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RESULTS OF A MAGNETOMETRY SURVEY AT TA-50, MDA C

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LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NM

TA-50 MDA "C"

January 1995

DRAFT

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TA-50 MDA C
MAGNETOMETER TOWED ARRAY SURVEY

The Naval Research Laboratory (NRL) in conjunction with The Sandia National Laboratory (SNL) and with contractor support by Geo-Centers, Inc. (GCI), Applied Research Corporation (ARC) and Hughes Associates, conducted a towed magnetometer survey/demonstration at The Los Alamos National Laboratory (LANL) on 20-25 August 1994. On 22-23 August, surveying was conducted at TA-50, MDA C, and on 24-25 August, TA-73, known as the Airport Landfill was surveyed. This demonstration/survey was conducted in support of the Department of Energy (DOE) Mixed Waste Landfill Integrated Demonstration (MWLID) program currently on-going at SNL. The purpose of this survey/demonstration was threefold; first to provide information relative to positioning of monitoring wells and boreholes, next to evaluate the Multi-sensor Towed Array detection System (***MTADS***) sub-system components when used in a Hazardous, Toxic and Radioactive Waste (HTRW) environment and lastly to demonstrate the systems capability at a potential users site.

This is the third cooperative survey conducted jointly by NRL and SNL as a joint DOD and DOE program. In December, 1991 demonstration surveys were conducted at sites TA-2 and TA-3 at SNL.[1] In September, 1993 site RB-11 at The Kirtland Air Force Base was evaluated.[2] In August, 1994 the sites TA-73, Airport Landfill and TA-50, MDA C at LANL were chosen for demonstration surveys.

The MDA C site is an 11.8 acre area, fenced into three sections with three separate entrance gates. Figure 1 shows an aerial photograph of the site. On this image we have outlined and highlited in white the fence lines around and internal to the site. The white stripes at the edge of Pajarito Road are marked in black. This outline mask is used later in conjunction with magnetometry image maps. The MDA C site is relatively flat except for a slope in the northeast, which rolls downward toward the Ten Site Canyon. The east and west areas are posted as sites containing radioactive materials. The western section also contains a chemical disposal site. The middle (southwest) section was not posted, but is also fenced. The east section (Section 1) contains 5 burial pits and 108 shafts for the disposal of hazardous waste. The west section (Section 2) contains 2 burial pits, including one designated as a chemical disposal pit. The middle section (Section 3) is not reported to contain any hazardous materials. Limited access to the site is controlled by LANL at all times. LANL's 8 hour hazardous materials training is required to work on site, as is the 40 hour EPA Hazwoper training course. The Personnel Protective Equipment (PPE) level required for site entry was level "D," based on previous chemical and radiation hand surveys. A Radiation Control Technical (RCT) was required to monitor all workers, when leaving each section and to swipe and analyze samples from the equipment used to conduct the site survey.

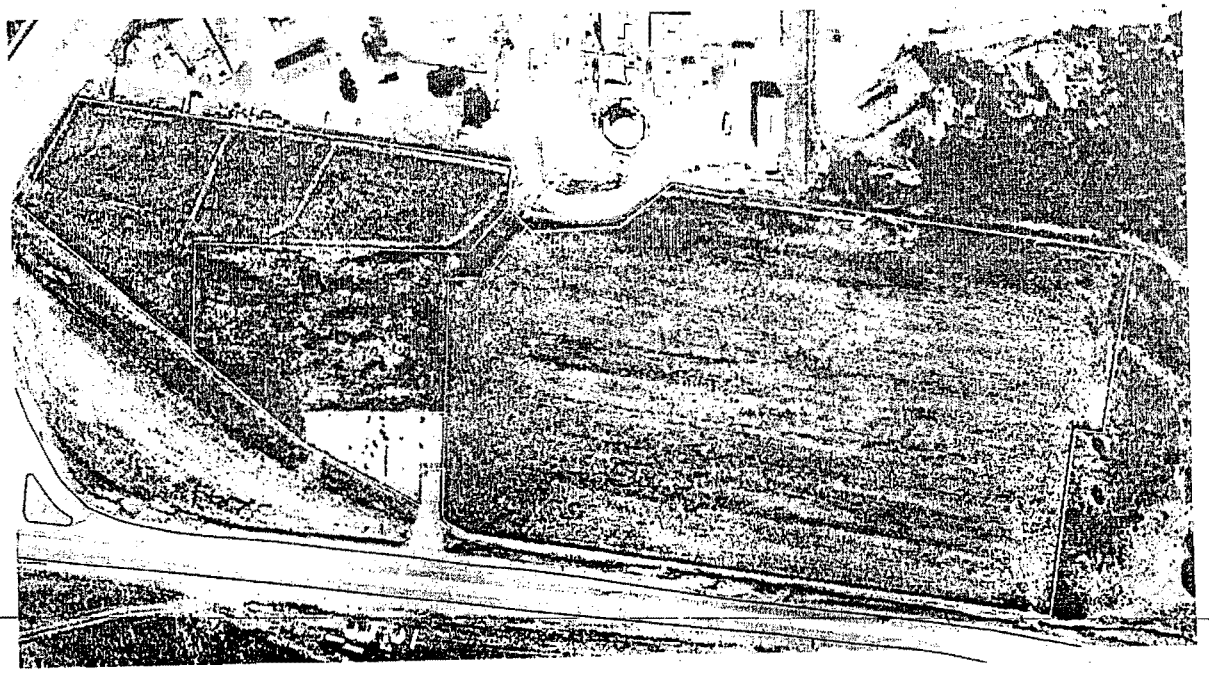

Figure 1. Los Alamos National Laboratory, TA-50, MDA C Aerial Photograph.

The ***MTADS*** survey system operated without any significant problems during the LANL surveys. Preliminary data analyses were performed to determine the validity of the data and to create preliminary magnetic image maps for on site inspection and demonstrations. This report contains the final results of the TA-50, MDA C field survey. Results of the TA-73, Airport Landfill Survey are reported in a separate document.[3]

Background

The MDA C Landfill[4] was established in May, 1948 as a replacement for Area "B" at TA-21. The completely fenced site covers 11.8 acres, and reportedly contains 7 pits, 107 numbered shafts and 1 unnumbered shaft that was used for a single strontium-90 disposal. The landfill was used from May 1948 until April 1974 but received waste only intermittently between 1968 and 1974.

The pits and shafts were excavated into the overlying soil and the Tshirege part of the Bandelier Tuff. About 1300 feet of unsaturated rock separate the trenches and pits from the main aquifer. Based on engineering drawings, Pits 1-4 were designed to be constructed 610'L x 40'W (the depth is not specified); Pit 5, 705'L x 110'W x 18'D; Pit 6, 505'L x 100'W x 25'D; and the Chemical Pit, 180'L x 25'W x 12'D. Shafts numbered 1-55 are described as 2' in diameter and 15' deep; shafts 56-67 as 2' in diameter and 10' deep; and shafts 68-107 as 1' or 2' in diameter and 20' to 25' deep. Shaft 108 has no design specifications available. No documentation is available to verify that the disposal sites were built to these specifications, or that they are at the locations designated. In 1984, as part of an effort to cover the contaminated soil surface, from 0.5-3.0 feet of topsoil was put over 1.5 feet of crushed tuff, except for the northeast corner of the site which received no additional cover. See Appendix A for more detailed information on site MDA C.

TA-50 Site Control Point

In order to conduct a modern site survey it is necessary to establish first-order survey control points. They provide an accurate coordinate framework to globally define the survey site and provide high accuracy fixes for waypointing or relocating targets following a survey. Establishing a first order control point is particularly important for the ***MTADS*** surveys which use Differential Global Positioning System (DGPS) navigation. The accuracy of the DGPS real time navigation is built on the corrections broadcast from the differential site to the roving vehicle. With centimeter accuracy for the position of the differential site, we have shown that submeter accuracies in real time at a one Hertz update rate are possible.[5] Postprocessing the DGPS data can improve the navigation accuracies to the decimeter level.

The control point used for TA-50 was established by LANL during earlier operations.

This control point has the coordinates given below.

TA 50 MDA "C" (A5001)
NMSP, Central zone (NAD 83) US feet
Northing: 1768420.43
Easting: 1625421.60
Elevation: 7274.6 ft.

Geo Lat/Lon (NAD 83)
35°51'37.10577"N
106°18'02.18578"W

Appendix "B" is the permanent monument record.

Survey System Hardware Integration

The field survey system, as it is currently configured, contains components from a commercial (Geo-Centers) STOLS II survey system and components developed and acquired under the ***MTADS*** program. The integration of the ***MTADS*** components with the commercial test bed provides for sub-system component field evaluation while the ***MTADS*** program is still in the development phase, thus ensuring the overall ***MTADS*** system integrity. It also allows for field evaluation of the commercial system components and demonstrates a government/commercial cooperative effort in the program. The field hardware is shown surveying in Figure 2.

The sensor suite for this study incorporates a towed array of seven cesium vapor total field magnetometers, Model #822 from Geometrics, Inc. The sensors are mounted on a low magnetic signature tow platform developed by Geo-Centers and towed by a four wheel vehicle. The tow vehicle is a four wheel off-road "dune buggy," developed by Chenowth Military Products, Inc., and modified to reduce magnetic self-signature. Data from the sensors, are collected at 20 Hz by a 486 PC, formatted and passed on to the Main Control Computer (MCC) (also a 486 PC) located in the tow vehicle. A proton procession magnetometer, Model #856 from Geometrics, Inc., is used as a reference station to monitor time variations in the earth's magnetic field which are recorded at 0.1 Hz and transferred to the MCC upon completion of a survey. See Figure 3 for reference station setup at TA-50. The navigation system uses two Trimble, Model 4000SSE, units.[6] One unit operates from a fixed first order static position broadcasting pseudo-range corrections *via* the RF radio link, (see Figure 4), to the roving unit which is mounted in the tow vehicle. Additionally, the system has the capability of recording landmark data. The antenna is removed from the tow vehicle, attached to a long cable and the antenna held over the position to be recorded. A short file is taken, given a landmark name and is then displayed as a landmark on the data output maps. Figure 5 shows the landmark data acquisition process. During survey the data acquisition computer reads the 20 Hz magnetometer sensor data and time correlates it with the 1 Hz DGPS navigation time

