DEPARTMENT OF THE ARMY
US ARMY CHEMICAL SCHOOL
401 MANSCEN LOOP
FORT LEONARD WOOD, MISSOURI 65473-8926

REPLY TO
ATTENTION OF:

Health Physics Office

U. S. Nuclear Regulatory Commission, Region II
Ms. Orysia Masnyk Bailey
Division of Nuclear Materials Safety
Sam Nunn Atlanta Federal Building
61 Forsyth Street SW Suite 23T85
Atlanta, GA 30303-8931

Dear Ms Bailey:

Enclosed is the Response to comments by the U.S. Nuclear Regulatory Commission in *NRC Inspection Report No. 01-02861-05/03-01*, dated August 25. The response was provided by the contractors that performed the work, The Shaw Group Inc. and Fugro Airborne Surveys.

If you have any questions or require clarification on any of the information above, contact Mr. John May at (573) 596-0131 extension 3-6224.

Sincerely,

Gary R. Wallace
Assistant Commandant

Encls

Shaw Environmental & Infrastructure, Inc.

11560 Great Oaks Way, Suite 500
Alpharetta, GA 30022-2424
770.475.8994
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Shaw The Shaw Group Inc.™

February 10, 2004

SHAW-MC-CK10-0417
Project No. 796887

Mr. Lee Coker
U.S. Army Corps of Engineers, Mobile District
Attn: EN-GE/Lee Coker
109 St. Joseph Street
Mobile, Alabama 36602

Contract: **DACA21-96-D-0018, Task Order CK10**
Fort McClellan, Alabama

Subject: **Response to NRC Comments on the Draft Airborne Radiological Survey for Fort McClellan**

Dear Mr. Coker:

Enclosed are responses to comments received from the U.S. Nuclear Regulatory Commission (NRC) on the *Draft Airborne Radiological Survey – Main Post and Pelham Range*. The NRC requested further information or clarification regarding the radiological flyover survey as detailed in NRC Inspection Report No. 01-02861-05/03-01 dated August 25, 2003.

At your request, I have distributed copies of this submittal as indicated below. If you have questions, or need further information, please contact me at (770) 663-1429 or Steve Moran at (865) 694-7361.

Sincerely,

Jeanne Yacoub

Jeanne A. Yacoub, P.E.
Project Manager

Attachments

Distribution: Lisa Holstein, FTMC (3 copies)
John May, U.S. Army Chemical School (6 copies)
Mike Kelly, AEC (1 copy)
Vicki Strause, NGB, Army Directorate (1 copy)
COL David McPherson, ALARNG Training Center (1 copy)
LTC Brian Barrontine, ALARNG-CFMO (1 copy)

Response to Comments by the U.S. Nuclear Regulatory Commission on the Airborne Radiological Survey – Main Post and Pelham Range Fort McClellan, Calhoun County, Alabama

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Comments from Thomas R. Decker, Chief, Materials Licensing/Inspection Branch1, excerpted from NRC Inspection Report No. 01-02861-05/03-01, *dated August 25, 2003.*

GENERAL COMMENTS

Further information or clarification is required concerning the flyover survey. There are no further concerns regarding the groundwater in this area or the final status survey of the burial mound. Review of the licensee's request for license termination can continue once the licensee's response is received. 10 CFR 20.1402 requires the consideration of residual radioactivity that is distinguishable from background radiation when evaluating site release for unrestricted use. 10 CFR 20.1003 defines residual radioactivity to include radioactivity from all licensed and unlicensed sources used by the licensee.

Once the USACE has completed the remediation of the LaGarde recreation area (Anomaly M1) and the NRC has received the final survey data for analysis in conjunction with the current Fort McClellan radiological data, license termination review can continue.

SPECIFIC COMMENTS

Comment 1: Much of the area surveyed was forested, with tree heights ranging from an estimated 70 to 100 feet. The licensee, in their report, described that the biomass had the effect of increasing the effective flying height by an additional 50 feet of altitude, and stated that an exposed source can be detected at heights of up to 150 feet; however, there is no discussion on the effect of burial on the sensitivity other than to mention that burial has a larger impact than flying height. The report does not provide the suspected burial depth.

Response 1: The information requested by the reviewer is provided in Attachment 1.

Comment 2: A range of sensitivities based on burial depth would help to determine if the system's sensitivity was adequate for the activity of the sources at the time of the survey. The range should account for a surface deposit down through to the likely maximum burial depth. The maximum burial depth should be chosen based on the historical site assessment (HSA). Sources buried greater than 12 to 20 inches in depth would not have a high probability for detection. Please provide this information.

Response 2: The information requested by the reviewer is provided in Attachment 1.

Comment 3: **The system was calibrated before and after each flight. Calibration was performed using three accurately positioned hand-held sources. Details of the calibration were not provided. Please provide additional detail including information such as calibration radionuclides used with their activity and positions, tolerance for energy calibration, full-width half-max, background level, and other general gamma spectroscopy quality control (QC) parameters. The detectors were packaged in unheated enclosures that were shock-protected and were automatically stabilized with respect to the K-40 peak. This approach was valid because K-40 would appear in all survey areas and would be useful to correct the electronics for thermal drifting and thereby maintain the system within calibration. Differences in background due to moisture were accounted for by fixed-site test line flights. These tests were also used to monitor the equipment. Please provide information as to what these tests were or acceptable QC parameters. Also, discuss the impact of the environment, such as weather, on the operation of the system.**

Response 3: The additional information requested by the reviewer is provided in Attachment 1.

Comment 4: **Discussion in the report indicates that radon background measurements could not be performed because there were no upward-looking detectors utilized during the survey. Radon banding was observed in the uranium window and to a lesser extent in other windows and was adjusted to base levels to match local backgrounds on a line by line basis. According to the report, this correction may cause errors in defining absolute background and concentration values, but does not affect identification of point source anomalies. Please provide additional information regarding this stripping technique, particularity a reference, to allow for validation of this conclusion.**

Response 4: The additional information requested by the reviewer is provided in Attachment 1.

Comment 5: **Following the radon correction, the Cs-137, Co-60, K-40, uranium, and thorium windows were first corrected for spectral overlap with the stripping ratios modified by altitude. Based on the reversed stripping ratio for uranium into thorium, an additional adjustment factor was calculated. According to the report, after the stripping was completed, there were still contributions of K-40 in the Co-60 window and uranium (Bi-214) in the Cs-137 window. It will affect the accuracy of absolute background and ground concentration values for Cs-137 and Co-60 but there is no discussion as to how to evaluate the impact. Please provide a reference or additional detail for the applied approach.**

Response 5: Additional detail for the applied approach is provided in Attachment 1.

Comment 6: Following the spectral overlap correction, the next correction accounted for attenuation due to air at the flying altitude. The correction reduced the data to a nominal flying altitude, the intended flying height, of 33 feet. No mention is made of any attenuation corrections for biomass. Considering the assumption that the biomass would add an effective 50 feet to the flying altitude, it would be conservative to apply the correction to any data collected at altitudes higher than the intended flying height of 33 feet. Please provide a reference or further clarification for the applied approach.

Response 6: Clarification of the applied approach is provided in Attachment 1.

Comment 7: Anomaly P4 had elevated Co-60 in addition to elevated exposure rate, unlike P3 and P5 through P10, which only exhibited elevated exposure rates. The P4 ground investigation exposure rate measurement was significantly greater than other shale outcropping anomalies. In addition, the exposure rate at the surface was nearly two times the one-meter measurement, compared to the other anomalies where the exposure rates did not significantly change with distance. During the M2 anomaly ground survey, the hand-held NaI spectrometer drifted and incorrectly identified Cs-137 in the spectrum. Because of the exposure rate results and potential for misidentification, or non-identification, for the P4 anomaly, please provide additional information supporting your conclusion that the elevated readings in this area were due to the shale outcropping.

Response 7: The additional information requested by the reviewer is provided in Attachment 2.

Comment 8: The report stated in the airborne survey documentation that if ground surveys of the lower priority anomalies identify sources, the assumptions used during the data reduction would need to be revisited. This would be especially true if additional surveys at the P4 anomaly identify a source.

Response 8: Comment noted.

ATTACHMENT 1

RESPONSE TO NRC COMMENTS – FUGRO AIRBORNE SURVEYS

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Response to NRC INSPECTION REPORT NO. 01-028161-05/03-01

Airborne Radiological Survey of Main Post and Pelham Range,

Ft. McClellan, Alabama

By

Fugro Airborne Surveys

Fugro Airborne Surveys Corp.
Mississauga, Ontario

February 2, 2004

Greg Hodges
Chief Geophysicist

Emily Farquhar
Manager, Data Processing

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In July 2003, the United States Nuclear Regulatory Commission completed an inspection at Ft. McClellan, Alabama, undertaken to determine compliance of the decommissioning activity with Nuclear Regulatory Commission requirements. The inspection findings were summarized in NRC INSPECTION REPORT NO. 01-02861-05/03-01.

Two documents were reviewed as part of the inspection:
"Airborne Radiological Survey – Main Post and Pelham Range, Walkover Radiological Survey at Rideout Field and Anomaly Surveys on Main Post and Pelham Range, and Groundwater Investigation – Burial Mound at Rideout Field"
"Final Radiological Status Report – Ft. McClellan – Pelham Range 'Burial Mound'"
The evaluation and discussion of these reports with the cognizant licensee and contractor personnel identified areas requiring clarification. These are outlined on pages 6 through 9 of the NRC report and cover the following issues as they pertain to the airborne survey.

1. Provide additional details of calibration and general gamma spectroscopy quality control parameters

Calibration Monitoring:

Source and Resolution tests are designed to verify that the measuring system sensitivity has remained constant through the duration of a survey. For normal survey monitoring, these source and resolution tests are carried out before and after every day's flying. The consistency of background corrected count rates in the thorium and uranium windows from a source test serve to verify that the sensitivity of the system has remained the same. The shape of either the 662 keV ^{137}Cesium peak or the 2615 keV Thorium photopeak serves to monitor the resolution of the spectrometer system. For the Mainpost and Pelham flying, the ^{137}Cs peak was used for measurement of system resolution.

