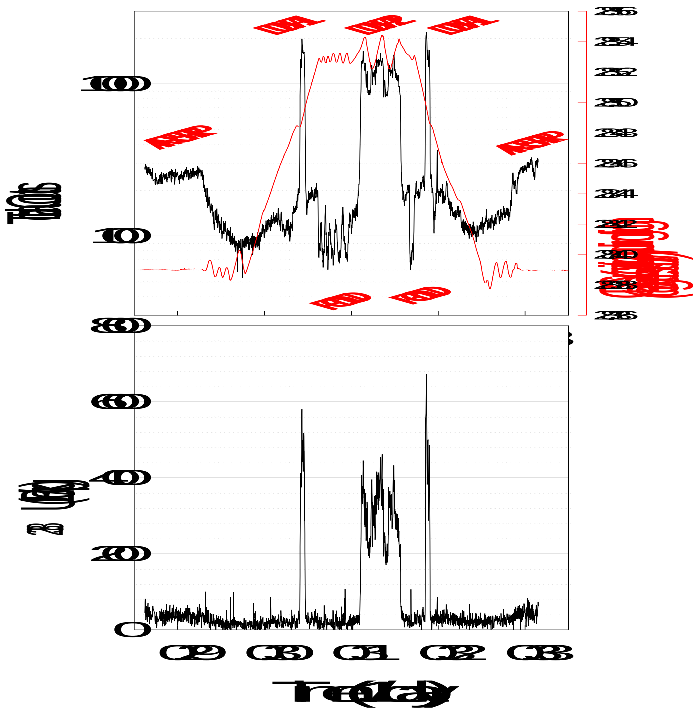


Figure 5 (upper): Total activity and northing (red) versus flight time. The various geographical locations (see figure 4) are indicated. Note the logarithmic y-axis. (Lower): ^{238}U concentrations (linear scale). The correlation between the ^{238}U variation and TC variation is virtually 1:1. The "sawtooth"-like structure found around T=0.315 stems from the circles that were flown over dump site 1. The minima occur when the plane is close to the periphery of the site

In this figure, the colors represent the total γ-activity as measured by MEDUSA. Clearly the two dump locations are enriched. Also note the low activity found on the upper path (back to the airstrip). This path was measured at much larger altitude than the lower path. The activity found is reduced by the increased absorption by the air layer between plane and the soil (also see figure 5).

Figure 5 plots the measured total activity (upper plot) and ^{238}U concentration (lower plot) versus the measurement time (fraction of the day). Indicated in red is the position (northing) of the plane. Note that all numbers shown here are not corrected for absorption effects. A number of comments can be made with respect to figure 5:

1. Variations in the total activity found in the surveyed area are almost completely determined by variations in the ^{238}U concentration. Also, the absolute magnitude of the total activity is largely due to ^{238}U.

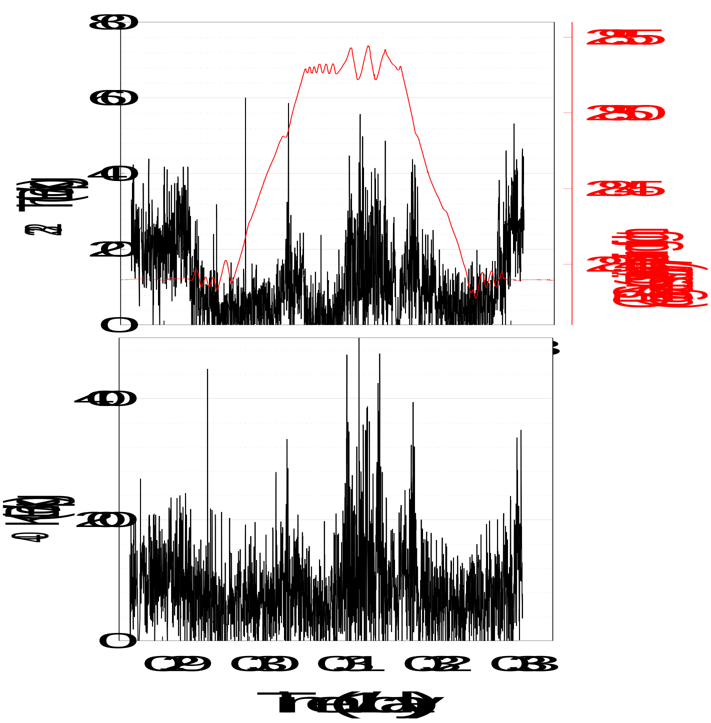
2. The first part of the plot (almost up to T=0.3), is made up of data acquired at the airstrip. During this time, the pilot was circling to a relative altitude of several 100 meters. The effects of increasing air-absorption are clearly visible as the total activity goes rapidly down from about 300 counts/s at T=0.29 to less than 100 counts/s at T=0.297