Figure 3. Reference magnetometer at TA 50 C site

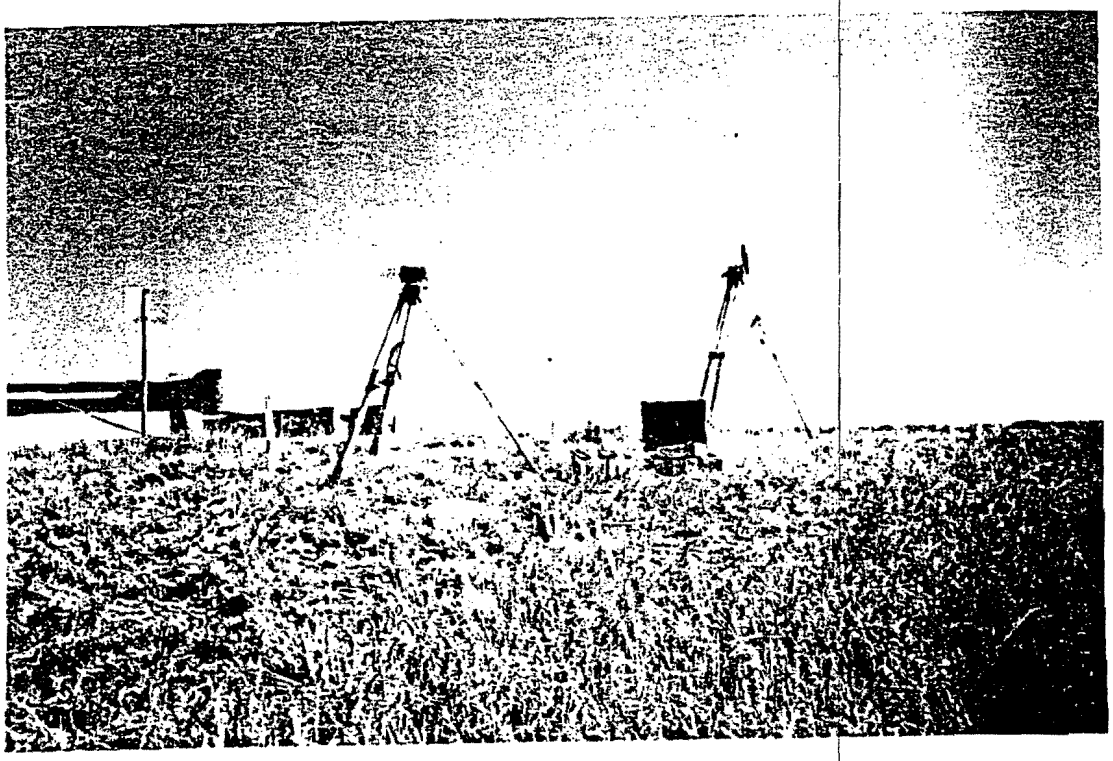

Figure 4. Navigation base station at the intersection of Pajarito Road and Pecos Drive

Figure 6. *MTADS* DAS analyzing LANL TA-73 data.

TA-50, Site Health and Safety

Site health and safety is an important consideration at LANL when working at a hazardous disposal site, such as TA-50, MDA C. MDA C is a controlled access site, completely enclosed by chain link fence and locked gates. Before work could begin, an approved Site Specific Health and Safety Plan (SSHSP) was required. Prior to approval of the SSHSP a radiological and chemical survey must be conducted and the results of these surveys incorporated into the plan.

Appendix C is the SSHSP for MDA C. Also determined from these surveys is the Personnel Protective Equipment (PPE) level required to work on-site. The PPE level for this site, based on the radiation and chemical surveys, was level D. Level D requires long pants, long sleeve shirt and sturdy work boots. Training for on-site workers includes an 8 hour LANL hazardous materials training course and 40 hours of hazwoper training. Monitoring all persons leaving the site was also required as shown in Figure 7.

A Radiation Control Technician (RCT) was present when any persons or equipment were exiting the site. The personnel were monitored for any radiation levels exceeding background, with a Ludlum, Model #2 counter, for beta/gamma, (background 150-200 cpm) and a Ludlum, Model #139 counter for alpha, (background 0 cpm). Swipes were taken of the vehicle tires and any equipment that came in contact with the ground. The swipes were analyzed on a laboratory counter and the results determined before any equipment could be removed from the site.

Figure 7. A RCT is shown conducting a radiation survey before personnel exit the MDA C, Section 1 perimeter gate.

The TA-50 Survey

TA-50, MDA C, an 11.8 acre site, is basically flat except for a roll off in the northeast edge, sloping down into Ten Site Canyon. The entire site is enclosed by a perimeter fence and is divided inside the perimeter by two additional fences. See Figure 1. This means that MDA C is divided into 3 separate sites with admittance to each only through perimeter gates. Movement from one internal site to another within MDA C requires leaving the perimeter gate and entering the other site through a separate gate. The equipment and personnel must be monitored by a RCT whenever moving among internal sites. Therefore, the MDA C area was treated as 3 separate surveys. The east most section, an area of about 8 acres located adjacent to Pajarito Road, is primarily flat except for the northeast corner. The west most section is about 2 acres in size with an entrance gate off Pecos Drive. The third site, about 1 acre in size, is located between the other sites at the south side of MDA C. A fenced corridor runs north to south through the middle of MDA C.

The east most site is documented as containing 5 pits (trenches) and 108 shafts. The shafts are 1′ to 2′ in diameter with depths between 10′ and 25′. Four pits were intended to be 610′L x 40′W, with depths unspecified. Pit #5 was described as 705′L x 110′W x 18′D according to the engineering drawings. The west most section was documented to

contain 2 pits (trenches); Pit #6 is described as 505'L x 100'W x 25D, and the chemical pit is described as 180'L x 25'W x 12'D. In addition, during inspection of Section 2 we observed the following surface features; two surface asphalt drains, with an erosion hole at the end of one drain, about 8'L x 3'W x5'D. Also on the site are a 2' x 2' concrete block believed to be the base for a former meteorological tower and two 6'x 6' concrete bases that anchored the meteorological tower. The south section is not documented as a hazardous disposal site. In this area we observed a clutter of electrical components and a small weather station and a water faucet extending above ground. The items listed above are included on the target maps from this study as landmarks.

Results of the TA-50 MDA C Survey

Figure 8 shows the magnetic anomaly image map of the entire MDA C site. The magnetic anomaly intensity scale is set such that black saturates at -500 gamma and white saturates at 1000 gamma. It is easy to discern that the history of burials at the site have involved trench landfills with the long dimensions of the trenches stretching generally in an east-west direction. The black border surrounding the perimeter of the magnetic anomaly image results from the negative magnetic signature from the chain link fences which rise above the height of the sensors.

MDA C was surveyed as three separate sites because of the fencing and access restrictions limiting uninterrupted surveying across the entire landfill. These sites are identified in Figure 9.

Figure 10 is a schematic rendering of the MDA C area. This map is reproduced from the "TA 50, MDA C Site History" document.[4] This historical document provided the information cited in the introduction of this report describing the layout and dimensions of the pits and shafts used for burials in this landfill. There was insufficient information available to us to verify the accuracy of the information in the map.

The aerial photograph shown in Figure 1 is a more modern rendering of the MDA C site. The photograph shows the perimeter and interior fences and Pajarito Road and Pecos Drive in their current configurations. The original color photograph shows the upper half of Section #3 as a disturbed area. Unfortunately for our purposes, Section 1 and Section 2 have been graded, covered with an overlayer of fill and seeded well before the photograph was taken; no evidence of the pits or shafts are evident in the photograph. We were unsuccessful in obtaining historical photographic information for the site while it was active.

During the process of surveying MDA C several data sets were taken. These include creation of magnetometry files using the roving vehicle to survey the areas of interest and creation of landmark files. Landmark files at MDA C involve acquiring static position information for the perimeter boundaries and surface features which can be correlated with photography, topography or permanent area markers.