Before surveying every day, a FULL system test and ground calibration was performed. The first part of this test measures the peak centre, the gain and the resolution (expressed as Full Width at Half Maximum or FWHM) for each crystal individually for both the 662 keV and the 2615 keV photopeaks. This was followed by a ground calibration where the Uranium and Thorium sources were placed in a repeatable position relative to the two crystal packs through the use of a jig that hangs underneath the helicopter. This location was chosen in an attempt to "illuminate" the crystal packs approximately equally. Every effort was made to maintain consistency in the position of the source day to day. An acceptable variation of the source tests was specified as 5 percent for daily survey monitoring. This is consistent with the level recommended in both "A Guide to the Technical Specifications for Airborne Gamma-Ray Surveys" published by the Australian Geological Survey Organization and the International Atomic Energy Agency (IAEA) Technical Report Series No. 323, "Airborne Gamma Ray Spectrometer Surveying"

As part of the ground calibration carried out at the start and end of daily surveying, the resolution of the system was also measured from the 662 keV Cesium peak. The simplest way to measure resolution is to first determine the amplitude of the peak. The width of the peak at half of the maximum amplitude is then determined and is referred to as the full width at half maximum, or FWHM. The resolution is then calculated as

$$\text{Resolution (\%)} = \frac{100 * \text{FWHM(channels)}}{\text{Peak centre(channels)}}$$

FUGRO AIRBORNE SURVEYS

An acceptable level for the resolution of the measurement system, as measured from the 662 keV ^{137}Cesium photopeak, was specified as less that 12% and should be in the 8.5-9.5% range. These levels are again compliant with those recommended in both the AGSO and the IAEA technical reports referred to above.

The results of the daily source and resolution tests for the Main Post and Pelham flying are shown below:

Sample Checks for Job#6014

Date	AM or PM	Uranium Counts	Average	% deviation	Thorium Counts	Average	% deviation	Cs Resolution (FWHM)
5-Oct-01	AM							
5-Oct-01	PM							
6-Oct-01	AM							
6-Oct-01	PM							
7-Oct-01	AM							
7-Oct-01	PM		7624.9			10547.5		
8-Oct-01	AM	7567	7567.0	0.00	10367	10367.0	0.00	8.6%
8-Oct-01	PM	7412	7489.5	-1.03	10396	10381.5	0.14	9.0%
9-Oct-01	AM	7484	7487.7	-0.05	10432	10398.3	0.32	8.7%
9-Oct-01	PM	7450	7478.3	-0.38	10324	10379.8	-0.54	8.4%
10-Oct-01	AM	7457	7474.0	-0.23	10469	10397.6	0.69	8.5%
10-Oct-01	PM	7520	7481.7	0.51	10661	10441.5	2.10	8.5%
11-Oct-01	AM	7532	7488.9	0.58	10461	10444.3	0.16	8.4%
11-Oct-01	PM	N/A	7488.9		N/A	10444.3		N/A
12-Oct-01	AM	7721	7517.9	2.70	10682	10474.0	1.99	8.5%
12-Oct-01	PM	7557	7624.9	-0.89	10583	10547.5	0.34	8.5%
13-Oct-01	AM	7648	7534.8	1.50	10544	10491.9	0.50	8.6%
13-Oct-01	PM	7709	7550.6	2.10	10563	10498.4	0.62	8.4%
14-Oct-01	AM	7857	7576.2	3.71	10693	10514.6	1.70	8.5%
14-Oct-01	PM	7642	7581.2	0.80	10553	10517.5	0.34	8.4%
15-Oct-01	AM	7674	7587.9	1.14	10549	10519.8	0.28	8.5%
15-Oct-01	PM	7734	7597.6	1.80	10595	10524.8	0.67	8.4%
16-Oct-01	AM	7654	7601.1	0.70	10482	10522.1	-0.38	8.4%
16-Oct-01	PM	7772	7611.2	2.11	10670	10530.8	1.32	8.4%
17-Oct-01	AM	NF	7611.2		NF	10530.8		NF
17-Oct-01	PM	NF	7624.9		NF	10547.5		NF
18-Oct-01	AM	NF	7611.2		NF	10530.8		NF
18-Oct-01	PM	NF	7611.2		NF	10530.8		NF
19-Oct-01	AM	7669	7614.4	0.72	10620	10535.8	0.80	8.5%
19-Oct-01	PM	7733	7620.6	1.47	10632	10540.8	0.86	8.5%
20-Oct-01	AM	7553	7617.3	-0.84	10453	10536.5	-0.79	8.5%
20-Oct-01	PM	7731	7622.7	1.42	10577	10538.4	0.37	8.4%
21-Oct-01	AM	7584	7620.9	-0.48	10724	10546.8	1.68	8.4%
21-Oct-01	PM	7712	7624.9	1.14	10563	10547.5	0.15	8.5%

The resolution of the system, as defined by the ^{137}Cs FWHM was better than the contractual specification of 12% for the duration of the survey. The deviation of both Uranium and Thorium daily source tests was also less than the contractual specification of 5% for the duration of the survey.

2. Provide information on the fixed-site test line flights and impact of the environment on operation of the system

Radiometric Test Line Monitoring of Survey Conditions

A survey test line was flown in a repeatable position each day at the nominal survey altitude. This repeatable line served two purposes, one to monitor the behavior of the equipment in the air and secondly to monitor the effects of soil moisture. Thorium has been selected as the window of choice for evaluating the test line data. The thorium window is relatively unaffected by the radon concentration in the air, unlike uranium, total count and to a lesser extent, potassium. The thorium window count rate will be affected by changes in terrain clearance, temperature, and pressure and should therefore be normalized to the nominal survey altitude at STP (standard temperature and pressure). The thorium background should be removed before altitude correction. The specification for the repeatability of the survey test line thorium results is chosen as +/- 10 percent from the average, which allows for identification of significant soil moisture changes but does not unduly restrict the flying due to minor changes.

TEST LINE:FLIGHT #	Average Th window at STP (cps)	% Deviation from Average
L1008101:2	86	-5.3
L1008102:3	89.9	-1.0
L1009101:4	91.4	0.7
L1011101:10	91.6	0.9
L1009103:6	90.5	-0.3
L1009104:6	92.6	2.0
L1009102:5	88.7	-2.3
L1010101:7	88.2	-2.9
L1010103:9	95.4	5.1
L1010102:8	91.7	1.0
L1011102:10	94.4	4.0
L1012101:13	95.8	5.5
L1011104:12	93.8	3.3
L1011103:11	95	4.6
L1013101:16	89.6	-1.3
L1012103:14	90.5	-0.3
L1012104:15	96.6	6.4
L1012102:13	93.2	2.6
L1013102:16	92	1.3
L1014101:17	84.8	-6.6
L1014102:17	86.8	-4.4

L1014103:19	91.1	0.3
L1015101:20	88.8	-2.2
L1015102:22	90.2	-0.7
L1016101:23	82.9	-8.7
L1016102:23	88.9	-2.1
L1019101:24	90.4	-0.4
L1019102:26	89.2	-1.8
L1020101:27	91.2	0.4
L1020102:29	95.3	5.0
L1021101:30	92.6	2.0
L1021102:30	91	0.2
ALL	90.8	

As can be seen from the above table, the repeatability of the thorium results from the daily test line falls within the +/- 10% contractual specifications.

The impact of the weather on the operation of the system will be determined by the changes in count rates due to changes in the temperature, pressure and soil moisture. Since the airborne count rates depend on the density of the air column between the ground and the detectors, they are therefore dependant on air temperature and pressure. The effects of pressure change on the count rate, as measured at a fixed barometric altitude, are relatively small. The significant changes in pressure that occur with varying barometric altitude, however, can have a greater impact on the measured count rate. It is critical to measure this barometric altitude and the ambient air temperature in order to correct for this effect – a correction that is made through calculation of an "effective height". This effective height is based on the actual radar altimeter, barometric altitude and temperature as measured by the airborne system and provides a height of measurement under the assumption that the system is flying at a "Standard Temperature and Pressure".

Soil moisture is another environmental affect and changes in moisture levels will commonly occur through the duration of an airborne survey. Its effect on airborne count rates is monitored through the use of a test line. According to the AGSO Guide to Technical Specifications for Airborne Gamma-Ray Surveys, an increase in soil moisture of 10 percent will decrease the airborne count rate in the thorium channel by roughly the same amount. One problem with the use of the test line is that, particularly for large survey blocks, changes in the test line soil moisture levels may not be representative of the area being flown. This will not be a concern with the small extent of the Main and Pelham blocks plus the proximity of the test line location to the survey areas.

Rain can also increase the effect of radon on the measured count rates, since precipitation of radioactive dust particles on the surface serves to increase ground gamma-ray activity. With half-lives of 20 to 30 minutes for the radon decay products, it is therefore advisable to not fly for at least three hours after any rainfall in a survey area.

3. Provide additional information regarding the stripping technique for removal of radon

Radon Background Removal

As mentioned in the report on the survey results from Fort McLellan Flyover, there are several procedures that have been recommended for the removal of the radon background component of airborne count rates.

One, recommended by the IAEA, is through the use of the upward looking detector. However, the spectrometer used for this survey, the Exploranium GR820, is limited to the collection of only 2048 cubic inches of crystal when recording in 512 channel mode. This precluded the use of an upward looking crystal to monitoring radon background.