3. On the outbound flight, the pilot made circles over the pond and dump #2. These circles (the "zig-zags" in the northing) seen back in the activity variations in the TC and ^{238}U signals.

4. The values found for the ^{238}U concentrations corroborate with the fact that gold of the Witwatersrand is associated with uranium. After processing, ^{238}U remains as a contaminant in the dumped material.

Figure 6 shows plots of the ^{232}Th and ^{40}K concentrations found during the survey. Obviously, the strong variations found in TC do not stem from variations in ^{232}Th and ^{40}K concentration, their variation mainly represents the statistical fluctuation of their presence in the surveyed area and the variations in air absorption (due to altitude variation) during the flight. Typically, the ^{238}U concentrations exceed those of ^{232}Th by a factor of 10. Finally, a general conclusion is that the MEDUSA system apparently is able to separate K, U and Th contributions to a high degree of accuracy from the total gamma-signal.

Figure 6 (upper): ^{232}Th concentration and (lower) ^{40}K concentration versus flight time. Again, indicated in red, the northing. Variations mainly represent the statistical fluctuation of the Th and K presence in the surveyed area and the variations in air absorption



Despite the technical difficulties encountered during test run II, a significant area could be mapped using MEDUSA, as is plotted in figure 7. The area under interest is roughly 5x15 km in size, and contains two gold-mine dump sites (indicated by the arrows). The two dump locations are clearly visible by their enhanced total activity. Figure 8 quantifies the variations in total activity (i.e. total count rate) of the detector system, versus the flight time. Note the large dynamic range of the total activity variations of a factor of 20-30. The material dumped

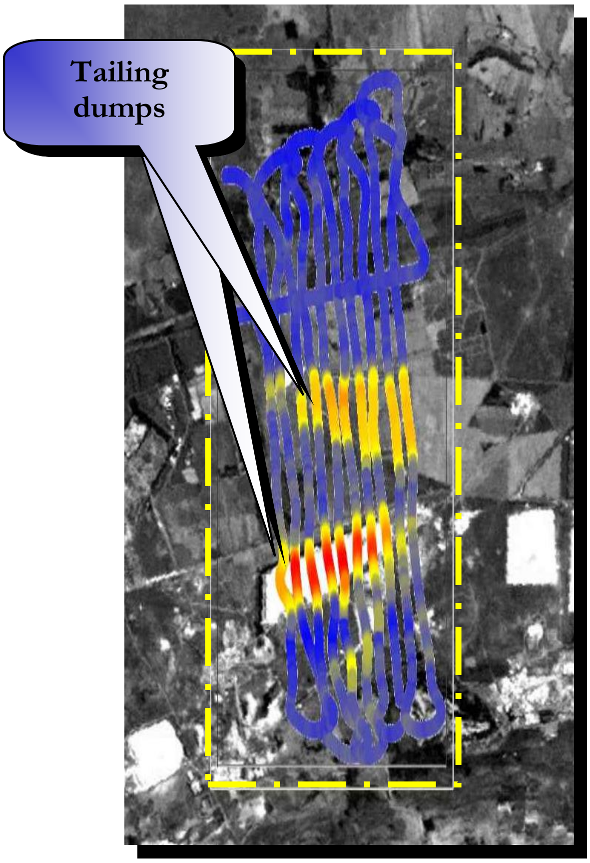


Figure 7: track flown during the Eagle II test. The area roughly spans 5x15 km, indicated are two gold-mine tailings that clearly show an enhanced activity. Colors indicate total activity variations, from blue (low activity) to red (high activity).