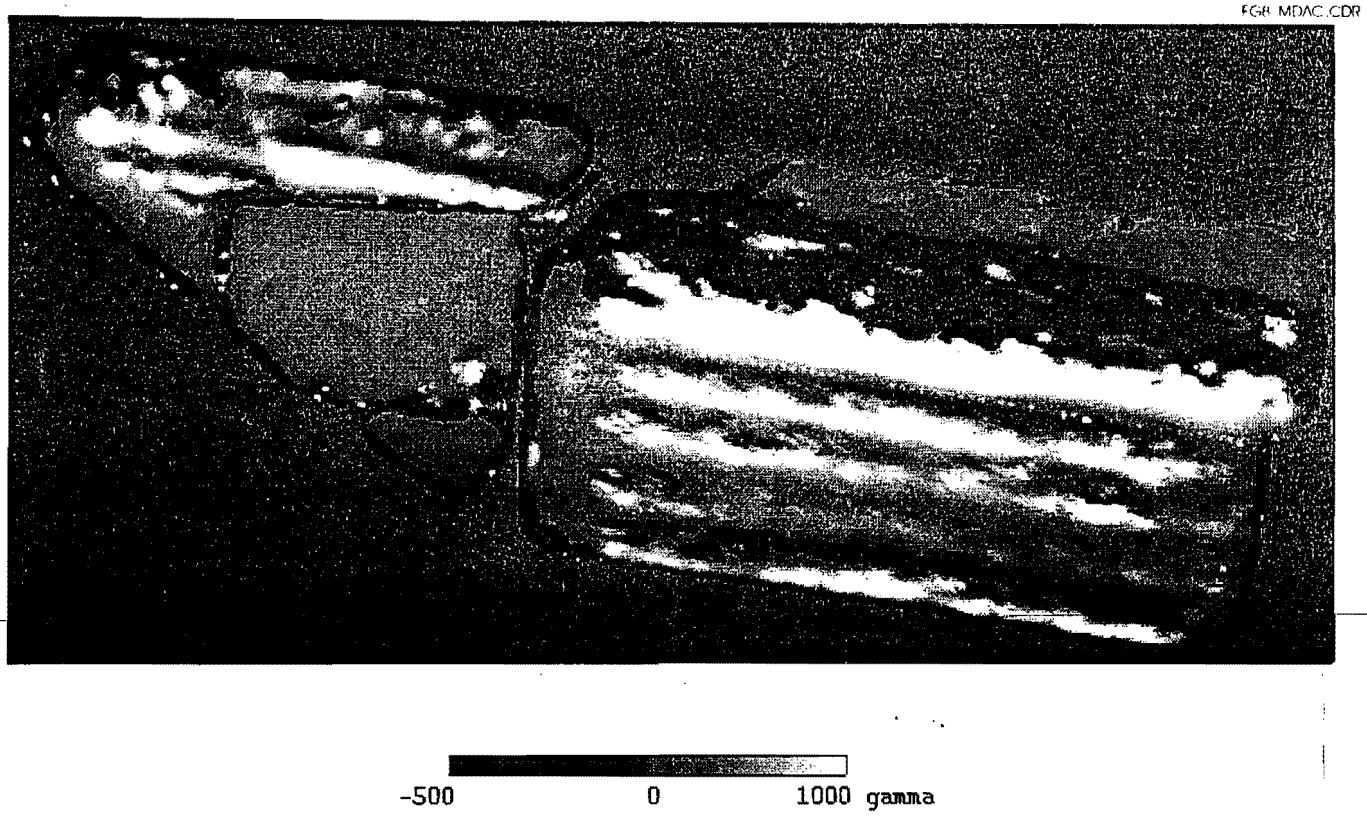

Figure 8. TA-50, MDA C, Site Map

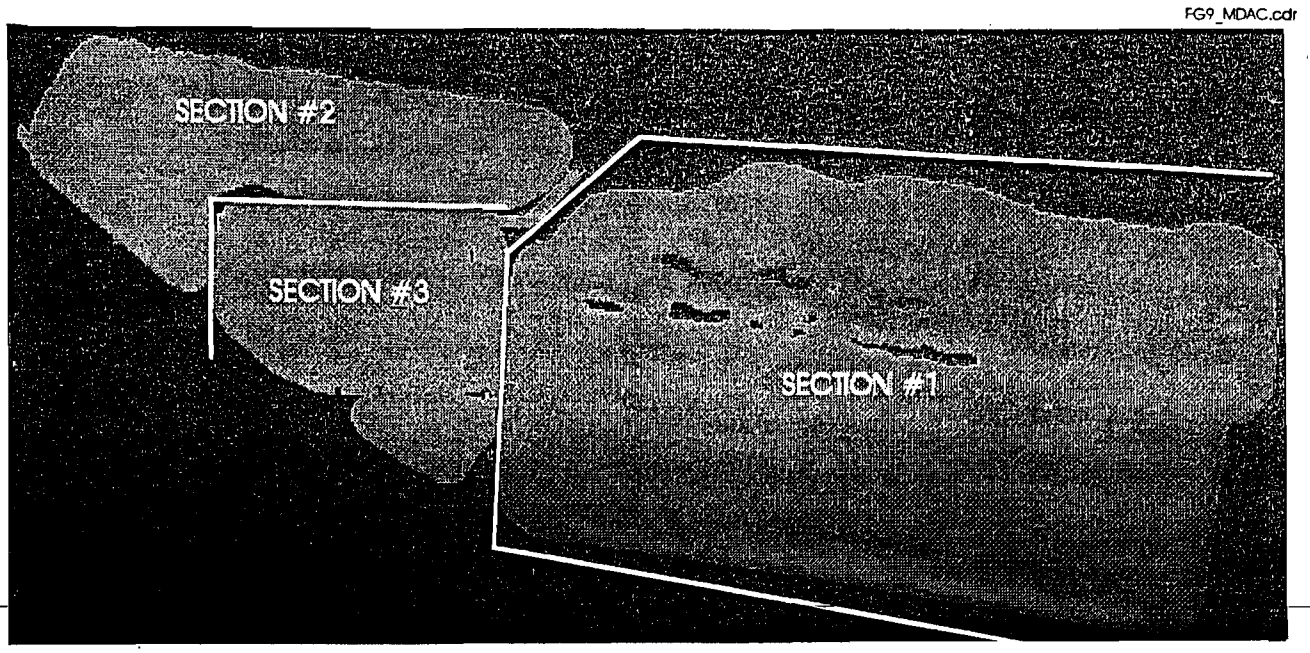

Figure 9. TA-50, MDA C, Section map

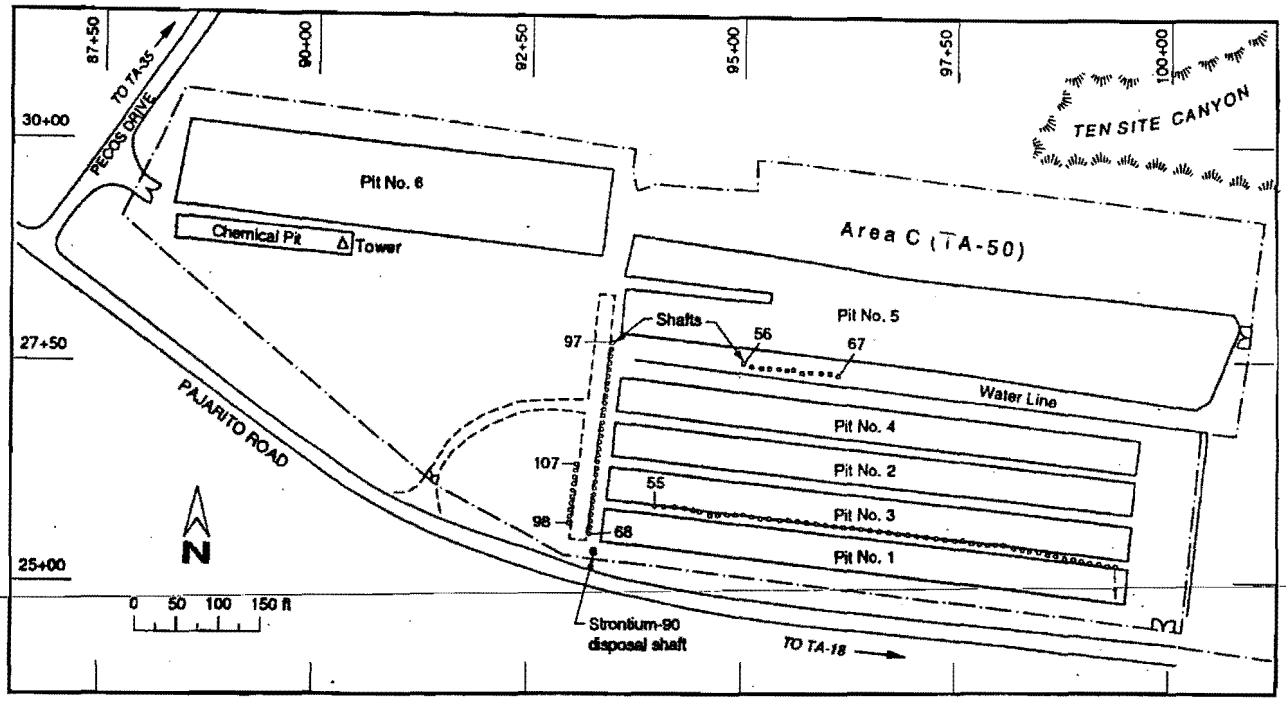

Figure 10. Schematic representation of MDA C including pits and shafts.

Seven magnetometry files were created for MDA C. These are described below.

File 1. An initial limited data set was taken in Section #1 of MDA C with the Magnetometers at a height of 18 inches. Two passes around the circumference of the site were made followed by several east-west traverses at the southern edge of the Section. This preliminary data set was taken to evaluate the performance of the equipment and to provide a data set to test the data analysis system following its setup at The Los Alamos Inn.

File 2. This file contains the survey of the entire MDA C, Section #1. The magnetometer array height is 18."

File 3. This file contains the survey of the entire MDA C, Section #2. The magnetometer array height is 18."

File 4. This file contains the survey of MDA C, Section #3. The magnetometer array height is 18."

File 5. This data set was not used for analysis.

File 6. This file contains a resurvey of a portion of MDA C, Section #1. The Pit 5 area was covered as was a portion of the western edge of Section 1. Magnetometer height was 18." The entire data set was taken at a vehicle speed of 2 to 3 mph. This survey and the following survey were undertaken to understand the cause for large data dropouts over Pit 5 in areas of high magnetic intensity.

File 7. The MDA C, Section #1, Pit 5 area was resurveyed at normal speed (5-10mph). For this survey the magnetometer array was deployed at a height of 6 feet above the ground.

Data Files 1-6 were all taken with similar operational parameters. These files would typically be added together for individual sites prior to data analysis. In this way inadvertently missed areas are often filled in by overlaying complimentary data sets. For target analysis and graphical imaging purposes care has been taken to correctly "average" overlying data points prior to interpolation onto the 10cm grid used for images. All target analysis is carried out using *uninterpolated* data.

For purposes of discussion the eastern side of MDA C (Section #1) is addressed as a single survey. Sections #2 and #3 are combined as contiguous areas and addressed together in discussion of the western half of MDA C.

Section #1

Figure 11 is a greyscale magnetic anomaly presentation for Section 1. Files 1, 2 and 6 were added to create this image. Positive magnetic anomalies saturate as white images at 1000 gamma and negative anomalies saturate as black images at -1500 gamma in this presentation. Blue areas either were not surveyed, were missed areas within the survey, or are data dropout areas. The extensive data dropouts in Pit 6 are discussed later. The small yellow dots are landmarks taken as part of the survey. Those at the outside edges of the survey are taken at fence line features and fence corners. Overlying the magnetometry image in Figure 11 is a rendering of the eastern half of Figure 10, the historical schematic map of the MDA C site features and landfill boundaries. Using the historical map, Pits 1-5 are outlined in yellow and the shaft markings are reproduced in red and labeled by number. The perimeter fences and gates from the schematic are shown in red and the utility labeled as "water line" is shown as green. Pajarito Road is schematically represented as black. The Figure 10 mask was scaled to overlay the magnetic anomaly image.

Figure 12 presents the same magnetic anomaly map as Figure 11 except that the positive magnetic signals above 750 gamma have been highlited in red. Similarly, Figure 13 shows the same magnetic survey information in a false color presentation. All landmark data for Section 1 are given in Table 1.

The line of features associated with shafts 98-107 was independently analyzed using data file 1 (the perimeter survey) and data file 6 (the slow partial resurvey). Figure 14 shows images from the perimeter data set in this region. We were able to analyze eight features which we associate with this line of shafts. These are labeled as targets 1, 2, 3, 5, 6, 7, 12, and 13 in the Figure 14. The target labeled 14 in Figure 12, following close analysis, we believe to lie north of shaft #107. Targets 6, 7, 12 and 13 are more apparent when unmasked from the fence "shadow" by display on other sensitivity settings. Target positions and assigned shaft numbers are presented in Table 2 in lat/lon and New Mexico State Plane and correlated with shaft numbers from historical data. The automated target analysis routine converged for four of the targets. The depth and magnetic moment analysis for target 5 is dubious because of strong masking from the fence. The southern four targets were hand picked; they could not be analyzed for depth or size because of the strong negative magnetic gradient generated by the adjacent fence.

Figure 15 shows a magnetic anomaly image of Section 1 similar to that shown in Figure 11. In this image all data files with equivalent settings are included and the data has been smoothed by more extensive averaging prior to interpolation. In this image we have overlaid the fence perimeter and road edge mask which was created in Figure 1 from the aerial photograph. The mask has been scaled and translated (but not rotated) to fit the landmarks in the magnetic image. The fit is excellent except in the northwest corner of the site. In this corner the relatively large elevation changes, not taken into account in

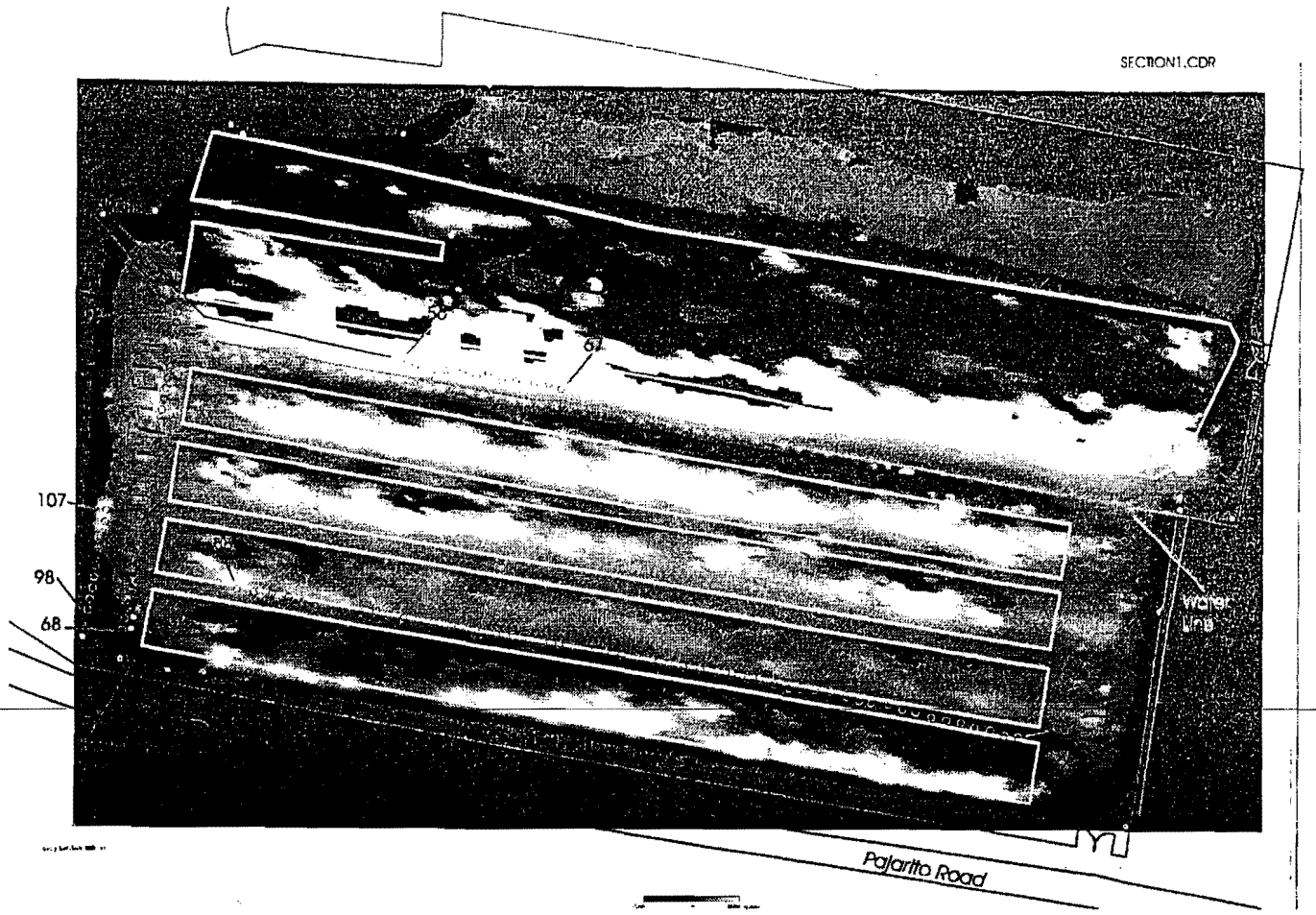

Figure 11. Magnetic anomaly image map of TA-50, MDA C, Section 1 plotted in greyscale. The fence, pit and road outlines are overlayed from the image in Figure 10.