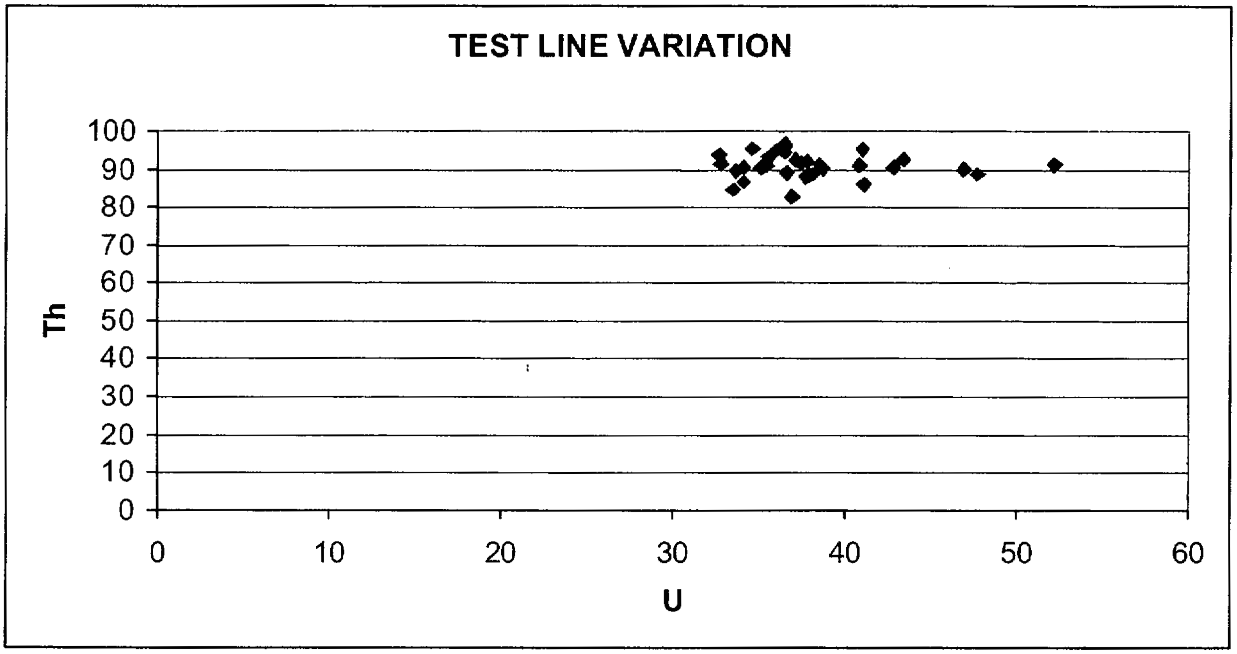
A second method is to do regular flights over a suitably large and nearby body of water. Variation in the count rate over water can be assumed to be due to changing radon atmospheric conditions so an over water test at the start and end of a survey flight can provide a linear correction for changing radon conditions. Unfortunately a suitable body of water was not available for the Fort McLellan survey.

A third method proposed by Minty in 1992 uses the differences in spectral shape between a radon spectrum from the ground and one measured in the air by the airborne survey platform. The shape differences are monitored through examination of high and low energy ^{214}Bi gamma-ray peaks. Unfortunately, in North America the low energy peak is obscured by the presence of gamma-radiation from ^{137}Cs due to atomic weapons testing or nuclear accident contamination.

The effect of radon in the Ft. McLellan survey was observed as banding in the uranium window and to a lesser extent in the total count and low/high energy windows. The effect of the radon on the measured count rates was minimized through adjustment of base levels or long wavelength adjustments on a line-by-line basis to match local backgrounds. This sort of DC shift or 1st order correction is similar to that which would be applied from measurements of background over water at the start and end of every flight and will not have a detrimental effect on the ability to detect point source anomalies.

In an attempt to identify only those flights that require background adjustment, the count rates from the repeat test line were reviewed. Repeat measurements over the Ft. McLellan survey test line allow for the demonstration of differences in survey conditions which are likely due to radon variation for specific flights. Under the assumption that the test line is flown at the same altitude and starts and stops in the same place each day, variation in the average daily count rates in the uranium window in particular, will be primarily due to the presence of radon background. This procedure was used to identify flights that might contain elevated radon backgrounds during the Ft McLellan surveying. Average Uranium counts for the test line are plotted against average Thorium, Potassium and Total Count channels – an example of which is shown in Figure 3-1 for Thorium versus Uranium. From this analysis, flights 2,3,17,20,24,27,29 and 30 in particular, are seen to have elevated average count rates in the Uranium window.

Figure 3-1



Examples of the corrections applied to the uranium window count rates for these flights are shown below, where the correction in U cps is plotted against the seconds of the flight.

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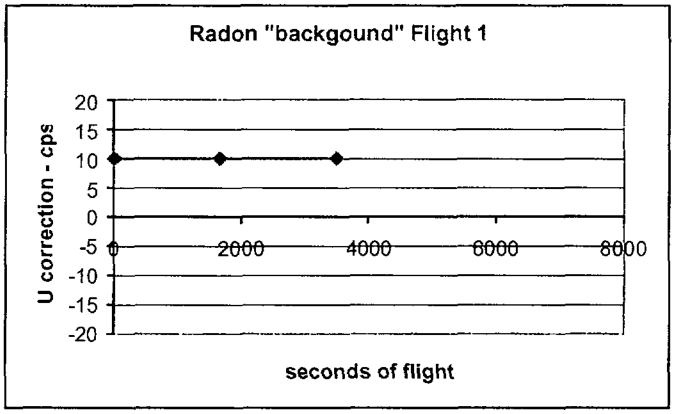
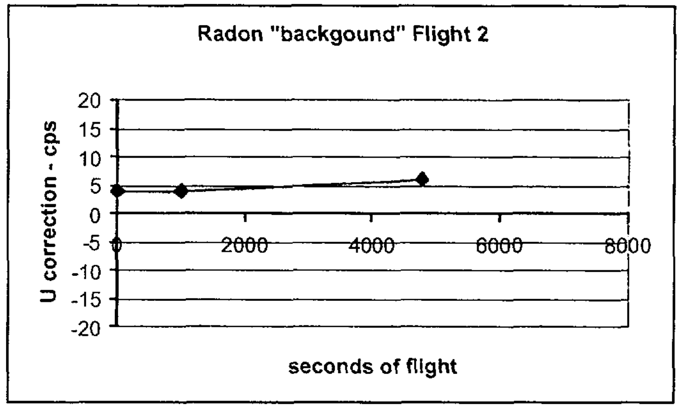
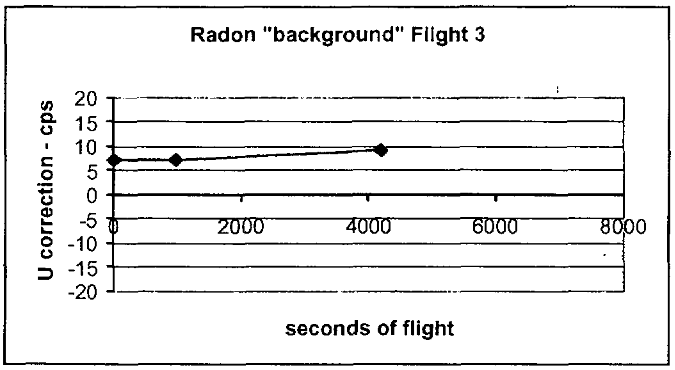
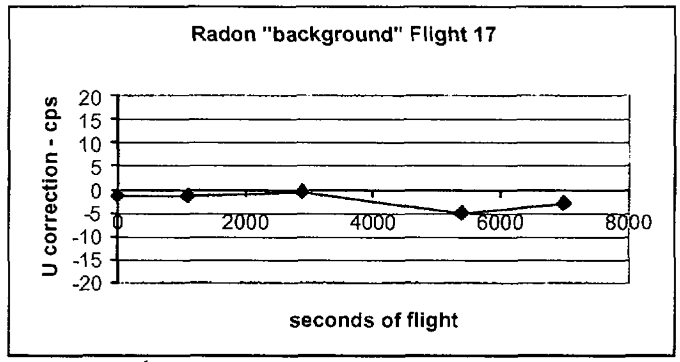
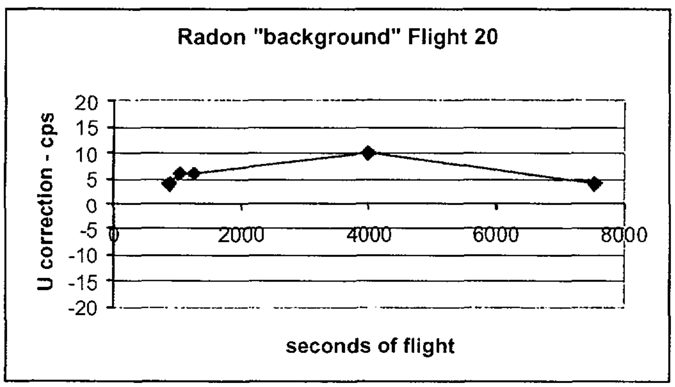
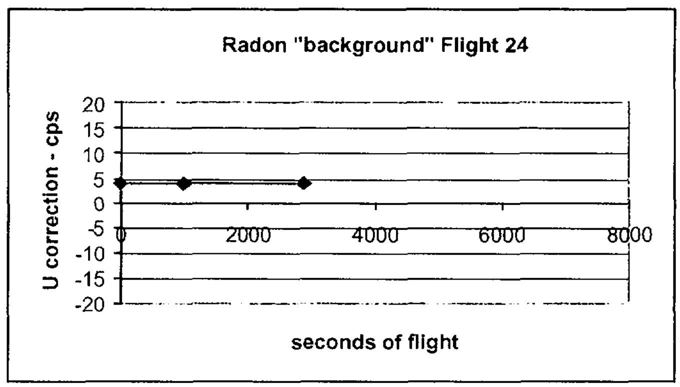