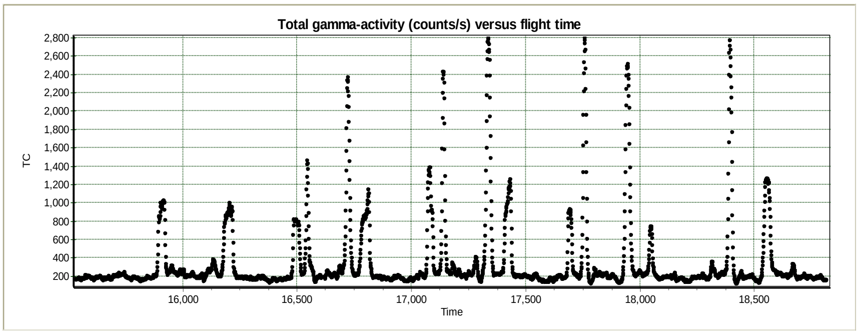


Figure 8: Total gamma activity versus flight time in survey II

in the tailing indicated in fig. 7 is similar of composition as the dump material of test flight 1. Therefore, we expect the same behavior for the radionuclide concentrations as in figs. 5 and 6. However, the data generated by the on-line analysis software show a somewhat different behavior, especially concerning the ^{232}Th and ^{238}U signals (see figs 8 and 9). The on-line analysis clearly shows the presence of almost equal concentrations of these nuclide series in the surveyed area.

To further investigate this feature, a post-analysis of the data was carried out. This post-analysis includes, amongst other things, a complete "simulated" re-run of the survey. This analysis clarified a few important issues:

1. During the survey, some data records were spoiled by strong "bursts" of detector noise.

2. After such bursts, the software gain stabilization of the

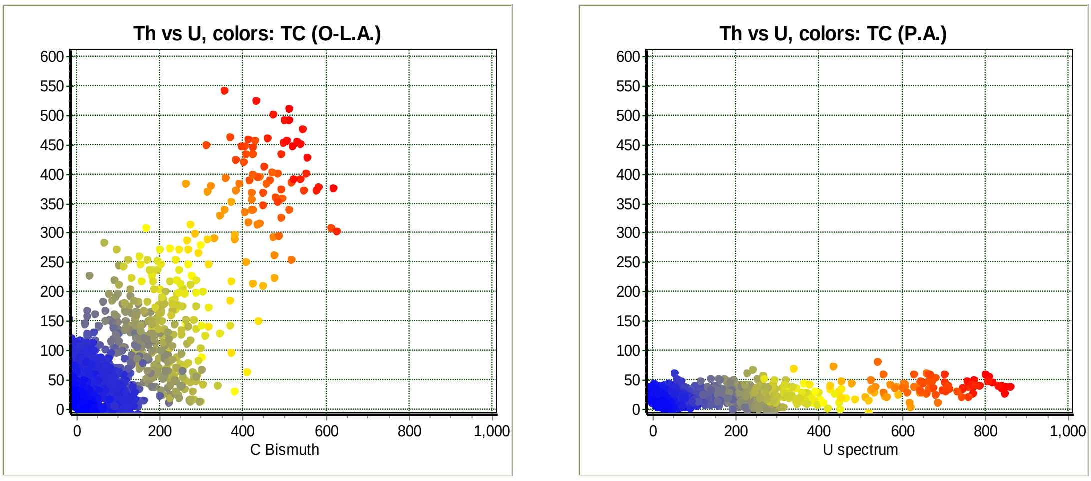


Figure 9: ^{232}Th vs. ^{238}U concentrations. Colors indicate total activity (from blue to red). Left box: results from the on-line analysis. Right box: results from enhanced (post-) analysis. The axes-scales are kept the same in both figures to show the dramatic difference in concentrations calculated by both analysis methods.

system appeared to be shifted, leading to erroneous results from the spectral fitting procedure.