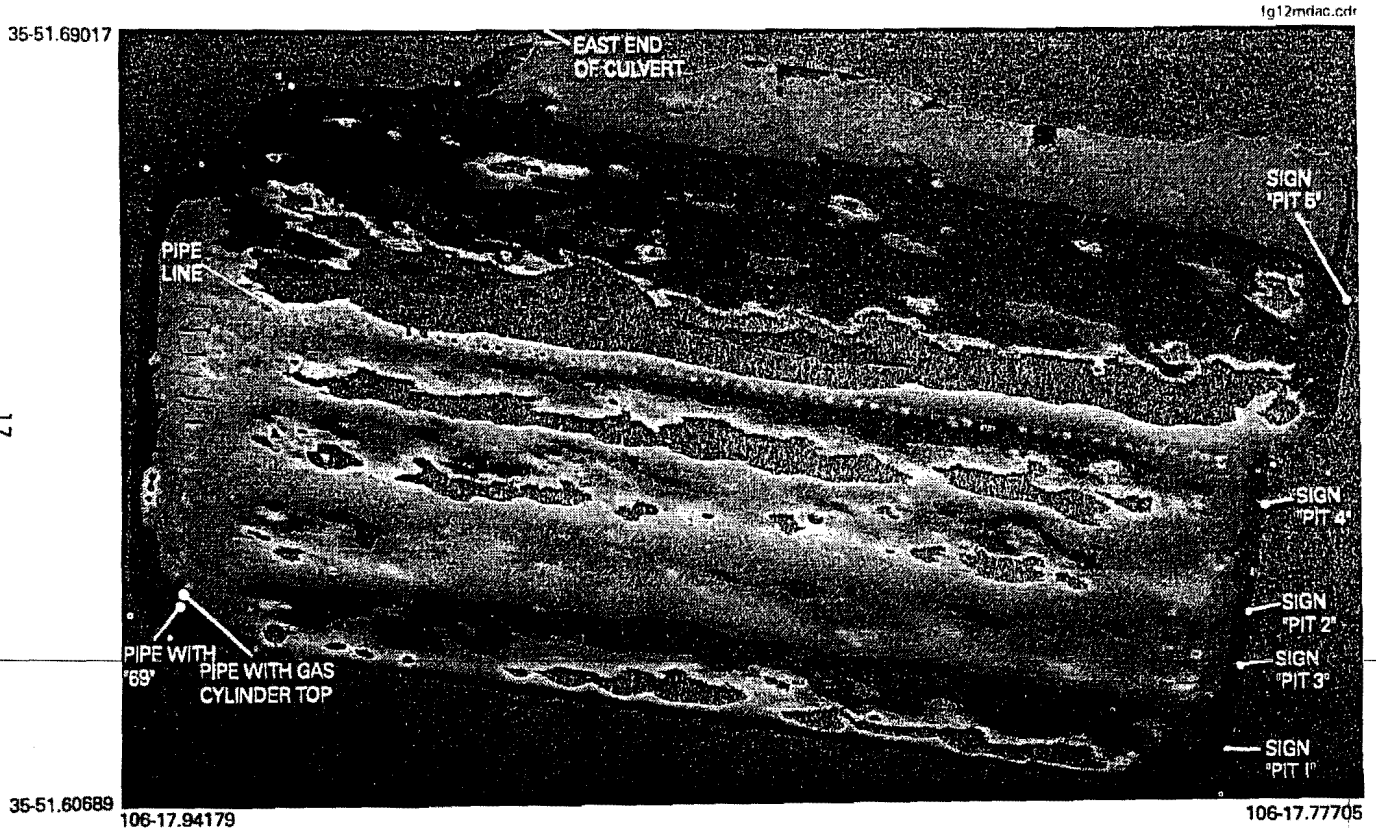

Figure 12. MDA C, Section 1, magnetic anomaly image presented in greyscale with signals >750 gamma highlited in red.

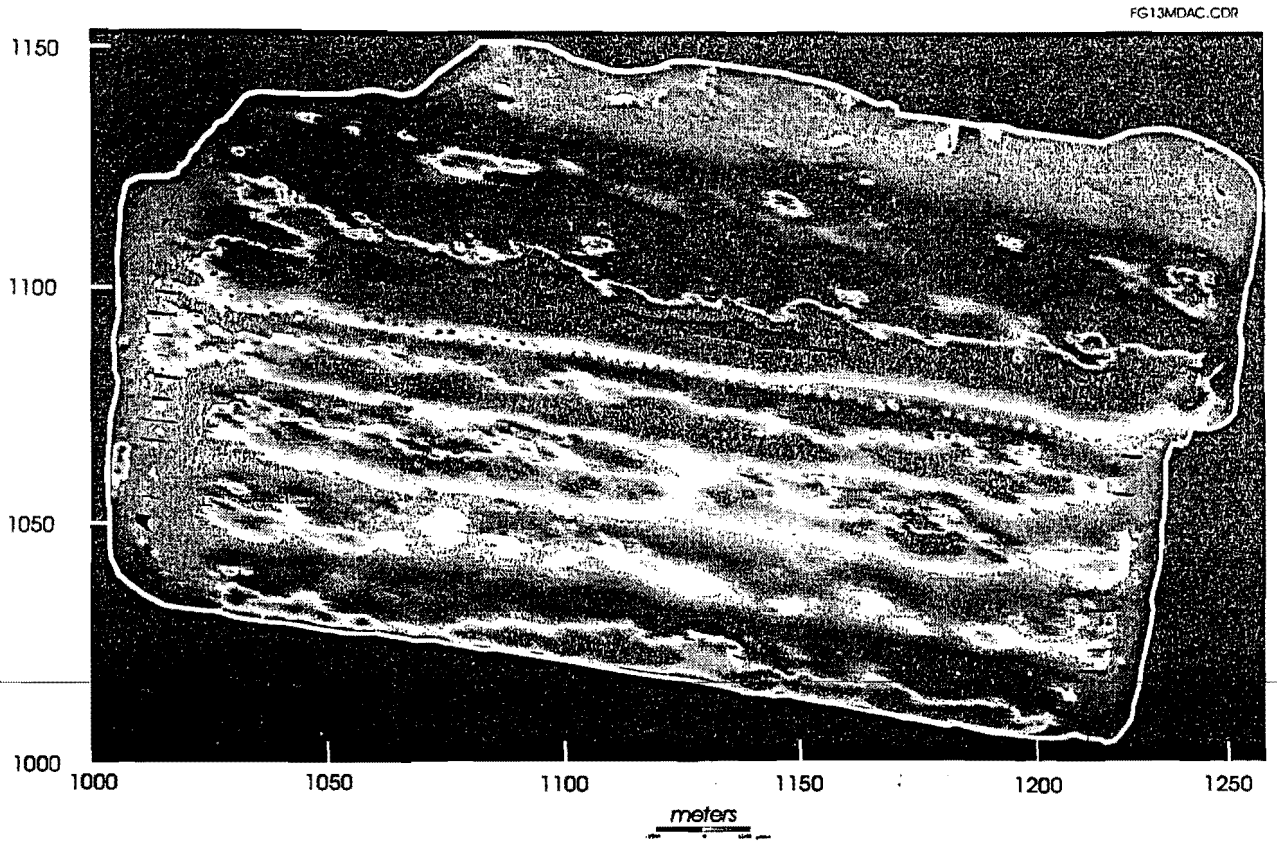

Figure 13. Magnetic anomaly image of MDA C, Section 1 plotted in false color. The perimeter of the surveyed area has been outlined in white.

Table 1. Landmarks located in Section 1.

Landmarks:

Name/number	Lat/lon NAD 83		New Mexico SP SPCS 83 (ft)	
Fenceline(F-1)	35°51.607445′	106°17.795844′	1768353.2	1626609.7
Fenceline (F-2)	35°51.642998′	106°17.788547′	1768568.9	1626645.8
Fenceline (F-3)	35°51.642052′	106°17.781383′	1768563.1	1626681.2
Fenceline (F-4)	35°51.678416′	106°17.774119′	1768783.7	1626717.2
Monitoring well	35°51.676230′	106°17.776898′	1768770.4	1626703.4
Culvert (East end)	35°51.690068′	106°17.884675′	1768854.7	1626171.2
Fenceline (F-6)	35°51.684163′	106°17.918651′	1768818.9	1626003.4
Fenceline (F-7)	35°51.685184′	106°17.920331′	1768825.1	1625995.1
Fenceline (F-8)	35°51.675563′	106°17.930769′	1768766.8	1625943.6
Fenceline (F-9)	35°51.675068′	106°17.938075′	1768485.4	1625890.4
Fenceline (F-10)	35°51.629183′	106°17.941514′	1768475.4	1625895.2
Fenceline (F-11)	35°51.627535′	106°17.940534′	1768460.8	1625921.0
Fenceline (F-12)	35°51.625124′	106°17.935303	1768489.0	1625929.9
Pipe "69"	35°51.629768′	106°17.933516′	1768763.8	1625907.5
Pipe (gas cyl top)	35°51.628492′	106°17.933814′	1768481.2	1625928.4