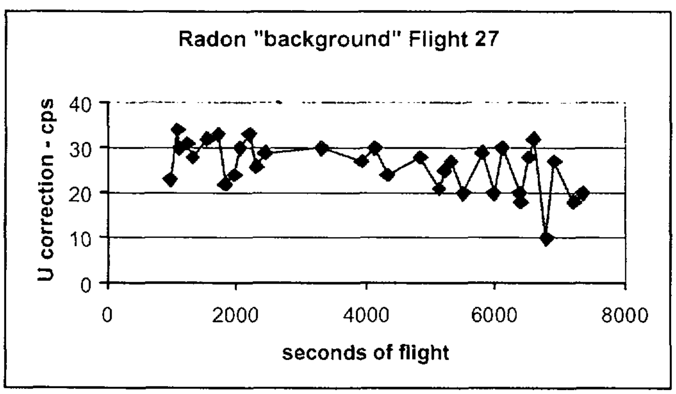


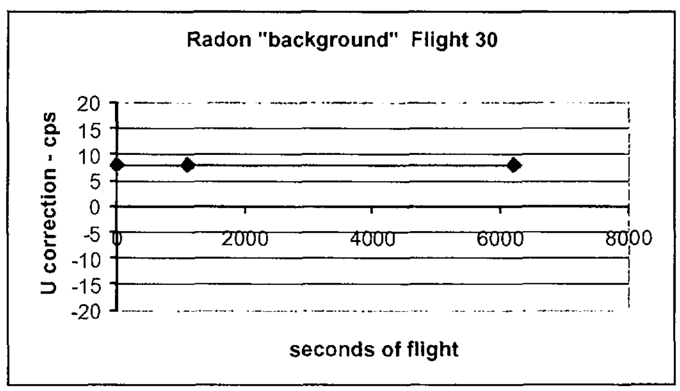






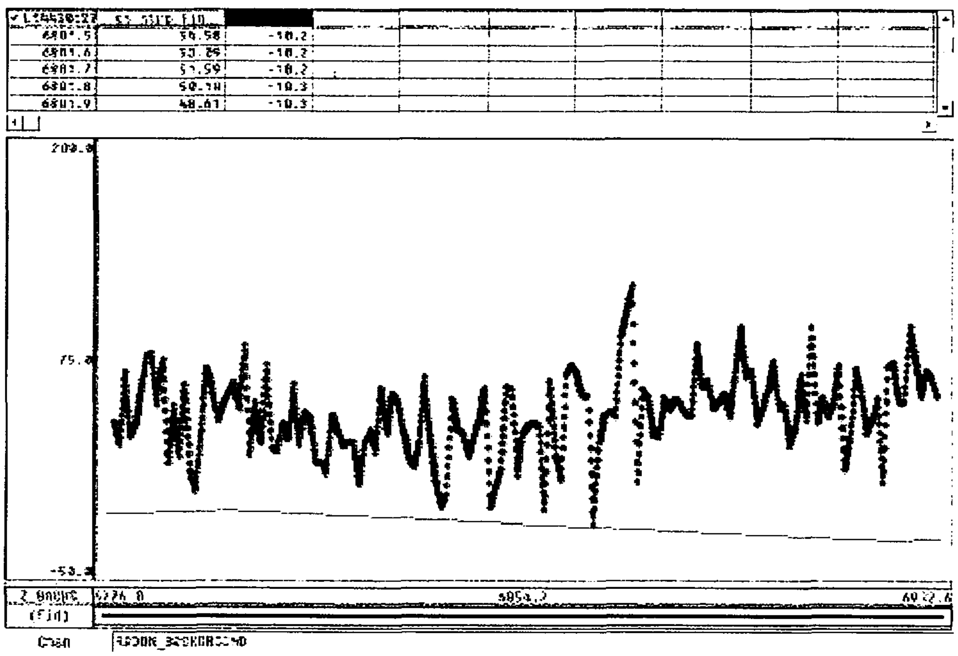




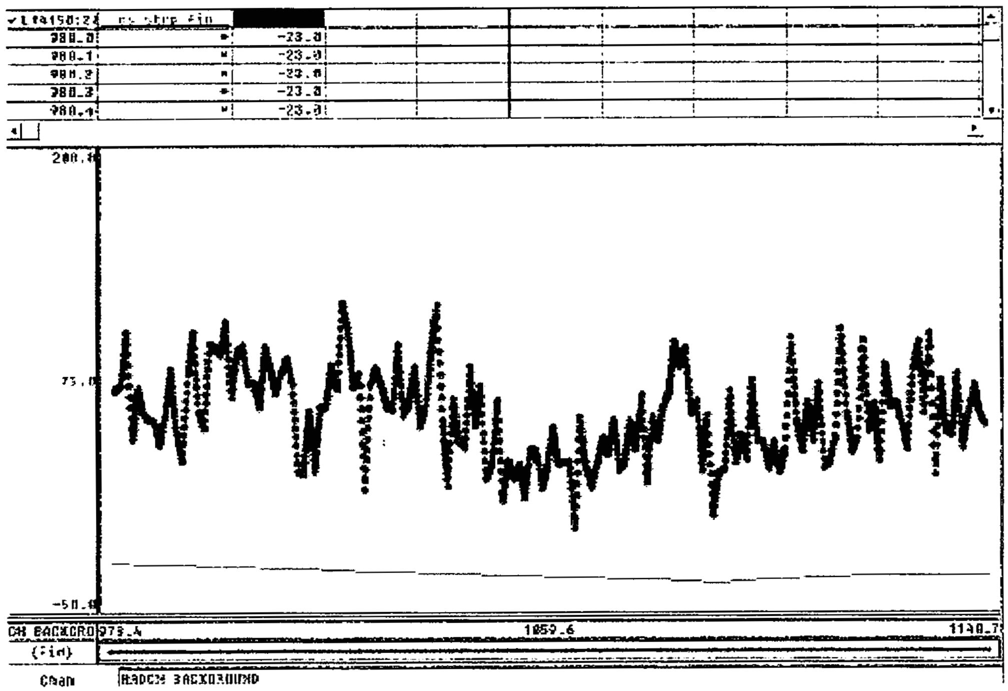


For all flights except flight 27, it can be seen that the removal of counts for the effects of radon will be a 0th order or 1st order correction for most survey lines. This relatively long "wavelength" of correction will not affect the identification of point source anomalies that are much more localized or short wavelength. Only the correction for flight 27 shows any significant short term variation which is probably due to higher "radon" at one side of the survey block, giving the correction the "zig-zag" appearance on the flight basis. In order to determine the potential effect of this on point source anomalies it is necessary to show this correction on a line-by-line basis. Examples of the most active corrections for two lines from flight 27 are shown below. The ^{137}Cs channel is shown in red and the radon "correction" to be applied to the Uranium channel is shown in blue. Both are measured in counts per second:

Line 14430



Line 14150



This technique for removal of radon "banding" improves the appearance of the Uranium grid but will affect the absolute background levels for the final ^{137}Cs and ^{60}Co channels through the stripping procedure described below. The wavelengths of the correction, however are sufficiently long that they will not affect the identification of any point source anomaly, which is the purpose of this airborne survey.

4. <u>Provide a reference or additional detail on the "stripping" technique in the Cs and Co windows</u>

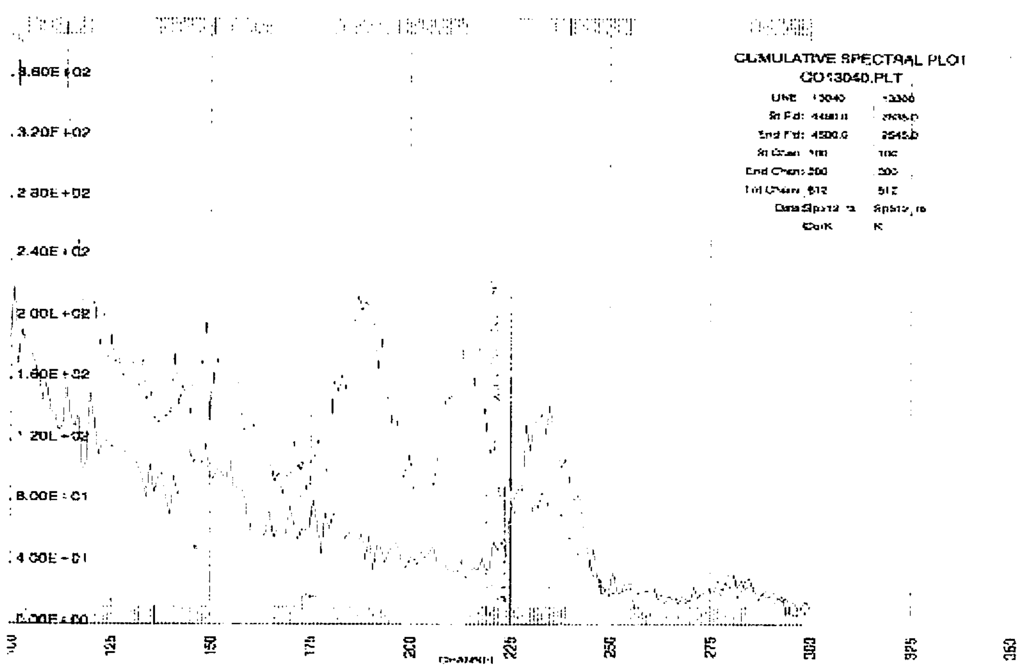
Spectral Stripping

Typically, airborne gamma-ray spectra can be considered the sum of three terrestrial and three background components. The terrestrial components originate in the earth's surface and contribute spectra from pure sources of potassium, uranium and thorium. The background components originate in the atmosphere and in the aircraft itself and produce the cosmic, radon and aircraft spectra.

Each spectral component has the same basic shape (the Compton continuum) except for its individual distinct peaks. Examples of these shapes are shown in Figures 3 through 6 in the paper "Airborne gamma-ray spectrometric background estimation using full spectrum analysis" by B.R.S. Minty, published in Geophysics, Vol 57, No 2, p 279-287. The shapes of all these spectra are combined into that measured by the spectrometer during airborne survey flight. When searching for point source anomalies of the type that were being pursued with this investigation, in effect we are looking for gamma-rays counts above the Compton continuum for these discrete photo-peaks.

In order to measure the count rates for ^{137}Cs and ^{60}Co, we effectively want to integrate the total area under the peak but above a localized straight line that represents the Compton continuum in the peak region. This continuum is made up of cosmic and aircraft spectra, radon spectra and the three terrestrial spectral components. In this investigation, the Cs and Co window data had the cosmic and aircraft background removed through the standard processing technique using the results of the cosmic/aircraft background test flight. The radon background has been estimated as per the procedure described above and contributes to the standard uranium window background. The localized straight line of the Compton in the region of the Cs or Co photopeaks, has been estimated through combination of the three terrestrial window count rates. The ^{40}K window overlaps the ^{60}Co energy window, so a significant ^{40}K anomaly could bias the estimate of the Compton "level" and result in an over or under estimation of the nearby Co peak. The overlap of this Co window is only 6 channels out of a total of 52 channels in a 512 channel spectrum which is approximately 11 percent of the window. An example of the spectral shapes is shown in the following figure, which shows the spectra from two lines for comparison. Line 13040 runs across the ^{60}Co anomaly in the centre of the Main Post grid. Line 13360 sits to the south and the section shown crosses an area with a relatively high, localized K count rate. It can be seen that the effect from the ^{40}K peak on the Co window is minimal and not likely to bias the local continuum level significantly. This effect is also unlikely to create point source anomalies, as the effect will mimic the typical terrestrial distribution of the potassium source. Experimental measurement of full spectral data from gamma-ray sources of known strength would allow estimation of the magnitude of this error, but is beyond the scope of this investigation. A similar situation exists for the ^{137}Cs peak that overlaps the ^{214}Bi peak.

