A MULTISPECTRAL SCANNER SURVEY OF THE TONOPAH TEST RANGE

NEVADA

DATE OF SURVEY: AUGUST 1993

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ABSTRACT

The Multispectral Remote Sensing Department of the Remote Sensing Laboratory conducted an airborne multispectral scanner survey of a portion of the Tonopah Test Range, Nevada. The survey was conducted on August 21 and 22, 1993, using a Daedalus AADS1268 scanner and coincident aerial color photography. Flight altitudes were 5,000 feet (1,524 meters) above ground level for systematic coverage and 1,000 feet (304 meters) for selected areas of special interest.

The multispectral scanner survey was initiated as part of an interim and limited investigation conducted to gather preliminary information regarding historical hazardous material release sites which could have environmental impacts. The overall investigation also includes an inventory of environmental restoration sites, a ground-based geophysical survey, and an aerial radiological survey,

The multispectral scanner imagery and coincident aerial photography were analyzed for the detection, identification, and mapping of man-made soil disturbances. Several standard image enhancement techniques were applied to the data to assist image interpretation. A geologic ratio enhancement and a color composite consisting of AADS1268 channels 10, 7, and 9 (mid-infrared, red, and near-infrared spectral bands) proved most useful for detecting soil disturbances.

A total of 358 disturbance sites were identified on the imagery and mapped using a geographic information system. Of these sites, 326 were located within the Tonopah Test Range while the remaining sites were present on the imagery but outside the site boundary. The mapped site locations are being used to support ongoing field investigations.

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1. INTRODUCTION

An airborne multispectral scanner (MSS) survey was conducted for a portion of the Tonopah Test Range (TTR) during late August 1993. The survey was conducted by the Multispectral Remote Sensing Department* of the U.S. Department of Energy's (DOE) Remote Sensing Laboratory (RSL). RSL is operated by EG&G Energy Measurements, Inc. (EG&G/EM), under the direction of the DOE Nevada Operations Office (DOE/NV).

1.1 Site Location and Background

The Tonopah Test Range is located in Nye County, Nevada, on the northern portion of the Nellis Air Force Bombing and Gunnery Range (Figure 1). It is about 37.5 miles (260 kilometers) northwest of Las Vegas by air, and about 40 miles (64 kilometers) southeast of Tonopah by road.

The TTR occupies approximately 850 square miles (1,360 square kilometers) and is bounded on three sides by the Nellis Air Force Bombing and Gunnery Range and on the north by sparsely populated public land administered by the Bureau of Land Management and the Forest Service. The remoteness of the TTR and its restricted airspace allows tests to be conducted with a high degree of safety and security.

Prior to 1957, this land was used as a bombing range by the U.S. Air Force. Since then, DOE has leased the TTR from the Air Force and the facility has been operated by Sandia National Laboratory. Sandia activities at the site are directed by DOE through the Albuquerque Operations Office (DOE/AL).

The first DOE test at TTR was conducted in 1957, after similar facilities at Salton Sea Test Base (California) and Yucca Flat Test Base (Nevada Test Site) became inadequate.¹ In 1958, the TTR was made into a permanent facility for field testing conventional and nuclear weapons, research rockets, and artillery.² The prime mission of the TTR is to provide research and development test support for DOE nuclear ordnance programs.³

Sandia National Laboratory activity at the TTR has included air drops, artillery projectile firings, ground-launched rockets (both high altitude and low altitude), air-launched rockets, explosion effect tests, earth penetrator tests, cruise missile flights, and many miscellaneous activities requiring a remote

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* Now designated the Spectral Imaging and Geographic Information Systems (SIGIS) Section.