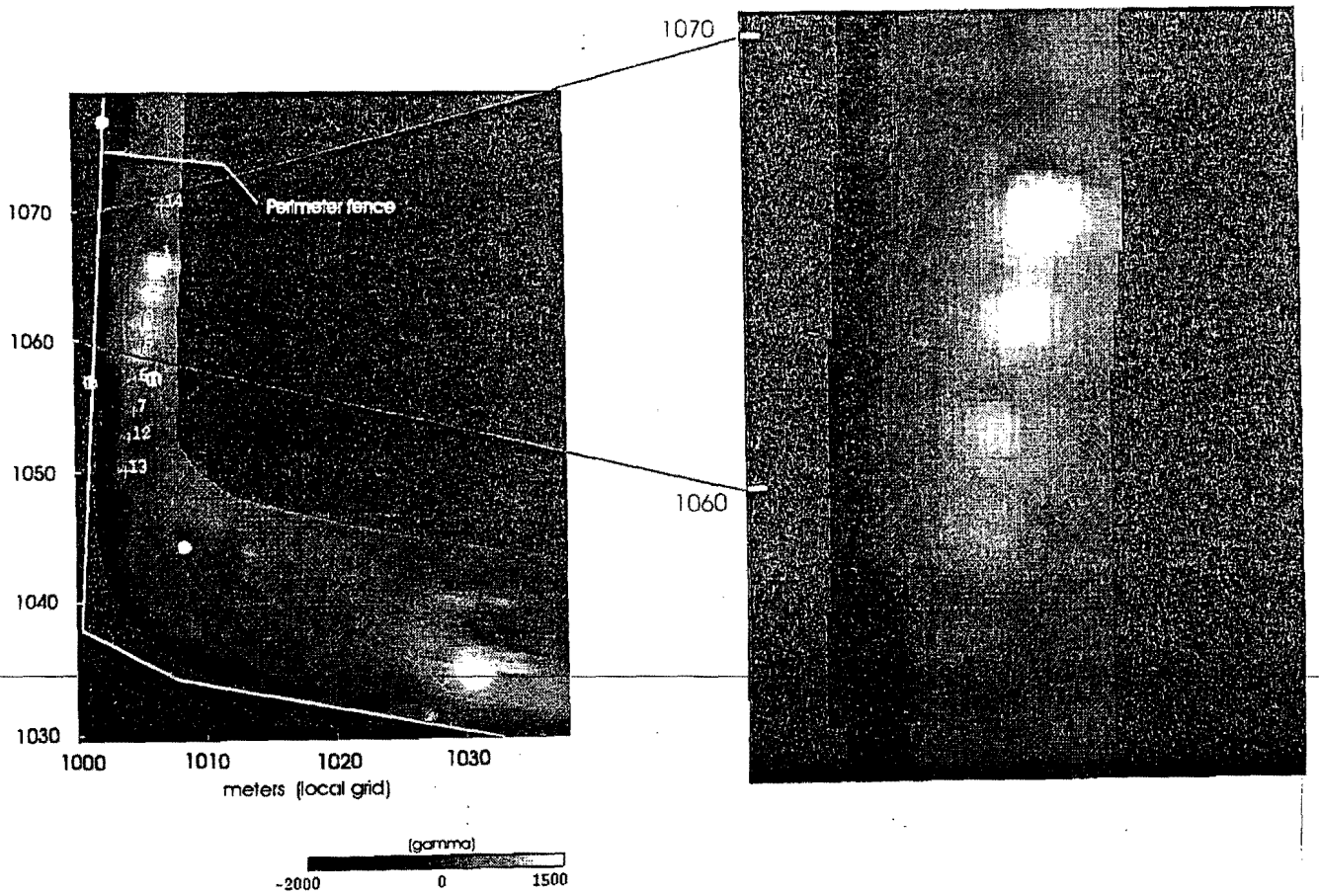

Figure 14. MDA C, Section 1, southwest corner. Shafts 98 to 107 illustrated from the perimeter survey

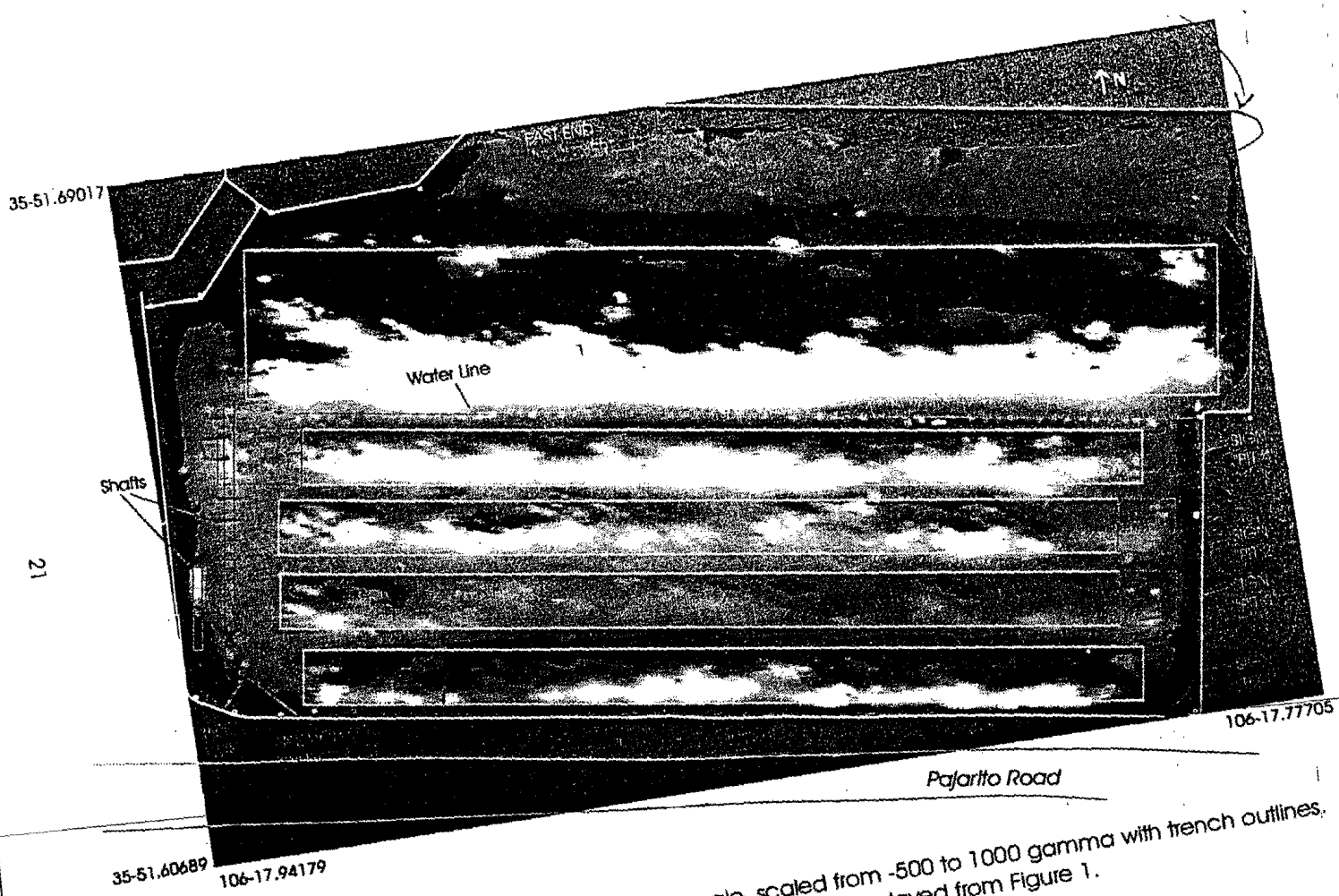

Figure 15. TA-50, MDA C, Section 1 in grayscale, scaled from -500 to 1000 gamma with trench outlines. Perimeter fence and road outlines have been overlayed from Figure 1.

Table 2. Magnetometry Analysis of Shafts 98-107 in MDA C.

Target #	Lat/Lon NAD 83		NM SP SP CS 83ft		Depth (m)	Moment	Assignment Shaft #
	E. Lat.	N. Long.	Northings	Eastings			
1	35°51.642600′	106°17.937600′	1768119.0	1625498.2	1.1	51.39	107
2	35°51.657600′	106°17.937600′	1768109.9	1625496.4	1.2	37.26	106
3	35°51.640200′	106°17.938200′	1768102.5	1625495.5	1.1	23.85	105
5	35°51.639000′	106°17.938200′	1768095.9	1625493.3	0.6	3.75	104
6	35°51.637800′	106°17.938800′	1768087.9	1625491.9	hand	picked	103
7	35°51.636600′	106°17.938800′	1768080.1	1625491.3	hand	picked	102
12	35°51.635400′	106°17.938800′	1768073.3	1625490.0	hand	picked	101
13	35°51.634200′	106°17.939400′	1768065.0	1625488.9	hand	picked	100

our GPS data treatment, and not taken into account in the two dimensional photo taken from south of the site, have created a small mismatch. The Pit Sign positions of the east fence are located on the image from measurements made using a survey tape.

Boundaries for Pits 1-5 are created using the historical dimensions cited in the introduction of this report. Pits 1-4 are shown as 610′ x 40′ and Pit 5 is shown as 705′ x 110′. The pit positions were adjusted to best fit the magnetic signatures. These features are shown as the yellow boxes in Figure 15. The 610 foot long yellow boxes do not appear to best represent the length of the trenches for Pits 2, 3, and 4. We have added 40 feet to the length of pits 2 and 3 and 60 feet to the length of Pit 4. These additions are shown in red at the east end of Pits 2 and 3 and the west end of Pit 4. The east west positions of the pit assignments have been adjusted to best approximate the likely pit positions. The southern edge of Pit 1 very closely approximates the south perimeter fence. We cannot tell how close because of masking of the magnetic signal by the perimeter fence. Pit 5 may also extend beyond the boundaries we have shown in yellow in Figure 15. We suspect that it may extend 10-20 feet further north than shown by the yellow boundaries and perhaps further west. It is likely that the west end of Pit 5 lies very close to (or perhaps under) the west internal fence. Table 3 gives our estimates for the locations of Pits 1-5 relative to the east and south fence lines.

Table 3. Locations of Pits 1-5 in MDA C

Pit Number	Distance From East Pit Boundary to East Fence	Distance From South Pit Boundary to South Fence
1	42′	9′
2	18′	119′
3	18′	65′
4	42′	171′
5	--	233′

We have located 8 of the 10 shafts in the eastern line of shafts (numbered 98-107). All of these shafts lie within 5 meters of the west perimeter fence and shafts 98 and 99 may lie almost under the fence. The two narrow red boxes near the left side of Figure 15 bound the burials for Shafts 68-107.

Summation of Section 1

The most identifiable magnetic features in Section 1 are the recurrent "white dots" which define the water line. Although these features are not easily explainable from a physics perspective, they are typical of magnetic anomaly images we observe from buried steel pipelines which are composed of pipe joints. The following observations are made ***by comparison of the magnetic anomaly image and the historical schematic map in Figure 11.***

- The east-west water line inside the perimeter faithfully mimics the magnetic image.
- Pits 1-4 generally encompass the most intense magnetic features associated with these landfill burials. The eastern boundaries of the pits likely extend beyond the indicated limits.
- Pit 5 is probably incorrectly outlined in this figure. Burials appear to extend both south and east of the indicated boundaries.
- The north and south perimeter fences and the eastern perimeter fence (north of the jog at the water line) are seriously misplaced. The correct position of the south fence is against the southern edge of the magnetic survey image. The correct fence corners are defined by the landmarks in yellow at the corners of the magnetic anomaly image. Our analysis indicates that the southern edge of Pit 1

and the eastern edge of Pit 5 extend to very near the current fence line. See the discussion following Figure 15.

- The line of shafts (numbered 1-55) are not prominent in our magnetic imagery. Three or four are likely visible in some presentations of the data. However, we are not confident enough of their analysis to assign them. We can say with confidence that they are not steel cased, they are not steel capped and they do not contain significant ferrous content (>10 lbs) at the top of the well heads. If this were so we would have observed them, even through 2 or 3 feet of soil cover.