<u>^{60}Co and ^{40}K Window overlap :</u>



5. <u>Provide information on the range of system sensitivities based on burial depth and the effect of biomass</u>

In considering the question of the effect of biomass on the attenuation corrections and the request for an estimation of system sensitivity based on burial depth, it seemed appropriate to address both these points through a discussion of minimum detectable target activity. With some reasonable assumptions about the survey environment in Anniston, Alabama, it is possible to create an estimate of the minimum detectable target activity for both ^{137}Cs and ^{60}Co for two variable conditions: forest cover, and target buried in soil.

The process for determining the probable target anomaly (in counts per second) for a radioactive source on surface, with no tree cover, is:

1. Estimate the minimum detectable anomalous counts per second rate, over the measured noise levels.
2. Correct the detected signal for the NaI detector thickness and probability of interaction and detection.
3. Determine, based on three-dimensional geometry, absorption in the air, and the detector size, the activity of a point source on the surface that would generate this number of gamma rays intersecting the surface area of the sodium-iodide detector crystals. This was done at altitudes from 10m to 30m in 5m steps. At this point the calculation indicates the number of gamma-rays that must be emitted from a source at surface to be detected.
4. Determine the activity of the source (in Curies or Becquerels) required to generate this minimum detectable anomaly, based on the nature of the decays and percentage of each type of decay emitting gamma rays in the energy window used to detect the radioelement.

The calculations to step 4 produce the minimum detectable point-source target, on surface, with no tree cover. The gamma-rays from such a target will be absorbed by any soil or vegetation cover overlying the target, reducing the anomaly. The absorption rate(s) can be used to calculate an increased point source activity necessary to generate the minimum detectable gamma ray anomaly through soil and trees, hence:

5. Calculate transmission rate through varying degrees of soil cover, and then calculate the increased minimum detectable target activity for depths from 0 to 18 cm, for each altitude.
6. Calculate absorption by biomass, for each target defined in step 5, to calculate new minimum detectable target with forest cover.

The equation used for steps 1 to 4 comes from IAEA publication "Airborne Gamma Ray Spectrometer Surveying", published in 1991. Equation 9.1 is:

$$N = \frac{BfAe^{-\mu H}}{4\pi H^2}$$ where

B is the activity of the source in Becquerels,

N is the number of gamma rays intersected per second
f is the fraction of disintegrations producing gamma rays
H is the altitude of the aircraft above the ground
μ is the linear attenuation in air of the gamma ray at the energy being considered, and
A is the cross section area of the detector.

What this equation does not consider is the probability *P* of detection by the spectrometer. If this probability is included, and the equation rearranged to calculate B_C, the source activity in μCuries:

$$B_C = \frac{N 4 \pi H^2}{3.7e4 \times P f A e^{-\mu H}}$$

The numbers for the probability of detection were derived from Figure 10.6 in Telford et al (1976). Figure 10.6 graphs the absorption (and detection) efficiency for 1.5" and 3" NaI crystals. This was extrapolated to the 10 cm (4") crystals used in this survey.

Once the number of counts per second for a source on surface with no forest cover is determined, estimations can be made for the absorption, and hence reduction in signal, due to the soil cover and tree cover. For the depth of burial estimation actual soil type measurements are not available, so we have to assume the density and geological composition of the soil, including water content. It is assumed that the forest cover is also highly variable, but the actual cover was not measured, so again an average "biomass", in tons per hectare was assumed. Once soil conditions or the biomass have been assumed, then calculations can be performed for any altitude. The effect of altitude does not change with changing biomass – the helicopter is always above the trees, so the absorption effect enters the calculation as a reduction in the number of gamma rays emitted.

For either soil or trees, the absorption is calculated from the equation for absorption in matter, or:

$$I(x) / I_0 = e^{-\nu \rho x}$$

where I_0 is the initial intensity, I(x) is the intensity after a path length x, ρ is the mass density of the matter, and ν is the mass attenuation coefficient (Handbook of Chemistry and Physics, pg 10-246). The relationship between mass attenuation coefficient and linear attenuation coefficient is

$$\upsilon = \mu / \rho$$

The CRC Handbook of Chemistry and Physics (pg 10-246) states that: "To a high approximation the mass attenuation coefficient is highly additive for the elements present, independent of the way they are bound in chemical compounds." For biomass, which is composed chiefly of cellulose and similar chains of starch/sugar molecules, a suitable approximation of the chemical composition is that of the basic glucose molecule $C_6H_{12}O_6$. This chemical composition was used to calculate the attenuation coefficient of the biomass, based on an assumed average density of 0.6 g/ml. The density is a rough average of the densities of wood given on page 15-28 of the Handbook of Chemistry and Physics. The water in the wood was not estimated or factored in. The chemical composition of water (H_2O) is sufficiently similar to wood that the mass attenuation coefficient will be in the same order. Variations in wood density and tree cover create much greater variations in the attenuation coefficient than any error in the effect of the water content

The "average" biomass in Alabama (reported by sources John Kush at Auburn University) was reported to be approximately 115 t/ha. At a density of 0.6, this is equivalent to an average thickness (assuming the 115t is spread evenly over the 100m x 100m of a hectare) of 1.9cm. This density and thickness was used to calculate the absorption of the biomass.

The chemical composition and density of soil is much more variable than that of wood. The soil will have varying fractions of mineral sand and clay, humus, water, and air. For the purposes of this study, the soil was assumed to be composed of 60% mineral, 20% water, and 20% air, which would have a density of approximately 1.8 (assuming the mineral density to be the average density of continental rock, at 2.7 g/ml). The mass attenuation coefficients used for rock and water comes from table 10B.1 on page 148 in Grasty (1979). The mass attenuation was summed for the volume percent and densities of each component of the soil described above to calculate a bulk mass attenuation coefficient for the soil, at a density of 1.82g/ml.

Another variable factor is the definition of "detectable anomaly". Whether an anomaly is detectable depends on the anomaly strength and shape relative to the local noise and geological variation background, as well as on the skill of the interpreter. A standard geophysical definition of a detectable anomaly is a signal level at least three times the noise level. The average noise level was measured from the data collected for each radioisotope energy over the survey area.

The results of the calculations are shown below in four tables for each element: ^{137}Cs and ^{60}Co. Table Xx-1 (where Xx is the element in question) lists the parameters for each element used for each calculation, as described above. Table Xx-2 lists the minimum detectable source (on surface, no tree cover) for sensor altitudes between 10m and 30m. Table Xx-3 shows, for a range of burial depths in centimetres, the transmission coefficients and from that the (increased) minimum detectable source activity. Table Xx-4 takes the minimum detectable buried target values, and recalculates the minima assuming tree cover.

The gamma-ray spectrometry detector was 50 litres of Tl-doped NaI crystals. The three crystal packs used had a thickness of 10cm, and a bottom surface area of 0.5 m^2.

Cesium Calculations:

Table Cs-1		
Gamma Ray Energy	MeV	0.66
Fraction of Decays	%	100%
Air LAC[1]	m	0.01
Wood MAC[1]	cm^2/g	0.0828
NaI Prob		0.06
Soil MAC	cm^2/g	0.078
Detection Limit	counts/s	45

1. LAC = Linear Attenuation Coefficient, MAC = Mass Attenuation Coefficient

Table Cs-2. Calculating Point Source Activity						
Energy	MeV	0.66	0.66	0.66	0.66	0.66
Anomaly	CPS	45	45	45	45	45

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Altitude	m	15.2	20.2	25.2	30.2	35.2
Volume	l	50	50	50	50	50
LAC Air	1/m	0.01	0.01	0.01	0.01	0.01
Probability		0.55	0.55	0.55	0.55	0.55
Source	uCi	14.9	27.8	45.4	68.6	97.9

Table Cs-3. Minimum Detectable Source in uCi, through Soil

Depth of Burial cm	Trans	Altitude m 10	15	20	25	30
0	1.000	15	28	45	69	98
2	0.753	20	37	60	91	130
4	0.567	26	49	80	121	173
6	0.427	35	65	106	161	229
8	0.321	47	86	141	213	305
10	0.242	62	115	188	284	405
12	0.182	82	152	249	377	538
14	0.137	109	203	331	500	714
16	0.103	145	269	440	665	949
18	0.078	192	357	585	883	1261

Table Cs-4, Minimum Detectable over Tree Cover.