116°55'0"

116°50'0"

116°45'0"

116°40'0"

116°

116°35'0" 116°30'0" 116°25'0"

Tonopah Test Range Site Map

- Tonopah Test Range Boundary
- Class 3 Roads
- Class 4 Roads
- Wash
- Dry Lake or Pond

TTR Site Location Map

2500 0 2500 5000 7500 10000 METERS

NTS-94-004

range for safety and/or security requirements. Range instrumentation includes tracking radars, optical tracking and recording instruments, telemetry receiving and recording equipment, and extensive radio and hardwire communications systems.

The MSS survey discussed in this report was initiated as part of an interim and limited investigation conducted by DOE/NV at the TTR. The focus of this effort is to gather preliminary information regarding historical hazardous material release sites which could have environmental impacts. The investigation includes an inventory of environmental restoration sites, a ground-based geophysical survey, an aerial radiological survey, and this aerial MSS and photographic survey.

The DOE/NV Environmental Restoration Division has assumed the lead role in conducting the investigation with DOE/AL maintaining an oversight role. The information collected in this limited investigation will provide a basis for the preparation of a Resource Conservation and Recovery Act Facility Investigation Work Plan to guide future characterization of sites discovered in this process.⁴

1.2 Project Objectives

The primary objectives of this project were to:

- Acquire 12-channel MSS data of the TTR covering an area approximately 18 miles by 20 miles (28 km by 30 km) at an altitude of 5,000 feet (1,524 meters) above ground level (AGL).
- Acquire 12-channel MSS data at selected study sites from an altitude of 1,000 feet (304 meters) AGL.
- Collect large-format color aerial photographs over the site simultaneously with the scanner data.
- Analyze these data and identify potential sites of buried waste, contaminated soil, and other man-made disturbances.

1.3 Project Deliverables

Standard project deliverables for an MSS and photographic survey include a proof set of the aerial photographs and a mission summary report.

This mission summary report includes the following:

- A summary description of the MSS and aerial photographic mission at the TTR
- A brief overview of the scanner system and data format
- A description of the analysis procedures used to prepare selected image enhancements
- An image map of the TTR created with Landsat Thematic Mapper data
- The MSS Data Index (3 sheets) for the entire set of scanner data collected during the aerial survey
- Selected MSS color composites, including a geological color enhancement and several multi-channel enhancements
- A color map showing the location of disturbance areas. The map data are stored in a Geographic Information System (GIS) database.

Two examples of GIS image map products are included in this report (Figures 1 and 11). These map products were produced using geo-coded Landsat Thematic Mapper satellite data as the background. The site boundary coverage was provided by International Technology Corporation (ITC) personnel using data provided in the AutoCAD DXF graphics file format. The roads and hydrography data layers used were extracted from United States Geological Survey (USGS) 1:100,000 scale digital line graph data sets.

Additional data products from this mission can be made available. These are briefly described in the next section.

1.4 Optional Products

Proof books of the aerial photographs are available from RSL. Specific photos in these books can be identified by the unique roll and frame identifier imprinted along the top edge of each photo. Original photography is archived at RSL, and copies and enlargements of any aerial photographs can be produced by the RSL Photo/Video Section.

The selected examples of MSS data presented in this report illustrate the unique capability of scanner imagery for detecting soil disturbance sites in an arid environment. MSS imagery can be processed for a wide variety of applications. These products may be requested in digital form (data in tape or optical

disk format), photographically produced images such as are presented with this report, or in more extensive analysis report form. Some products can be prepared with a minimum of direction from the end-user; others may require a great amount of interaction with site personnel and/or scientists from multiple disciplines. Field visits by the image analysts are often involved to improve site familiarity.

2. MULTISPECTRAL SCANNER SYSTEM

The Daedalus AADS1268 MSS is an airborne electro-optical scanner system of proven quality and usefulness for the environmental remote sensing community. It is one of three Daedalus scanners maintained and operated by RSL for DOE applications. These MSS systems are flown on a regular basis and the collected data are used for a variety of environmental and target signature applications.