3. In the on-line analysis, no background was subtracted from the measured spectra. This lead to rather poor fit results, especially at the statistically very significant low-energy side of the spectra.

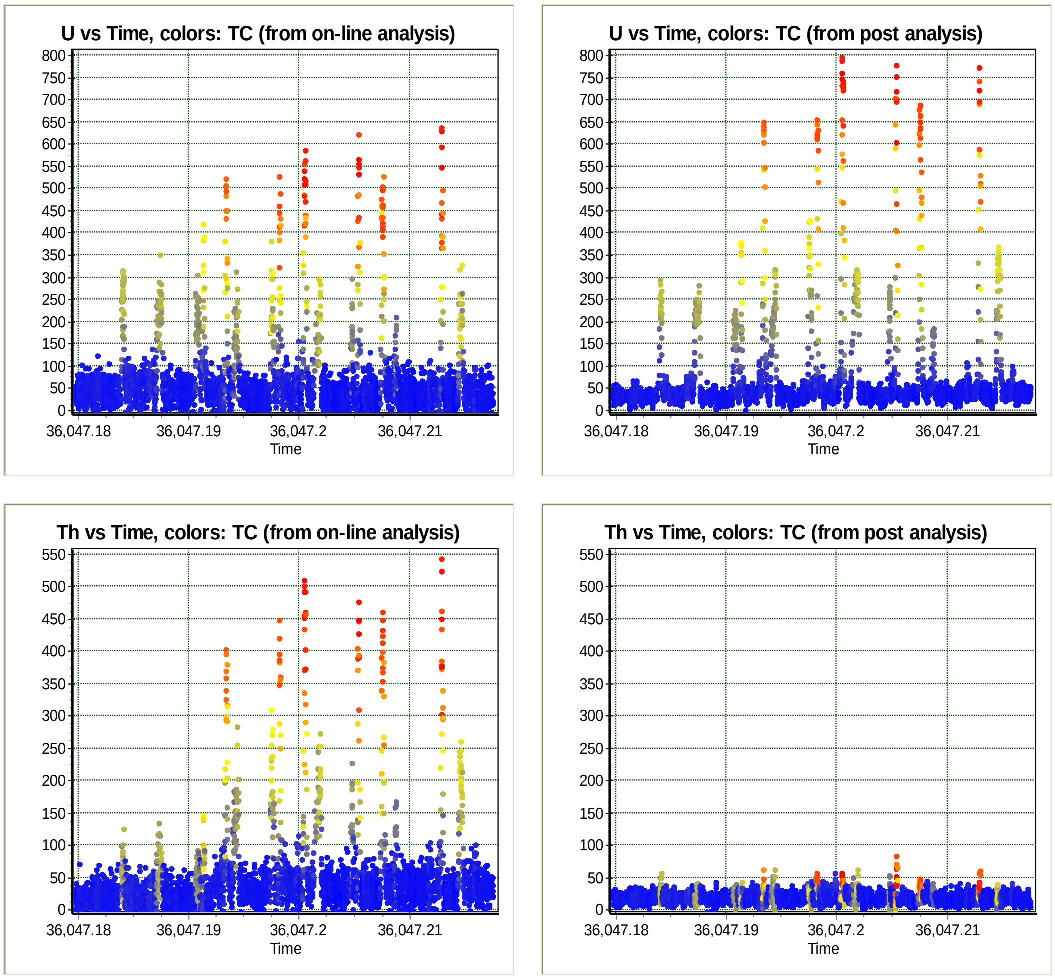


Figure 10: ^{238}U (top) and ^{232}Th (bottom) concentrations vs flight time (time is in date+time format). Colors indicate total activity (from blue to red). Left boxes: results from the on-line analysis. Right boxes: results from post analysis.