Depth of Burial cm	Altitude 10	15	20	25	30
0	17	31	50	76	108
2	22	41	67	101	144
4	29	54	88	134	191
6	39	72	118	177	253
8	51	95	156	236	337
10	68	127	207	313	447
12	91	168	275	416	594
14	120	224	366	553	789
16	160	297	486	734	1048
18	213	395	646	975	1392

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Cobalt Calculations

Table Co-1		
Gamma Ray Energy[1]	MeV	1.25
Fraction of Decays	%	85%
Air LAC[2]	m	0.00737
Wood MAC[2]	cm^2/g	0.0612
NaI Prob		0.037
Soil MAC	cm^2/g	0.058
Detection Limit	counts/s	20

1 ^{60}Co emits two gamma rays with each decay, at 1.173 and 1.332 MeV. An average energy of the two photons was used to calculate the attenuation coefficients

LAC = Linear Attenuation Coefficient, MAC = Mass Attenuation Coefficient

Table Co-2. Calculating Point Source Activity						
Energy	MeV	1.20	1.20	1.20	1.20	1.20
Anomaly	CPS	20	20	20	20	20
Altitude	M	10	15	20	25	30
Volume	l	50	50	50	50	50
LAC Air	1/m	0.00737	0.00737	0.00737	0.00737	0.00737
Probability		0.4	0.4	0.4	0.4	0.4
Source	uCi	4.3	10.0	18.5	30.0	44.9

Table Co-3. Minimum Detectable Source uCi, through Soil						
Depth of Burial cm	Transmission Fraction	Altitude m				
		10	15	20	25	30
0	1.000	4	10	19	30	45
2	0.810	5	12	23	37	55
4	0.656	7	15	28	46	68
6	0.531	8	19	35	57	85
8	0.430	10	23	43	70	104
10	0.348	12	29	53	86	129
12	0.282	15	36	66	107	159
14	0.228	19	44	81	132	197
16	0.185	23	54	100	163	243
18	0.150	29	67	124	201	300

ATTACHMENT 2

RADIOLOGICAL EVALUATION OF THE PELHAM RANGE P4 ANOMALY AT FORT McCLELLAN, ALABAMA

Radiological Evaluation of the Pelham Range P4 Anomaly Fort McClellan, Alabama

1.0 Executive Summary

Two areas on the Main Post and ten areas on Pelham Range at Ft. McClellan, Alabama were identified for further investigation based on the results of an airborne radiological survey. Upon further investigation, one of the Main Post areas, or anomalies, was found to be an area of cesium-137 contamination and has been secured pending remediation. Two of the areas on Pelham Range were discovered to be a radioactive waste site that was undergoing remediation at the time of the airborne survey. The remaining anomalies (one on the Main Post and eight on Pelham Range) were investigated using a portable gamma survey meter and a portable gamma spectrometer. Only naturally occurring radionuclides were identified at these anomalies and observed variations in exposure rates were attributed to the geological makeup of the soils with shale outcroppings having higher exposure rates than clay soils and clay soils having higher exposure rates than sandy soils. However, one of the anomalies (identified as P4) exhibited significantly higher area exposure rates than the others and the U.S. Nuclear Regulatory Commission (NRC) has requested additional justification to support the conclusion that the observed exposure rate is due to naturally occurring radioactive materials in the shale outcropping.

To support this conclusion Shaw reviewed the gamma spectra collected at the P4 anomaly, performed a geological evaluation of the P4 shale outcropping, performed a screening analysis of a specimen of the shale, and calculated external exposure rates that would be expected from the radioactivity in the shale. The physical characteristics of the shale and the estimated activity are similar to that of the uraniferous black shale in an adjacent county and the calculated exposure rates are consistent with those observed at the P4 site. It is concluded that the elevated readings at the P4 anomaly are due to naturally occurring radioactive materials.

2.0 Background

Aerial surveys of the Pelham Range and Main Post areas at Ft. McClellan were performed by Fugro Airborne Surveys (Fugro) under contract to Shaw E&I, Inc. (Shaw, formerly IT Corporation). The surveys were performed to verify that there were no areas of contamination that had not been addressed in previous investigation or remediation activities. The surveys identified three cesium-137 (Cs-137) and cobalt-60 (Co-60) sources including one on the Main Post (M1) and two on Pelham Range (P1 and P2). The survey also identified four other anomalies for additional investigation. These anomalies included three on Pelham Range (P3, P4, P5) and one on the Main Post (M2). The anomalies were selected based on historical land use and/or proximity to roads used to transport supplies and equipment during the time radiological training activities were conducted on the base. Fugro selected anomaly P-4 for further investigation because of the relatively high total exposure rate and because of historical land use. P-4 also had a coincident Co-60 high but the Co-60 counts were not above the "noise" in the spectrum. Further analysis of the spectrum indicated that the relatively high total exposure rate at anomaly P4 appeared to be due to natural uranium and potassium.

Anomalies P1 and P2 were found to be a radioactive waste site that was undergoing remediation concurrent with the airborne survey. This waste site contained Co-60 and Cs-137 sources that had been used for training exercises. Remediation of the site has been completed and a final status survey has been submitted to and accepted by the NRC.

Anomaly M1 on the Main Post was found to contain Cs-137. This material is believed to be from operations conducted by the Army in the early 1950s. The M1 anomaly has been secured and will be remediated consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

In addition to the sources and anomalies identified by Fugro, five additional anomalies or artifacts (P6-P10) were selected for investigation by Shaw based on the airborne survey and historical land use. The Main Post anomalies are shown on Figure 1 and the Pelham Range anomalies are shown on Figure 2.

3.0 Anomaly Investigation

Shaw conducted an investigation of anomalies P3 through P10 and M2 using a Ludlum 2221/44-10 sodium iodide (NaI) detector, a Ludlum Model 19 microR meter, and an Exploranium GR-135 portable gamma spectrometer. Each anomaly was located and flagged from the coordinates of the airborne survey. The Ludlum 2221/44-10 was used to survey the area surrounding the flags to identify the areas with the highest count rate. At these locations, surface and 1-meter high exposure rates were measured with the microR meter and a 30-minute spectrum was collected with the portable gamma spectrometer on the surface.

Surface exposure rates ranged from 8 to 42 microroentgens per hour (μR/hr) with the higher exposure rates being associated with extensive visible shale outcroppings at anomaly P4 (see Figure 3). One-meter exposure rates ranged from 5 to 21 μR/hr, again, with the higher exposure rates recorded at the P4 anomaly.

The portable gamma spectrometer was used to collect spectra at each of the anomalies (P3 through P10 and M2). The only radionuclides identified with the portable gamma spectrometer were uranium series and potassium-40 (K-40). A gamma spectrum collected at P4 is shown as Figure 4. As can be seen in Figure 4 only radium-226 (Ra-226) and K-40 were identified in the spectrum. Ra-226 is in the uranium series and is identified by the 352 kiloelectron volt (keV) gamma from Pb-214 and the 609 keV gamma from Bi-214, daughter products of Ra-226.

Results from a soil sample collected at the P4 anomaly by an inspector from the Alabama Department of Public Health, Division of Radiation Control showed naturally occurring radioactive materials from the uranium, thorium, and actinium series and K-40. A specimen from the P4 anomaly shale outcropping was collected and sent to the Shaw Knoxville office for inspection by a geologist. A portion of this specimen was subsequently taken to the Shaw Technology Development Laboratory (Shaw TDL) for screening by gamma spectroscopy. The purpose of the screening was to determine if gamma-emitting radionuclides were present other than those that are naturally occurring. Screening also provided a rough estimate of the activity of the shale for use in exposure rate calculations. The sample was crushed, placed in a Marinelli beaker, and sealed to allow in growth of short-lived progeny. The sample was screened by gamma spectroscopy 40 days after sealing. Only naturally occurring uranium, thorium, and actinium series radionuclides and K-40 were identified in the sample. Uranium-238 (U-238) activity was estimated to be approximately 13.8 picocuries per gram (pCi/g) based on the low-energy gamma rays from Th-234.

4.0 Exposure Rate Survey

Surface and 1-meter exposure rates were measured at the P4 anomaly. The surface exposure rate measured with the Ludlum Model 19 was 42 μR/hr while the 1-meter exposure rate was 21 μR/hr. Since the exposure rates were significantly higher than those measured at other shale outcroppings at Pelham Range and since there was a significant difference in the surface and 1-meter readings not observed at the other anomalies, the NRC has requested additional clarification to support the conclusion that the elevated readings are due to naturally occurring radionuclides in the shale outcropping. To this end, the External Radiation Dose Calculator located at the WISE Uranium Site[1] was used to estimate the external dose rate that would be expected from the radionuclide concentrations found in the specimen of shale from the P4 anomaly. This calculator can be used to provide a rough estimate of the external dose rates for a number of common materials and compositions of natural radionuclides or a custom mix of elements and radionuclides can be entered. Results from the sample screening conducted at the Shaw TDL were used as input into the External Radiation Dose Calculator. Exposure rates were calculated at the centerline of detector placed on the surface and a 1-meter height. The calculated exposure rates of 53 and 18 μR/hr are in reasonable agreement with the measured exposure rates of 42 and 21 μR/hr for surface and 1-meter height, respectively at the P4 anomaly.

5.0 Geological Evaluation

The shale that outcrops at the P4 anomaly in Calhoun County, Alabama is identified as the Athens Shale; the Athens Shale is assigned an age of Middle to Upper Ordovician. The Athens consists of dark gray to black laminated carbonaceous shale containing in the lower part interbeds of argillaceous dark-gray to black carbonate mudstone. Fossils are rare with the exception in several localities where graptolite fossils are preserved as thin carbon films on bedding planes (Rheams, 1992). The dark color, fine laminations and lack of appreciable fauna suggest the Athens is a basinal deep-water marine deposit.

Most black shale is actually dark gray or grayish black; dark hues of brown and olive are not uncommon. The dark color of most black shale is imparted largely by disseminated carbonaceous material. It has been suggested that only carbonaceous shale containing 2 or more percent organic carbon by weight should be classed as a black shale (Swanson, 1961). The Chattanooga shale is a black shale of Late Devonian and early Mississippian age that occurs in outcrops extending from Kentucky, Tennessee, Georgia, and Alabama. The Chattanooga shale has a content of organic matter that ranges from less than 1 percent to greater than 25 percent. Analysis of four shale samples from the Athens Shale in Bibb and Shelby County, Alabama range from 0.35 to 1.12 percent total organic carbon (Benson and Mink, 1983).

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[1] World Information Service on Energy Uranium Project (http://www.antenna.nl/wise/uranium/)

5.1 Uranium Content in Black Shales

The origin of uranium in shale is a complex subject and is not completely understood. The uranium in marine black shales may be localized and incorporated in several ways. The materials involved include resistates (e.g., zircon, biotite), clay particles by ionic substitution, vegetal material by adsorption (e.g., on land plants, marine algae), phosphatic material (e.g., phosphatic layers or nodules by ionic substitution), and hydrogen sulfide (represented indirectly by iron sulfide minerals). Of these five types of materials, the vegetal and the phosphatic materials probably account for 90 percent of the total amount of uranium (Swanson, 1961b).