For some applications, the unique features of the airborne MSS systems operated by RSL offer major advantages over traditional aerial photography and commercial remote sensing satellites. The scanners collect spectral responses at wavelengths that are impossible to collect with aerial photography. By flying at lower altitudes, the scanners can also collect data at much finer spatial resolution than that available from current commercial satellites.

The manufacturer's nominal system specifications for the instrument flown during the TTR survey are summarized in Table 1. The measured channel sensitivities are provided in Table 2.

Table 1. Daedalus AADS1268 MSS Specifications	
Number of Channels	12
Operating Wavelengths	0.42 μm to 12.5 μm
Scan Rate	12.5, 25, 50, or 100 scans/second (selectable)
Instantaneous Field of View (IFOV)	2.5 milliradians (1.25 mrad half-angle mode)
Total Field of View (FOV)	85.92 degrees
Temperature Resolution	0.1 centigrade
Roll Correction	± 15 degrees
Reference Sources	Infrared: two controllable, thermal blackbodies
Video Words/Scan Line	716
Digitizer Gains	0.5, 1, 2, 4, or 8 (selectable)

Table 2. Measured Spectral Sensitivity of Daedalus AADS1268 MSS System		
Channel Number	Wavelength (μm)	Color Spectrum
1	0.42 - 0.44	Violet / Blue
2	0.46 - 0.51	Blue / Green
3	0.52 - 0.59	Green / Yellow
4	0.59 - 0.62	Orange
5	0.62 - 0.67	Red
6	0.67 - 0.72	Near Infrared
7	0.73 - 0.85	Near Infrared
8	0.84 - 0.97	Near Infrared
9	1.59 - 1.79	Middle Infrared
10	2.1 - 2.4	Middle Infrared
11	8.28 - 10.67	Thermal Infrared
12	8.28 - 10.67	Thermal Infrared
Alternate Configuration		
10	—	—
11	3.16 - 5.20	Thermal Infrared
12	8.28 - 10.67	Thermal Infrared

The scanner contains four detector packages with a total of eleven discrete elements (Figure 2). Reflected and/or emitted electromagnetic energy enters the scanner from the bottom and strikes a rotating “axe-blade” mirror, which reflects it into the detector housing. Within the housing a prism and a series of dichroic filters spectrally decompose the energy onto the detectors.

Channels 1 through 8 are generated by a single silicon detector array. This array is contained in an integrated circuit-like package. Channels 9 and 10 are generated by separate detectors. A thermal infrared (TIR) detector that generates channels 11 and 12 resides inside a dewar, which is cooled by liquid nitrogen to increase its sensitivity. Channels 11 and 12 can be set at different gain levels for the same TIR signal, providing an increased sensitivity for one channel and a broader dynamic range for the other.

Electromagnetic energy striking the detectors produces a photovoltaic effect proportional to the number of photons striking at a given instant. The signal is amplified and converted into an 8-bit digital

value, which is then recorded onto a high-density digital tape (HDDT). The resulting spatial array of data represents a two-dimensional image proportional to the reflectance or emitted energy of the scene features. The scanner has selectable scan rates (up to 100 scan lines per second), which are necessary to assure contiguous coverage from different altitudes and relative ground speeds.

3. MSS AND PHOTO DATA ACQUISITION

The MSS imagery and vertical photography were acquired simultaneously during the TTR survey. The survey was flown with a Citation CE-550, a small twin-engine jet aircraft, modified with multiple ports in the floor to accommodate remote sensing equipment. Sky conditions were clear during both days of the MSS acquisitions, but summer thermals created substantial air turbulence. These were especially noted during the lower altitude acquisitions.

3.1 MSS Acquisition

A major portion of TTR was covered by twenty parallel flightlines. These lines were flown at 5,000 feet (1,524 meters) AGL with north/south headings. The nominal spatial resolution of scanner pixels at this altitude was approximately 12.5 feet (4 meters). The area covered was approximately 18 miles by 20 miles (28 km by 30 km).