- The line of shafts (numbered 56-67) are not observable because they are masked by the strong positive magnetic signal (1000-2000 gamma) from the massive burials along the southern edge of Pit 5.

- The line of shafts (numbered 68-97) are not prominent in any of the presentations of the magnetic data. Numerous features are faintly observable along this line in more sensitive image displays. Significant ferrous clutter and near surface magnetic anomalies prevent analysis of individual targets. Again, these shafts are not steel cased, or steel capped and do not contain significant ferrous materials near the surface.

- The ^{90}Sr disposal shaft is obviously misplaced on the overlay in Figure 11. The two landmarks (associated with visible surface features) immediately north of the labeled position we expected might be associated with this burial shaft. There is no significant magnetic anomaly under or near either of these landmarks, however. The bright white round anomaly at the southern edge of Pit 1 and east of the indicated position should be suspect if one is searching for the ^{90}Sr burial.

- The line of shafts (numbered 98-107) do closely correlate with observed magnetic anomaly features.

- We feel that the landfill outlines in Fig. 15 and positions in Table 3 better describe the burials than information derived from Fig. 11.

Section 2/Section 3

Sections 2 and 3 collectively constitute the remainder of MDA C. Although they were surveyed separately they will be discussed together. Figure 16 is a greyscale magnetic anomaly presentation for the two sections. The image was created by adding magnetometry survey files 3 and 4. In this presentation positive magnetic anomalies saturate white at 1000 gamma and negative anomalies saturate as black at -1500 gamma. The yellow dots are landmarks taken during the survey. Twelve landmarks were taken in Section 2 and eleven were taken in Section 3. The landmark data are presented in Table 4.

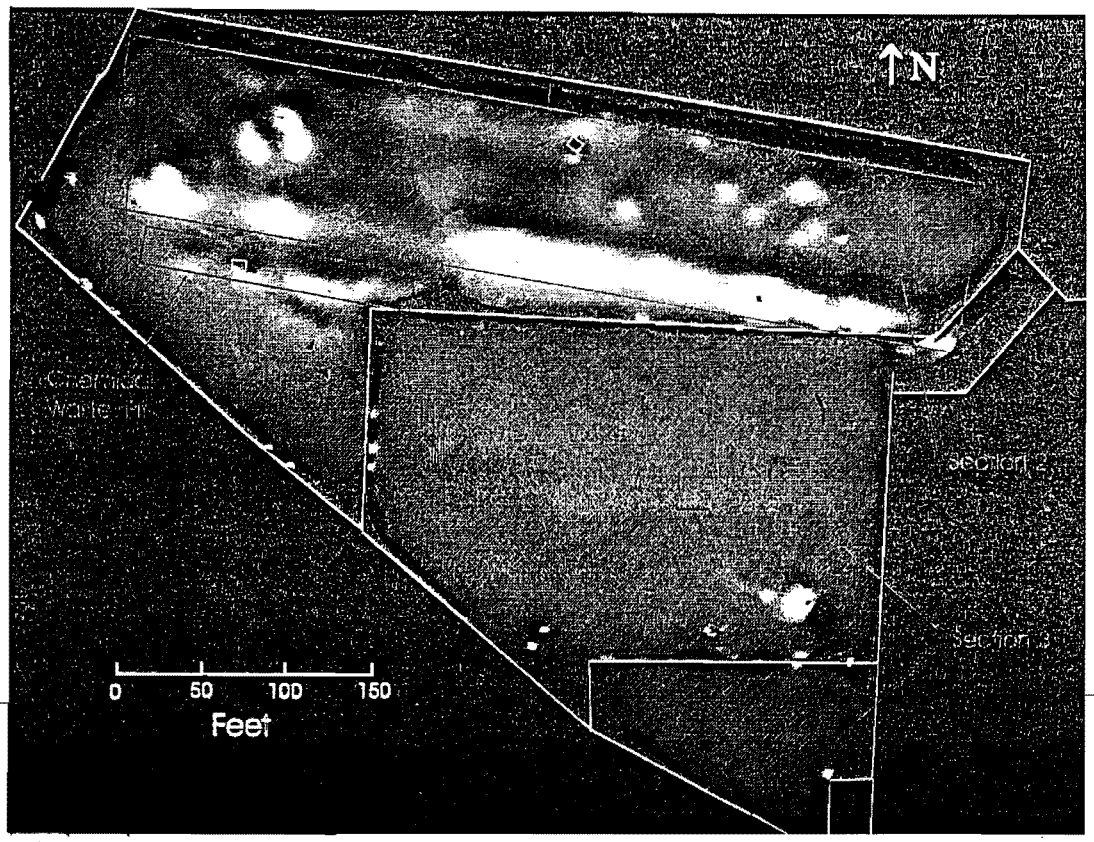

Figure 16. Magnetic anomaly image of Sections 2 and 3 of MDA C. Overlaying in yellow are the fence lines defined from the aerial photograph shown in Figure 1.

Table 4. Landmarks established in Section 2 and Section 3 of MDA C.__

Landmarks in Section 2.

Name/number	Lat/lon NAD 83		New Mexico SP SPCS 83 (ft)	
Fenceline (WF-1)	35°51.661750′	106°18.008980′	1768683.2	1625557.3
Fenceline (WF-2)	35°51.682753′	106°17.999844′	1768810.6	1625602.7
Fenceline (WF-3)	35°51.679676′	106°17.933670′	1768791.7	1625929.3
Fenceline (WF-4)	35°51.688338′	106°17.924530′	1768844.6	1625974.4
Fenceline (WF-6)	35°51.710834	106°18.026701′	1768981.0	1625469.9
Asp drain #1 (S)	35°51.682599′	106°18.003235′	1768809.6	1625585.7
Asp drain #1 (N)	35°51.704266′	106°17.990385′	1768941.0	1625649.2
Asp drain #2 (S)	35°51.684027′	106°17.983217′	1768818.5	1625684.6
Asp drain #2 (N)	35°51.700751′	106°17.965342′	1768919.7	1625772.9
Guideline base #1	35°51.698517′	106°17.975820′	1768906.1	1625721.2
Guideline base #2	35°51.686742′	106°18.015545′	1768834.8	1625525.0
Tower base	35°51.683131′	106°17.991696′	1768812.8	1625642.7

Landmarks Section 3:

Name/number	Lat/lon NAD 83		New Mexico SP SPCS 83 (ft)	
Fenceline (SF-1)	35°51.680697′	106°17.937913′	1768797.9	1625908.3
Fenceline (SF-2)	35°51.682618′	106°17.999806′	1768809.7	1625602.7
Fenceline (SF-3)	35°51.661544′	106°18.000818′	1768681.9	1625597.6
Guideline base #3	35°51.664890′	106°17.983399′	1768702.2	1625683.6
Weather station	35°51.651780′	106°17.979938′	1768622.6	1625700.7
Water faucet	35°51.650498′	106°17.981413′	1768614.8	1625693.4
Fenceline (SF-4)	35°51.643133′	106°17.973763′	1768570.1	1625731.2
Fenceline (SF-5)	35°51.648811′	106°17.973852′	1768604.6	1625730.7
Fenceline (AF-1)	35°51.637651′	106°17.940898′	1768536.8	1625893.4
Fenceline (AF-2)	35°51.637761′	106°17.945911′	1768537.5	1625868.7
Fenceline (AF-3)	35°51.630813′	106°17.947386′	1768495.3	1625861.4

In this image we have again overlaid the fence perimeter mask that was created in Figure 1 on the aerial photograph. The mask has been scaled and translated (but not rotated) to fit the magnetic image. The fit is excellent as shown by the perimeter and interior fences shown in yellow. The yellow squares in the Chemical Pit and Pit 6 are from the mask created in Figure 1 by boxing the tower anchor pads visible in the photograph. They correlate well with the magnetic signatures arising from the rebar in the concrete pads.

Boundaries for Pit 6 and the Waste Chemical Pit are created using the historical dimensions cited in the introduction of this report. Pit 6 dimensions were specified as 505′ x 100′ and the Chemical Pit dimensions as 100′ x 25′. The pit positions were adjusted to best fit the magnetic signatures and the perimeter fences. Pit 6 fills most of the northern part of Section 2. Its northwestern corner probably ends very near the western fence. The eastern boundary of Pit 6 stretches beyond the internal fence into the passage between Sections 1 and 2. This conclusion is based both on the pit dimensions and the observed magnetic signatures. The southern edge of Pit 6 contains so much ferrous material that it presents almost continuous positive anomaly signatures. These signatures are reminiscent of Pits 4 and 5 in Section 1. The northern two-thirds of Pit 6 is more sparsely filled with ferrous materials. In several cases individual ferrous targets are sufficiently isolated that we can analyze them independently. The targets are listed in Table 5. The analyzed depths range between 3 and 12 feet and their magnetic moments are very large (probably hundreds of pounds of ferrous material in the larger targets). The chemical pit also contains extensive ferrous materials. We did not analyze individual targets within the pit.

The two enclosed areas in Section 3 are just under one acre in size. These areas have not been reported as containing waste burial sites. On the scale shown in Figure 16 little is apparent. Section 3 is presented with more sensitive settings in Figure 17. At these settings smaller targets become discernible. Numerous magnetic anomalies were analyzed as isolated targets, six converged and six others are presented as hand-picks. The target analyses that converged identified items between 2 and 5 feet deep with magnetic moments between 0.6 and 40 amp/m^2. These targets represent buried ferrous materials, but the intensities and burial patterns do not suggest a constructed landfill. The targets in Section 3 are listed in Table 6.

Holidays in the Magnetometry Data

While analyzing the data from files 1 and 2 taken in MDA C, Section 1, we observed relatively large holidays (areas of data dropout) primarily within the Pit 5 region. The holidays appear to be associated with the areas of highest (positive and negative) magnetic intensities. We have observed this dropout artifact in surveying at two other sites, the NRL North Parking Lot Landfill[7] and to a lesser degree at the LANL TA-73 Landfill.[3] At NRL the landfill contains several feet of rebar reinforced concrete rubble.