The average uranium content of shales is estimated to be between 3 to 4 parts per million (ppm) (Mason and Moore, 1982, Swanson, 1961a). Black or carbonaceous shales have a uranium content that generally ranges from 1 to 100 ppm, to in excess of 1,000 ppm; very few, however, contain more than 50 ppm. Swanson (1961a) estimates that the average of all carbonaceous shales is probably about 8 ppm. On a worldwide basis elevated levels of uranium are found in black shales ranging in age from Late Cambrian to organic rich marine muds of Recent age. In the United States most uraniferous black shales are of Paleozoic age (Swanson, 1956). Among the radioactive black marine shales that have been studied in the United States, the Chattanooga is best known.

5.2 Comparison of P4 Anomaly to Uranium in Chattanooga Shale

At the P4 anomaly outcrop, samples of the Athens shale are moderately weathered and are a yellowish-brown color. The affect of weathering, evidenced by oxidation and color changes of the organic material, is not anticipated to decrease uranium content. To the contrary, data suggests that weathering of a shale may actually increase its uranium content. An increase in radioactivity and uranium content with degree of weathering is reported from a faulted and moderate to intensely weathered section of the Chattanooga shale from DeKalb County, Alabama (Glover, 1959). Over a 6-foot interval of faulted, intensely weathered shale, field-scintillation-counter readings rose from an average of 0.10 milliroentgen per hour (mR/hr) to around 0.20 mR/hr, peaked at 0.50 mR/hr before decreasing to approximately 0.15 mR/hr. The uranium content showed a corresponding increase across the weathered zone from a background of 40 ppm, to 70 – 90 ppm, and back down to 40 ppm.

Table 1 presents data on the uranium content of 104 shale samples of the Chattanooga shale from six counties adjacent to Calhoun County (Rheams and Neathery, 1988). Also shown is the estimated uranium concentration of 13.8 pCi/g of uranium-238, based on thorium-234 activity, calculated for the Athens Shale at the P4 anomaly. This value is below the high-end range of values obtained for the Chattanooga shale from all but one of the adjacent counties, and is slightly below the average value obtained for Etowah County, the county closest to the P4 anomaly.

5.3 Conclusion of Geological Evaluation

The lithology, black color, and organic content of the Athens Shale are similar to that of the uraniferous black shale of the Chattanooga. The estimated uranium content of the Athens Shale, 13.8 pCi/g, is not significantly higher than the average uranium content estimated for black shales worldwide. Further, the calculated uranium content is below the high-end of uranium values obtained from the Chattanooga shale in all but one of the nearby counties in Alabama to the P4 anomaly. In addition, the value calculated is below the average of uranium values obtained from 46 Chattanooga shale samples in adjacent Etowah County. Based on the above data, it is concluded that the radioactivity observed at the P4 anomaly is consistent with the interpretation that it is produced from naturally occurring radioactive material in the Athens Shale.

Table 1. Uranium Content of Athens Shale at P4 Anomaly, Calhoun County, Alabama and Uranium Content of Chattanooga Shale, Adjacent Alabama Counties

Location	Shale Fm	Geologic Age	No of Samples With Uranium Detected (> 0 ppm)	Range of Values (ppm)	Range of Values (pCi/g[b])	Average of Uranium Values (ppm)	Average of Uranium Values (pCi/g[b])
Blount Co, AL	Chattanoga Sh	Devonian	14	1.8 - 18[a]	1.2 - 12.2	13.9	9.5
Cherokee Co, AL	Chattanoga Sh	Devonian	26	1.6 - 88[a]	1.1 - 59.8	11.41	7.8
Etowah Co, AL	Chattanoga Sh	Devonian	46	3.9 - 37.5[a]	2.7 - 25.5	20.4	13.9
Jefferson Co, AL	Chattanoga Sh	Devonian	5	1 - 43[a]	0.68 - 29.2	14	9.5
St. Clair Co, AL	Chattanoga Sh	Devonian	12	12 - 27[a]	8.2 - 18.4	17.4	11.8
Tuscaloosa Co, AL	Chattanoga Sh	Devonian	3	1.7 - 3.5[a]	1.2 - 2.4	2	1.4
Calhoun Co, AL	P4 Anomaly Athens Shale	Ordovician	1	n.a.	n.a	n.a.	13.8[c]

[a] - Uranium values for the Chattanooga Shale, Alabama (modified from Rheams and Neathery, 1988), in Mineral Resources of the Valley and Ridge Province, Alabama, Geol. Survey of Alabama, Bulletin 147, 1992

[b] - Conversion of concentration of natural uranium, with fixed abundance of the three major isotopes, from ppm to pCi/g is possible using the conversion factor 0.68 pCi/g (EPA, 1991), in Agency for Toxic Substances and Disease Registry, Toxicological Profile for Uranium, September,1999

[c] - Uranium concentration is based on Th-234 activity

6.0 Conclusion

The investigation of the Ft. McClellan P4 anomaly consisted of exposure rate measurements and in-situ gamma spectroscopy, gamma spectroscopy analysis of a shale sample by the Alabama Division of Radiation Control, geological evaluation of the shale outcropping, gamma spectroscopy screening of a shale specimen at the Shaw TDL, and comparison of calculated and measured exposure rates at the P4 anomaly.

Only naturally occurring radioactive materials from the uranium, thorium, and actinium series and K-40 were identified by the in-situ and ex-situ gamma spectroscopy. The physical characteristics and radioactivity of the shale are similar to that of the uraniferous black shale in nearby counties and the calculated exposure rate is consistent with the exposure rates measured at the P4 anomaly. Based on these findings it can be concluded that the radiological characteristics of the P4 anomaly are due to naturally occurring radioactive materials.

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Table Co-4, Minimum Detectable over Tree Cover.					
Depth of Burial cm	Altitude m				
	10	15	20	25	30
0	5	11	20	32	48
2	6	13	25	40	60
4	7	16	30	49	74
6	9	20	38	61	91
8	11	25	46	75	112
10	13	31	57	93	139
12	16	38	71	115	171
14	20	47	87	142	212
16	25	59	108	175	261
18	31	72	133	216	323

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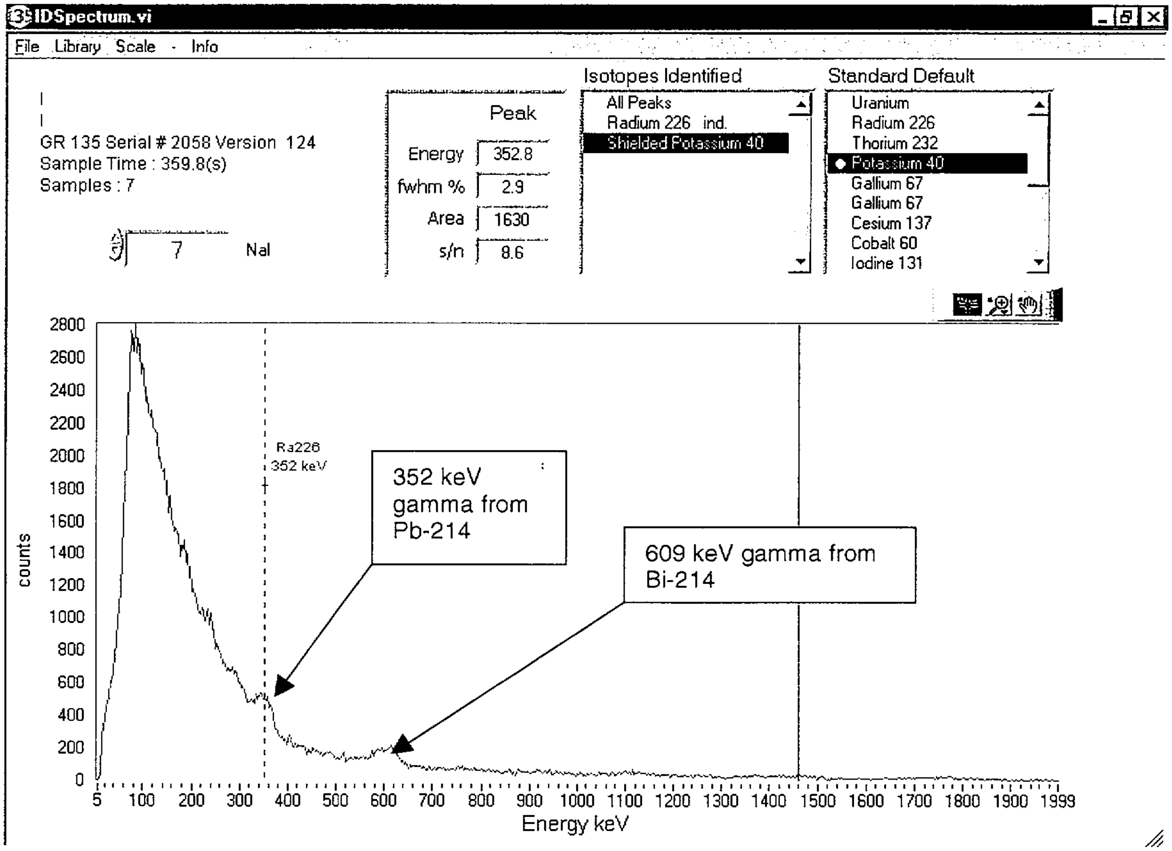
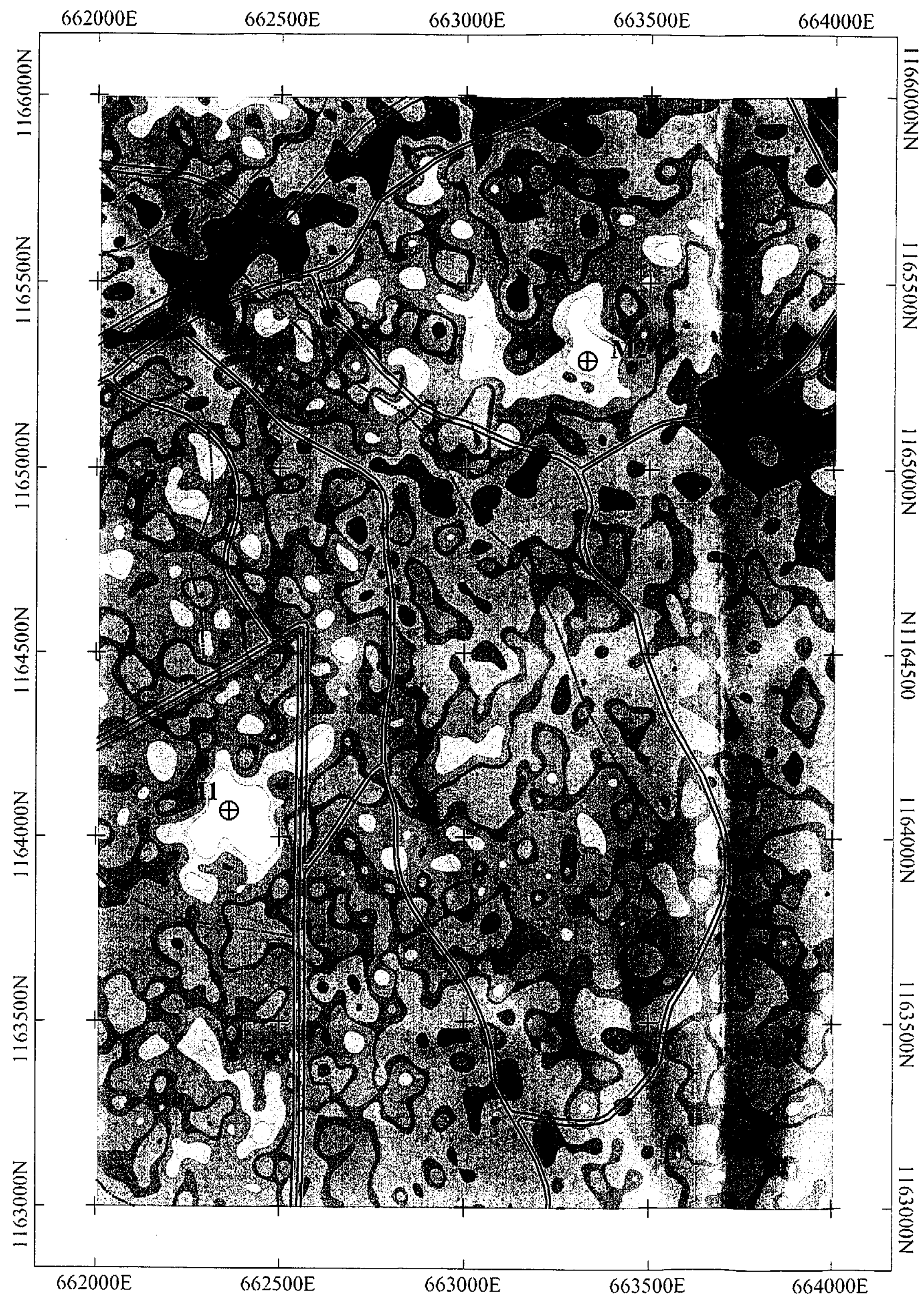
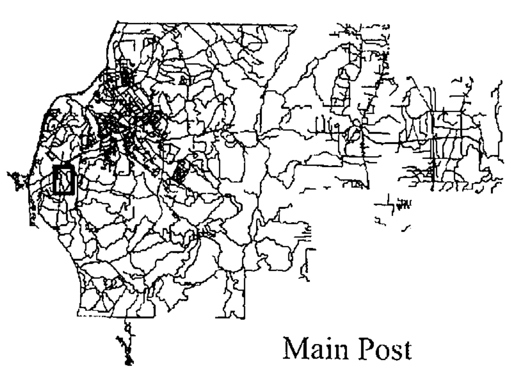
Figure 3. Fort McClellan Pelham Range P4 Anomaly – Shale Outcropping