In the post-analysis of the data, these effects were accounted for by removing the spurious data records and by using a proper set of standard spectra (including a background spectrum). The effects of this treat are plotted in figure 10. Note the strong reduction in scatter in the post-analyzed data and the mere disappearance of the "hot-spots" in the post-analyzed ^{232}Th data. The reduction in data-scatter is most prominent in the low-activity ("blue") regions and amounts up to an average reduction of 25-50% compared to the original on-line data! The ^{40}K data shows a similar scatter-reduction. Results for potassium are, however, omitted for brevity.

Figure 11 displays a "zoom" on one of the active areas covered during the survey. In the top-inset, the measured spectrum (blue points) and fitted spectrum (red line) are shown; in the lower inset the standard spectrum used for ^{238}U is displayed. The measured spectrum closely resembles the ^{238}U standard spectrum – the activity enhancements found at the dump locations thus indeed

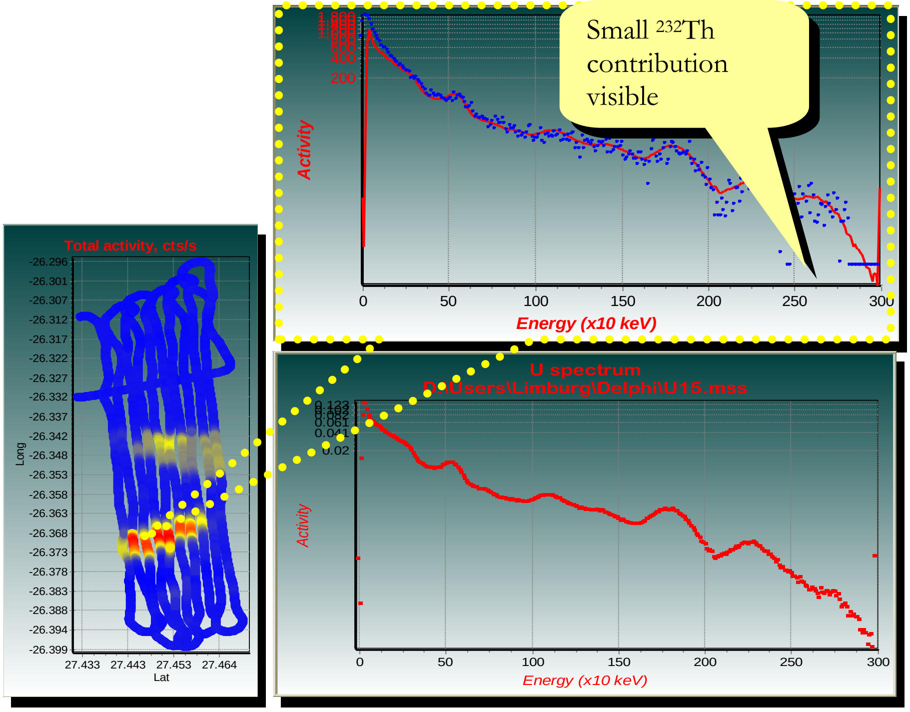


Figure 12: a "zoom" on an active part of the surveyed area reveals that the enhanced activity stems from ^{238}U-enriched material. The top-right box plots the measured spectrum (blue points) and the fitted spectrum (red line); the bottom-right box displays the 238U standard spectrum.

almost completely stems from ^{238}U-enriched materials. However, some Th still is present in the spectrum.

Finally, a tentative comparison between the total activity measured with a commercial 235 kg NaI system and our MEDUSA system is presented in figure 13. This figure plots the total activities found by both systems on adjacent areas. Unfortunately, due to the aforementioned technical problems, the whole area could not be covered during survey II. However, the patterns arising from both systems closely resemble one another. This is a clear indication that the dynamic range of the (2.8kg)