Table 5. Targets identified in Section 2 of MDA C

Lat/lon NAD 83

Targ	Location (NAD 83)		Depth	Size	comment
	Lat	Lon	Meters	amp/m²	
#5	35°51.6900′	106°17.9448′	0.9	30.3	
#6	35°51.6906′	106°17.9496′	2.6	125.6	
#7	35°51.6912′	106°17.9478′	-	-	would not converge
#8	35°51.6948′	106°17.9496′	2.3	148.1	
#9	35°51.6900′	106°17.9526′	-	-	would not converge
#10	35°51.6924′	106°17.9550′	-	-	would not converge
#11	35°51.6924′	106°17.9586′	3.5	102.0	
#12	35°51.6942′	106°17.9586′	-	-	would not converge
#13	35°51.6990′	106°17.9616′	-	-	would not converge
#14	35°51.6924′	106°17.9700′	-	-	would not converge
#15	35°51.7002′	106°17.9754′	-	-	would not converge
#16	35°51.6996′	106°17.9694′	-	-	would not converge
#17	35°51.7014′	106°17.9724′	-	-	would not converge
#18	35°51.6948′	106°17.9742′	-	-	would not converge
#19	35°51.6942′	106°17.9928′	-	-	would not converge
#20	35°51.7026′	106°17.9886′	-	-	would not converge
#21	35°51.7026′	106°17.9964′	-	-	would not converge
#22	35°51.7044′	106°18.0144′	-	-	would not converge
#23	35°51.6984′	106°18.0144′	-	-	would not converge
#24	35°51.6984′	106°18.009′	-	-	would not converge
#25	35°51.7008′	106°18.0108′	-	-	would not converge

Table 5. (Continued)

SPCS 83

Targ	Location (spcs 83) (ft)		Depth	Size	comment
	northing	easting	Meters	amp/m²	
#5	1768854.4	1625874.3	0.9	30.3	
#6	1768858.0	1625850.6	2.6	125.6	
#7	1768861.7	1625859.6	-	-	would not converge
#8	1768883.5	1625850.6	2.3	148.1	
#9	1768885.4	1625835.8	-	-	would not converge
#10	1768869.0	1625824.0	-	-	would not converge
#11	1768869.0	1625806.2	3.5	102.0	
#12	1768879.9	1625806.4	-	-	would not converge
#13	1768909.9	1625791.4	-	-	would not converge
#14	1768869.0	1625749.9	-	-	would not converge
#15	1768916.3	1625723.2	-	-	would not converge
#16	1768912.7	1625752.9	-	-	would not converge
#17	1768923.6	1625738.1	-	-	would not converge
#18	1768883.6	1625729.2	-	-	would not converge
#19	1768880.0	1625637.3	-	-	would not converge
#20	1768930.9	1625658.1	-	-	would not converge
#21	1768930.9	1625619.5	-	-	would not converge
#22	1768941.9	1625530.7	-	-	would not converge
#23	1768905.5	1625530.6	-	-	would not converge
#24	1768905.5	1625557.3	-	-	would not converge
#25	1768920.1	1625548.4	-	-	would not converge

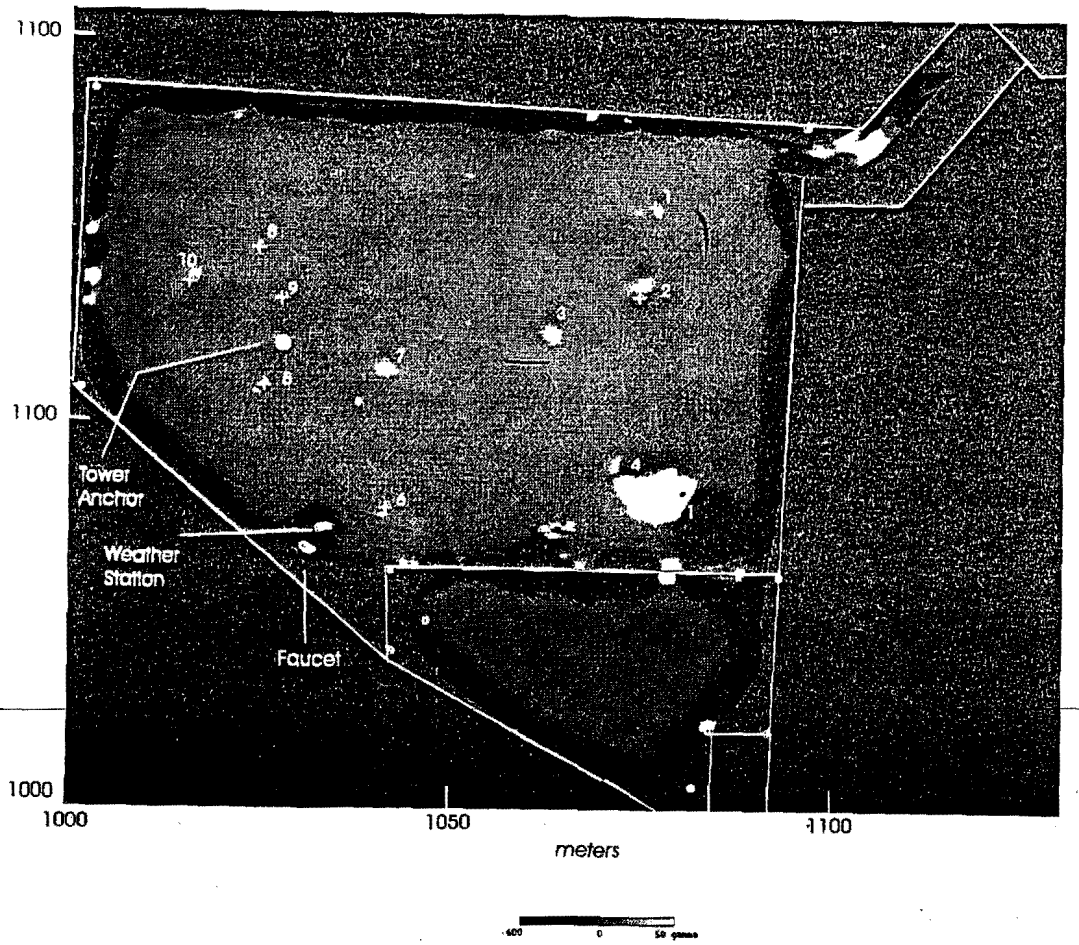

Figure 17. Magnetic anomaly image of MDA C, Section 3, plotted in greyscale. The fence definitions are overlayed from the aerial photograph shown in Figure 1.

Table 6. Targets identified in Section 3 of MDA C.

Lat/lon NAD 83

Targ	Location (NAD 83)		Depth	Size	comment
	Lat	Lon	Meters	amp/m²	
#1	35°51.6750′	106°17.9514′	0.4	0.6	
#2	35°51.6684′	106°17.9526′	2.2	41.4	
#3	35°51.6660′	106°17.9604′	0.9	6.9	
#4	35°51.6552′	106°17.9538′	1.1	40.9	
#5	35°51.6618′	106°17.9850′	1.6	9.3	
#6	35°51.6534′	106°17.9742′	1.7	10.1	
#7	35°51.6636′	106°17.9748′	-	-	would not converge
#8	35°51.6714′	106°17.9856′	-	-	would not converge
#9	35°51.6684′	106°17.9838′	-	-	would not converge
#10	35°51.6690′	106°17.9916′	-	-	would not converge
#11	35°51.6768′	106°17.9796′	-	-	would not converge
#12	35°51.6546′	106°17.9502′	-	-	would not converge

SPCS 83

Targ	Location (spcs 83) (ft)		Depth	Size	comment
	northing	easting	Meters	amp/m²	
#1	1768763.4	1625841.7	0.4	0.6	
#2	1768723.4	1625835.7	2.2	41.4	
#3	1768708.8	1625797.2	0.9	6.9	
#4	1768643.3	1625829.8	1.1	40.9	
#5	1768683.4	1625675.7	1.6	9.3	
#6	1768632.4	1625729.0	1.7	10.1	
#7	1768694.3	1625726.1	-	-	would not converge
#8	1768741.7	1625672.8	-	-	would not converge
#9	1768723.4	1625681.7	-	-	would not converge
#10	1768727.1	1625643.1	-	-	would not converge
#11	1768774.4	1625702.4	-	-	would not converge
#12	1768639.6	1625847.5	-	-	would not converge

The TA-73 landfill is likewise filled with many years accumulation of ferrous wastes. Both sites are characterized by very large magnetic signatures. Following the study at the NRL landfill and in anticipation of large magnetic signatures at the LANL TA-73 landfill, we modified the tow platform, allowing us to raise the height of the magnetometer array to 72" (from the previous maximum of 18"). These are data files 6 and 7. Figure 18 shows the tow vehicle with the fiberglass fixture for mounting the magnetometers at 72". Since the holidays are centered on the maximum intensity anomalies they do not result in missed targets. However, it is important that we understand what creates these data anomalies. Figure 19a shows a "normal" data set taken at Pit 5 with the magnetometers at 18" and a vehicle speed of approximately 8 mph. Relatively large data holidays are apparent.

Two effects were considered as possibly contributing to the holidays. The first is the rate of change in the absolute magnetic signal strength. This could be manifested as a data dropout in two ways. The magnetometers have a maximum magnetic strength gradient which they can track. This is reportedly 500 gamma/inch. Additionally, our data acquisition process uses a data compression scheme to compact the data for recording on the PC in the tow vehicle. This data compression scheme has recently been made more robust to accommodate very large magnetic signatures and fast vehicle speeds. In theory, it should faithfully track the magnetic signatures observed at MDA C. Figure 19b presents the data set taken with the vehicle speed slowed to less than 3 mph. The two data sets appear almost identical. This indicates that the rate of change of the data over large magnetic signatures was not a problem at a survey speed of 8 MPH.

A second concern involves the absolute magnitude of the magnetic intensities. We did not expect that it would be possible to exceed the dynamic range of the Cs vapor sensors. The sensor specifications claim a linear dynamic range of 20,000 to 100,000 gamma. The ***MTADS*** DAS creates images of the magnetic *anomaly* intensity (i.e. the measured field strength minus the average background field strength). The earth's field in Los Alamos is about 52,000 gamma, so the upper limit of the dynamic range (in anomaly signal intensity) should be 100,000 - 52,000 = 48,000 gamma and the lower end of the range should be 20,000 - 52,000 = -32,000 gamma.

Reviewing the LANL TA-73 and NRL Landfill data sets, we highlited (in red) at increasing thresholds, until at about 32,000 gamma, most holidays appeared to be outlined thinly in red. However, the threshold for dropout in the MDA C data, we observed to occur at lower (and variable) levels with dropouts often appearing at levels above 5,000 gamma. While the signatures recorded at TA-73 and NRL are very high they still do approach the 48,000 gamma predicted maximum measurable signal. To further address the problem it is necessary to consider how the sensor measures data. The EG&G Geometrics Model G-822A sensor reads the earth's magnetic field strength as a total field vector quantity. Figure 20 shows a low resolution plot of the earth's the field strength (which is ~52,000 at Los Alamos). The vector field intersects the earth's surface at a characteristic angle of inclination as shown in Figure 21. The angle of inclination for Central New Mexico is about 62°. These are ambient or background figures for an undisturbed field. However,

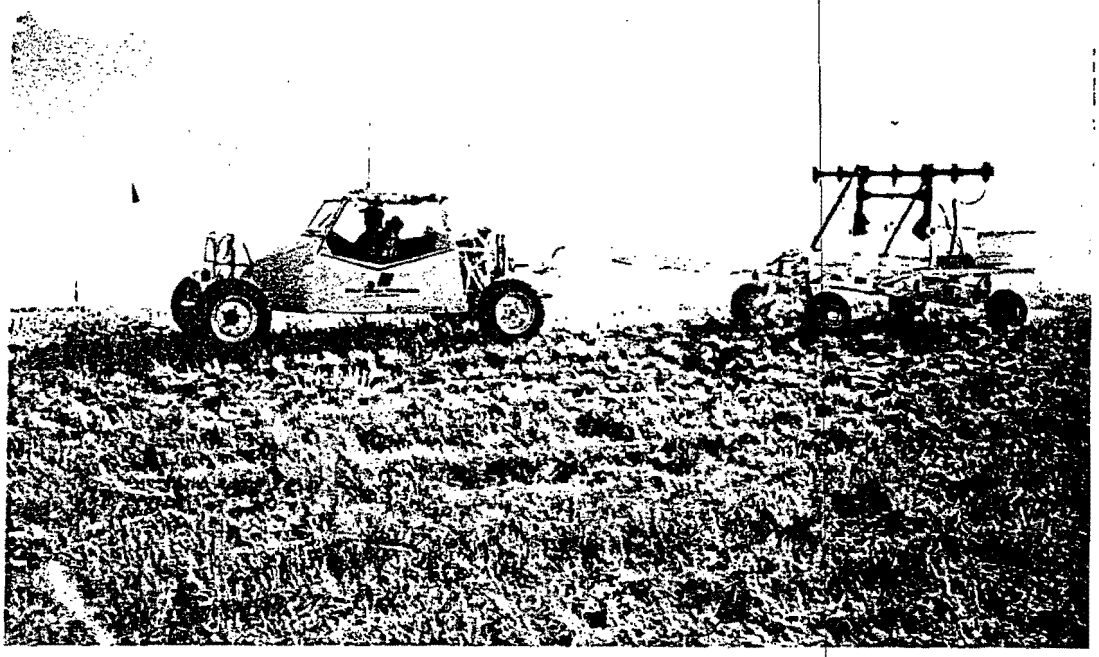

Figure 18. The tow vehicle with the magnetometer array set at 72."

when a magnetic dipole is induced in a ferrous target by the earth's field, a profound affect is created on the earth's field lines and their inclination. Figure 19c presents the same study taken at a speed of 8 mph with the magnetometer array at 72" above the ground. More than 90% of the holidays have disappeared and are replaced by normal magnetic anomaly data.