Three of the higher altitude flightlines of MSS imagery were successfully acquired on August 21, 1993. A hardware problem was encountered that affected the remaining flights for that day. The equipment was repaired and the remaining flightlines were flown on August 22, 1993. The solar off-axis azimuth ranged from 17° to 84° off the axis of the flightline during the MSS acquisitions. The solar elevation ranged from 30° to 64° above the horizon.

Six specific areas, previously identified by ITC for further study, were flown at 1,000 feet (304 meters) AGL to provide better spatial resolution data. The nominal scanner pixel resolution at this altitude was 2.5 feet (0.8 meters). These sites of special interest were flown at various headings and required eight flightlines for complete coverage.

3.2 Photo Acquisition

A Wild Leica RC-30 metric mapping camera was used to acquire large-format (9-inch or 228mm) photographs of the site and surrounding area. A 6-inch (153mm) lens was used with Aerocolor film for color photography. Photo scales of 1:10,000 and 1:2,000 resulted from the two altitudes that were flown in conjunction with the scanner. All photos were collected with standard 60% endlap to facilitate stereoscopic viewing and sufficient sidelap (30%) to ensure contiguous coverage. The photos are of general utility as well as a valuable aid for MSS image analysis.

Data quality problems were encountered on flightline (+30) of the aerial photography. This one line was reflown a week later (September 3, 1993), without the MSS, and good quality photography was obtained.

3.3 Flightline Summary

A summary of the flightline specifications is presented as Table 3. Each of the first four columns in the table provides information needed to uniquely identify each data set. The first, second, and fourth columns are the date, time (military notation), and the target or site location. The third column lists the run and line number combination.

The run number is a sequential number advanced after each flightline by the scanner operator and imbedded into the data housekeeping. It is normally begun at number 11 when starting a new tape. The next number will identify the blank period on the tape before the next flightline of data, hence the skipping of numbers in the sequence. Aborted or bad lines that are not listed in a final version of the data acquisition table will cause other skipped numbers. It is normal to have more than one "Run 11" during a mission as multiple HDDTs are typically used.

The line number is a reference to the MRS (Microwave Ranging System) navigational system alignment. To set up the MRS program, it is necessary to first identify an axis or "0" flightline. The 0 line is the one from which all other parallel lines are referenced. The 0 line is selected prior to the survey and can be anywhere within, or outside of, the survey area as long as it has the correct heading and two ground features that can be used as control or "hack" points.