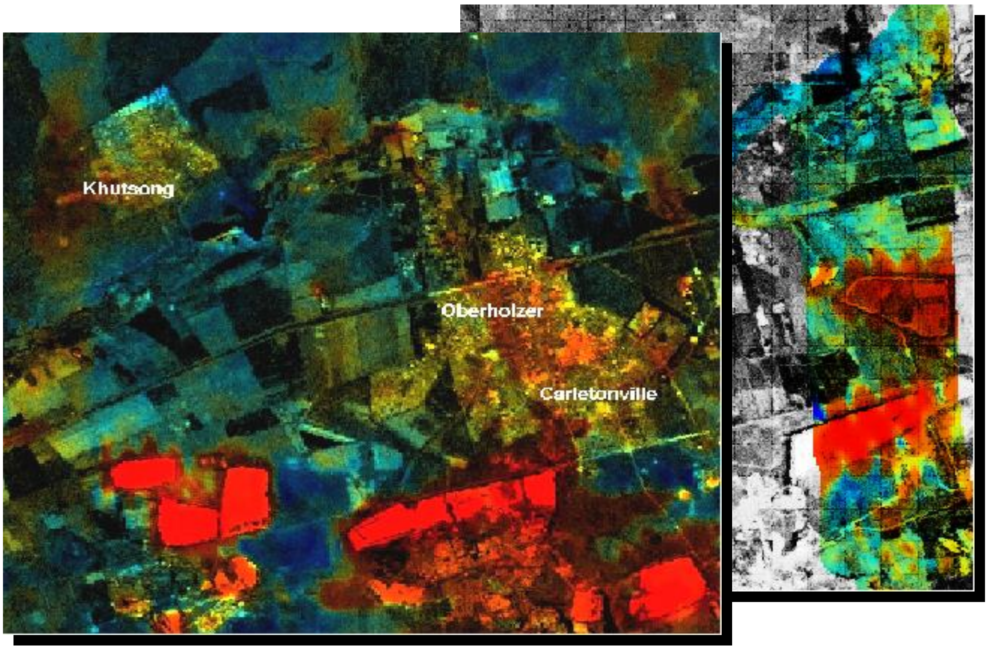


Figure 13: Comparison between total-activity measurements by a (235 kg) commercial NaI system (left) and the (3.5 kg BGO) MEDUSA *system (right).*

MEDUSA BGO system is sufficiently large to deliver a data quality similar to that of a much heavier commercial system.

DISCUSSION AND CONCLUSIONS

The aims of the Eagle I and Eagle II projects – to test the feasibility of a small "smart" BGO-based natural-radioactivity logger as a tool on an airborne survey platform and to acquire a reference dataset which can be compared to an existing set of data – have partly been fulfilled.

The lightweight MEDUSA system has proven to be sufficiently sensitive to be a possible candidate for a lightweight airborne system. The sensitivity of the system is typically identified by the uncertainties in the K, U and Th values it delivers – especially in the values for the lowest activities found (say, the "blue" points in the data presented before). Those uncertainties are – for the given conditions of a single spectrum per second – of the order of 20%-30% per ("blue") point. In the active areas, of course the uncertainty is less (~10% per point). To further reduce the uncertainties, both the hardware and the analysis will be further optimized. A doubling of the detector volume will readily yield a reduction of the uncertainties by 50%. The detector shape should be optimized for the purpose of air-borne work as well. This can be done by proper simulation of the shape-dependence of the detector response in the given geometry. Moreover, by using a small, upward looking detector mounted on top of the downward looking BGO, a proper estimate of the (cosmic and radon) background can be made during the survey. This technology is already being utilized in some commercial systems. Inclusion of techniques like the spectral component analysis described by Hovgaard and Grasty [HOV97] can refine the data-analysis even further.

OUTLOOK

However, a definite system design based on MEDUSA-technology can still not be given until a sound comparison can be made between MEDUSA-generated data and data generated by a commercially available system – measured at the same location, with the same flight parameters and preferably measured concurrently. At the moment of writing of this document, two more test surveys are anticipated – one of which will focus on such a comparison.

Besides these tests, work is ongoing to implement computer codes to simulate absorption eefects and detector response, to optimize detector shape and volume for a given application. A lot of attention is being paid to the optimization of the analysis methodology; research into enhanced spectral analysis method and improved stabilization routines is ongoing.

LITERATURE

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