Figure 22 illustrates the active measurement zone for the Model 822 magnetometer. The sensors are mounted vertically on the tow vehicle. The earth's field (intersecting the surface at ~60° falls well within the active zone of the sensor. If the earth field lines impact the sensor at ≤15° to the vertical or ≤15° to the horizontal, the sensor will be in its "dead zone," its output will be incoherent and it is said to "go out of Larmour." Discussions with technical engineers at EG&G Geometrics, manufacturer of the sensor, confirmed that very large gradients are observed to bend the earth's magnetic field lines into the inactive zone, causing the sensor to lose Larmor. We therefore concluded that the 30,000 gamma holidays that we encountered at the NRL Landfill is a magnetic anomaly strength which correlates with driving the sensors into the inactive (incoherent) zone. In the design of the ***MTADS*** and STOLS II prototypes we had modeled this effect, concluded that it was not important and removed the angular tilt adjustment for the magnetometers which was built into the STOLS I preprototype.

We experienced data holidays at MDA C, Section 1 at ≤5,000 gamma. In retrospect we realize that Pit 5 lies on a significant down slope. We conclude that this slope, in

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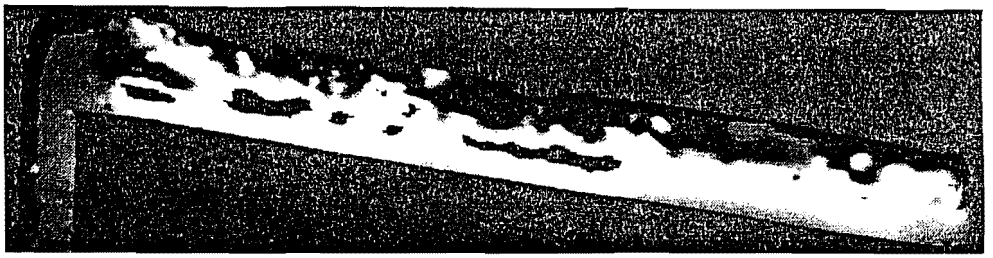
(a)

(b)



(c)

Figure 19. TA-50 MDA C , Section 1 magnetic anomaly images in greyscale. (a) survey taken with a magnetometer array height of 18" at a vehicle speed of 8 mph. (b) survey taken with a magnetometer array height of 18" at a vehicle speed of 3 mph. (c) survey taken at a magnetometer array height of 72" at a vehicle speed of 8 mph. All images are presented with sensitivity settings of -500 to 1000 gamma.

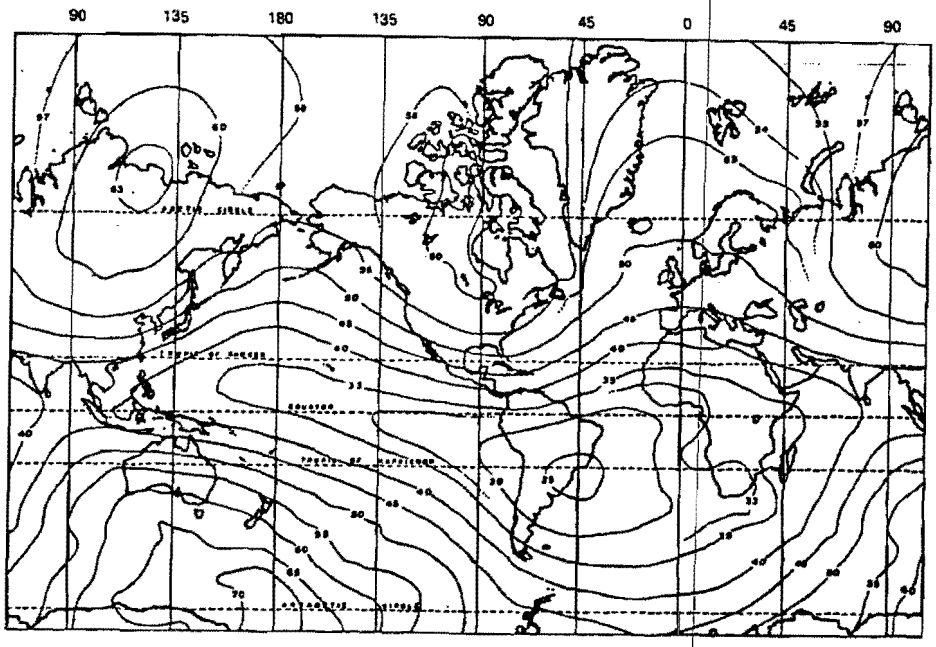


Figure 20. Contour plot (in kgamma) of the total intensity of the earth's magnetic field. See Ref. 8.

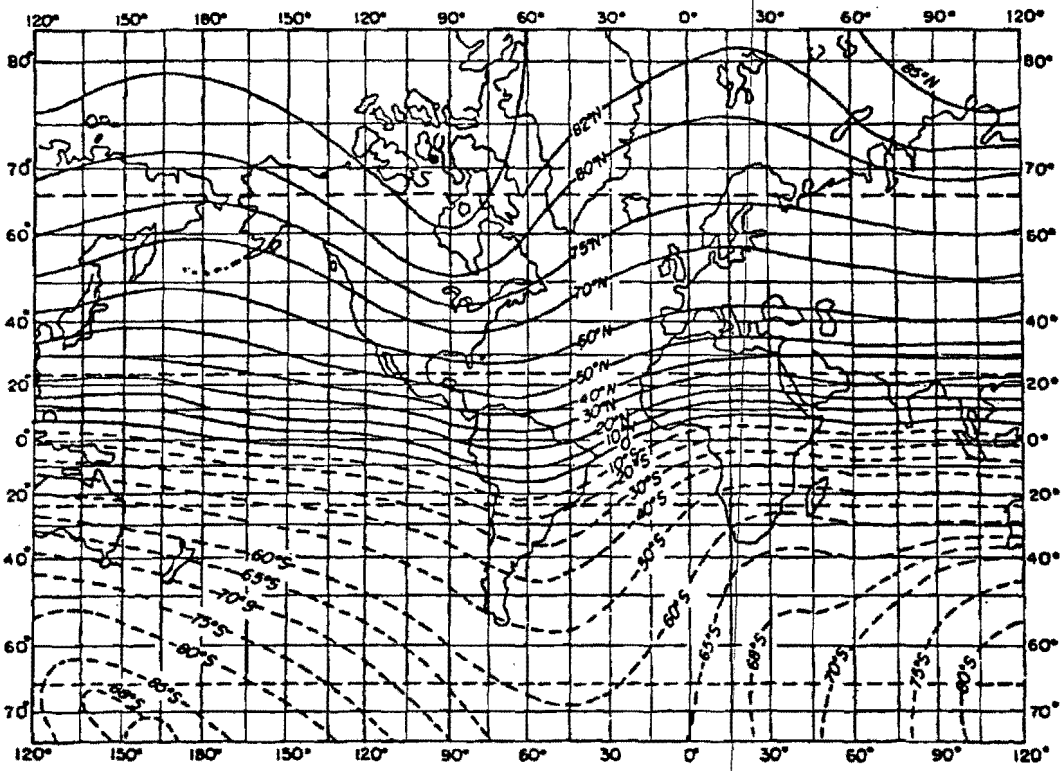


Figure 21. The geomagnetic inclination of the earth's field in degrees of arc from the horozontal. See Ref. 8.

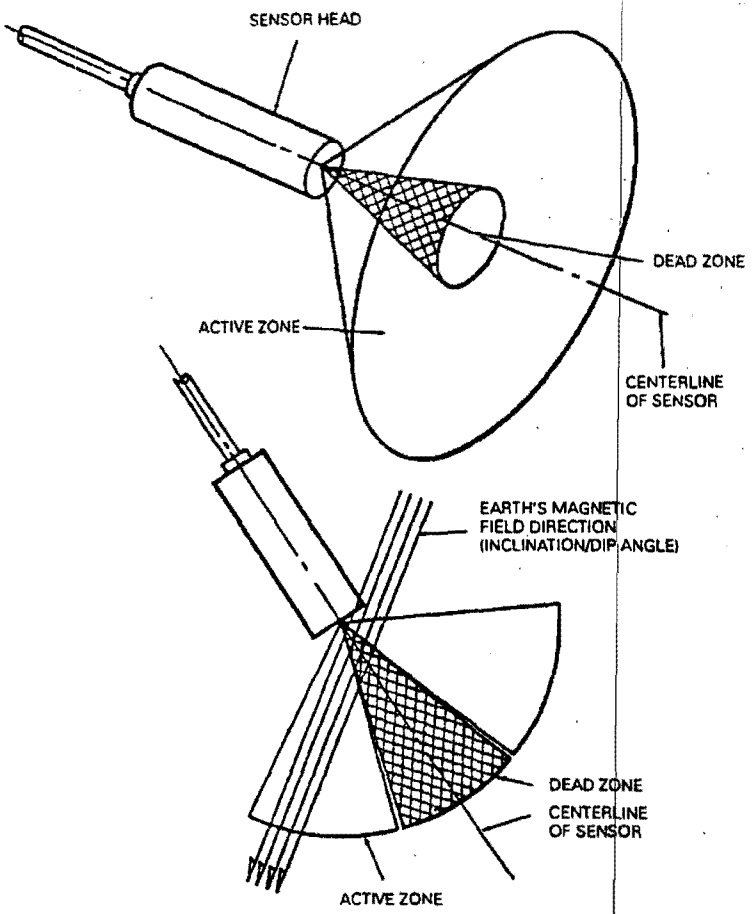


Figure 22. Definition of the active zone for Cesium vapor total-field magnetometers. See Ref 9.

conjunction with the change in the earth's magnetic field lines at 5,000 gamma, is enough to put the sensors in the dead zone, so the sensors went out of Larmor. A fix for the final ***MTADS*** prototype allowing setting the sensor orientation to vertical on relatively steep slopes when surveying landfills will allow one to avoid data holidays typical of those observed at Pit 5. Alternatively, the manufacturer is currently working on a sensor redesign to increase the size of the active zone.

Conclusion

The MDA C survey was very successful thanks in large part to the support provided by the Los Alamos staff in coordinating the surveys and the logistical support. We particularly wish to express our appreciation to Cheryl Roper, Alan Cogbill and Rene Evans for their support at MDA C. The equipment performed outstandingly well, and the data provide a view of the buried waste landfills at MDA C with a fidelity and accuracy that is apparently not otherwise available from other sources.

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