Table 3. Multispectral Scanner and Photography Summary

Date	Time PDT	Run/Line#	Target	Feet AGL	True Head	Perf #	Frame #s	Photo Scale	Comments
8/21/93	0848	11/+60	TTR Site	5,000	185°	7520	001-038	1:10,000	Good
8/21/93	0900	13/+45	TTR Site	5,000	360°	7520	039-076	1:10,000	Good
8/21/93	0908	15/+55	TTR Site	5,000	185°	7520	077-113	1:10,000	Good
8/21/93	0917	NA/+40	TTR Site	5,000	005°	7520	114-128	1:10,000	MSS data bad, abort
8/21/93	0926	NA/+40	TTR Site	5,000	002°	7520	129-167	1:10,000	MSS data bad
8/21/93	0936	NA/+50	TTR Site	5,000	185°	7520	168-206	1:10,000	MSS data bad
8/21/93	1120	NA/-35	TTR Site	5,000	360°	7521	001-040	1:10,000	MSS data bad, turbulent
8/21/93	1136	NA/-20	TTR Site	5,000	185°	7521	041-081	1:10,000	MSS data bad
8/21/93	1145	NA/-5	TTR Site	5,000	359°	7521	082-122	1:10,000	MSS data bad, speed changing
8/21/93	1155	NA/+10	TTR Site	5,000	185°	7521	123-161	1:10,000	MSS data bad
8/21/93	1204	NA/+25	TTR Site	5,000	004°	7521	162-199	1:10,000	MSS data bad
8/21/93	1221	NA/+30	TTR Site	5,000	184°	7522	013-037	1:10,000	MSS data bad, camera not level
8/21/93	1251	NA	Area 9 (west)	1,000	185°	7522	038-048	1:2,000	No MSS data
8/22/93	0848	31/+50	TTR Site	5,000	360°	NA	NA	NA	No photos acq.
8/22/93	0858	33/+40	TTR Site	5,000	188°	NA	NA	NA	No photos acq.
8/22/93	0908	35/+35	TTR Site	5,000	003°	7522	049-083	1:10,000	Ch 1&3 some sat.
8/22/93	0924	37/+30	TTR Site	5,000	188°	NA	NA	NA	37.5 T spread; Ch 5 some sat. Ch 1,3 gain lowered
8/22/93	0934	39/+25	TTR Site	5,000	003°	NA	NA	NA	Ch 5,7 gain lowered
8/22/93	0944	41/+20	TTR Site	5,000	187°	7522	084-119	1:10,000	Good
8/22/93	0954	43/+15	TTR Site	5,000	004°	7522	120-155	1:10,000	Ch 2,4,6 gain lowr'd
8/22/93	1003	45/+5	TTR Site	5,000	187°	7522	156-193	1:10,000	Ch 8 gain lowered
8/22/93	1011	47/+10	TTR Site	5,000	001°	NA	NA	NA	Good
8/22/93	1130	11/0	TTR Site	5,000	187°	7523	001-042	1:10,000	Turbulent
8/22/93	1140	13/-5	TTR Site	5,000	005°	NA	NA	NA	Ch 1-5 some sat.
8/22/93	1139	15/-10	TTR Site	5,000	185°	7523	043-081	1:10,000	Good

Note: Headings have been by adjusted ( ) 15° in this summary to read "true" rather than "magnetic" north. Daedalus 1268 Multispectral Scanner: Spectrometer, 1.6 mm, 2.2 mm, and 8-12 mm Detectors; 2.5 Mrad IFOV. Wild RC-30 camera: 153mm Lens, Aerocolor Negative Film.

Table 3. Multispectral Scanner and Photography Summary (continued)

Date	Time PDT	Run/Line#	Target	Feet AGL	True Head	Perf #	Frame #s	Photo Scale	Comments
8/22/93	1159	17/-15	TTR Site	5,000	360°	7523	082-121	1:10,000	Good
8/22/93	1208	20/-20	TTR Site	5,000	185°	NA	NA	NA	Good
8/22/93	1218	22/-25	TTR Site	5,000	002°	7523	122-162	1:10,000	Good
8/22/93	1226	25/-30	TTR Site	5,000	184°	7523	163-202	1:10,000	Good
8/22/93	1236	27/-35	TTR Site	5,000	003°	NA	NA	NA	Good
8/22/93	1254	29/vis	Double Tracks Decon Area	1,000	075°	7524	001-020	1:2,000	Good, turbulent
8/22/93	1259	31/vis	Roller Coaster Decon Area	1,000	055°	7524	021-027	1:2,000	Good
8/22/93	1300	33/vis	Ned's Lake	1,000	345°	7524	028-033	1:2,000	Good
8/22/93	1303	35/vis	Area 9 (west)	1,000	345°	7524	034-044	1:2,000	Good
8/22/93	1306	37/vis	Area 9 (center)	1,000	165°	7524	045-060	1:2,000	Good
8/22/93	1310	39/vis	Area 9 (east)	1,000	345°	7524	061-074	1:2,000	Good
8/22/93	1312	41/vis	Area 9 (east)	1,000	166°	7524	075-088	1:2,000	Good
8/22/93	1315	43/vis	Artillery Round (38)	1,000	314°	7524	089-103	1:2,000	Good
8/22/93	1318	45/vis	Artillery Round (38)	1,000	145°	7524	104-115	1:2,000	Good
8/22/93	1328	47/vis	Area 3 CP (west)	1,000	210°	7524	116-131	1:2,000	Good
8/22/93	1326	50/vis	Area 3 CP (east)	1,000	216°	7524	132-149	1:2,000	Good
9/3/93	0938	NA/+30	TTR Site	5,000	005°	7524	171-188	1:10,000	No MSS, good