Figure 4. Spectrum Collected at Fort McClellan, Pelham Range Anomaly P4 with an Exploranium GR-135







LEGEND

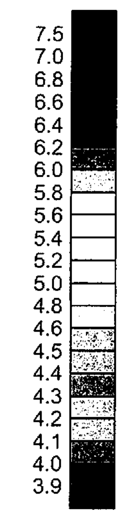
⊕ Follow-up Survey Location

——— Road

—·—·— River

——— Main Post Boundary

Note: Coordinate System is NAD83, Alabama East State Plane.



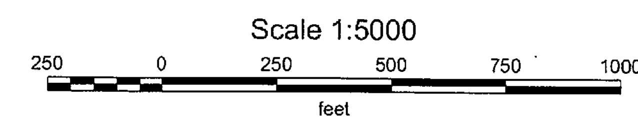
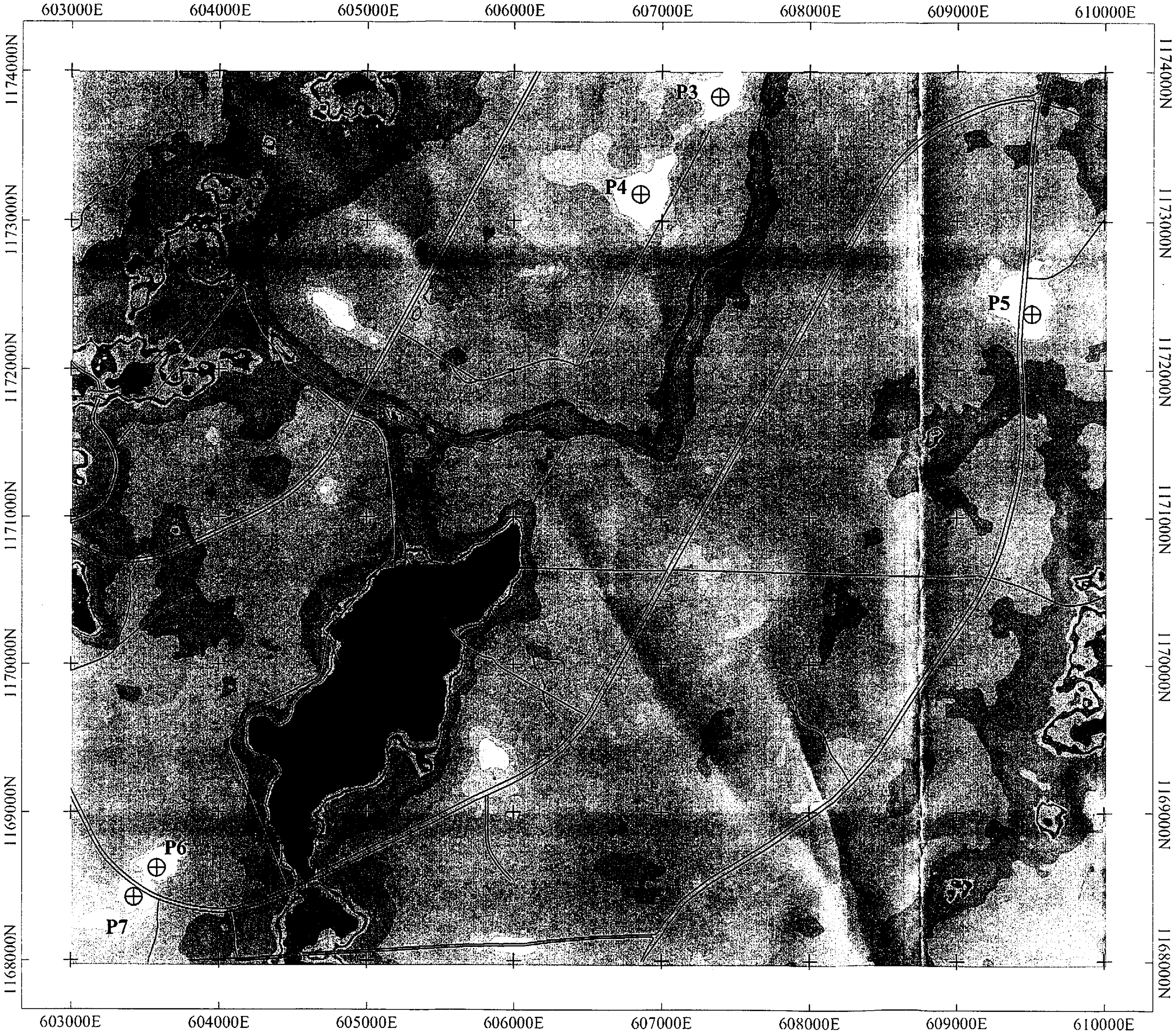


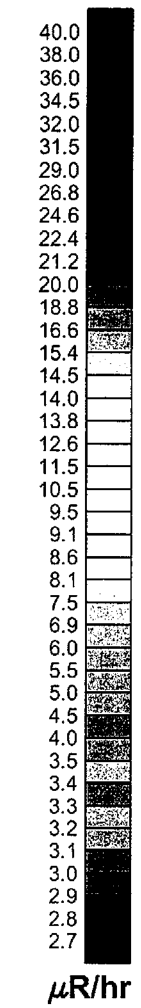
FIGURE 1

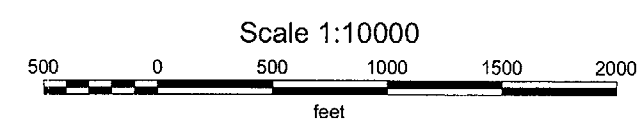
MAIN POST ANOMALIES
MAIN POST
FORT McCLELLAN

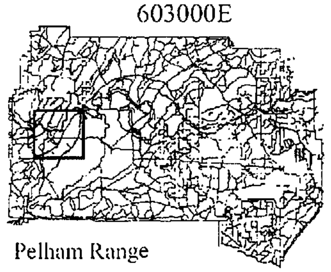
AIRBORNE LOW ENERGY/ HIGH ENERGY RATIO DATA

U.S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT
FORT McCLELLAN
CALHOUN COUNTY, ALABAMA
Contract No. DACA21-96-D-0018









LEGEND

⊕ Follow-up Survey Location

——— Road

—·—·— River

Note: Coordinate System is NAD83, Alabama East State Plane.

FIGURE 2

PELHAM RANGE ANOMALIES
PELHAM RANGE
FORT McCLELLAN

AIRBORNE TOTAL EXPOSURE RATE DATA

U.S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT
FORT McCLELLAN
CALHOUN COUNTY, ALABAMA
Contract No. DACA21-96-D-0018