Note: Headings have been by adjusted ( ) 15° in this summary to read "true" rather than "magnetic" north. Daedalus 1268 Multispectral Scanner: Spectrometer, 1.6 mm, 2.2 mm, and 8-12 mm Detectors; 2.5 Mrad IFOV. Wild RC-30 camera: 153mm Lens, Aerocolor Negative Film.

The run/line number combination is only applicable when the scanner and the MRS are both used. A scanner line flown without benefit of the MRS would show a run number only, or a run number combined with "vis" for a flightline that was navigated visually. The MRS may also be used for photo collection alone, without the MSS, and when this is the case there will be no run number, just the line number. It is possible that a run number and line number combination will be repeated, making it necessary to use the date and/or time to differentiate between the two. Often, more than one 0 line will also be set up for a mission, making the target or location name also a necessary part of the identifier. To understand where the flightlines are located, a map, with at least the 0 line(s) and the + and - offset direction identified, is necessary.

4. MSS DATA PREPROCESSING

The Daedalus AADS1268 MSS data undergoes a series of standard data preprocessing steps prior to analysis. These include decommutation, systematic geometric processing, and radiometric calibration of the thermal channels. In addition, index images are often prepared to assist data review and selection.

4.1 MSS Data Decommutation

MSS data recorded on the HDDT must be decommutated prior to digital image processing. Decommutation is the conversion of an analog, serial, bit data stream to a digital format that is readable by computer. The data are decommutated from HDDT format into a computer compatible format. The data are quality checked and then archived to optical disk. The output raw byte data can be provided on several different types of media, currently including 8mm and 9-track computer tapes, and optical disk. A variety of standard image processing systems file formats are also available.

4.2 Geometric Correction

Prior to analysis, the decommutated data are usually corrected for systematic geometric distortions. The data are processed to minimize the tangential distortion (s-bend) inherent in electro-optical scanner data and to compensate for any overscan based on the scan rate and velocity/height ratio.

4.3 Radiometric Calibration

The channels containing thermal infrared data (channels 11 and 12) are radiometrically calibrated, based on the recorded temperatures of the two internal reference blackbodies. The relative difference in apparent temperature between two features is considered nominally accurate to within one tenth of a degree centigrade. To obtain the absolute temperature of any feature, additional information about atmospheric conditions and the emissivity characteristics of the feature must be known. This usually involves on-site ground temperature measurements during the airborne data acquisitions.

4.4 MSS Data Index

The preprocessed data are used to produce an MSS data index. The image resulting from each flight-line is subsampled, annotated, and positioned on the index sheets. The digital image index is then film recorded. The index provides an overview of the entire survey and can be used to select specific lines of interest for subsequent analysis. It also provides an indication of the MSS data quality. Three index sheets, Figures 3, 4, and 5 (SIGIS 94066.01, 94066.02, and 94066.03), were prepared for the TTR survey.

5. MSS IMAGE ENHANCEMENT

The spectral signals recorded by MSS systems have proven useful for characterizing a variety of environmental conditions. As these signals are recorded in digital format, computer-assisted image processing techniques can be used to enhance specific spectral features and thereby increase the utility of the image products for specific applications.

Interactive digital image analyses were performed on the TTR data using Hewlett Packard workstations and the EASI-PACE Image Processing system developed by PCI (Ontario, Canada). The image processing techniques employed ranged from very simple and straightforward enhancements to complex and iterative processing algorithms. The systematic application of image enhancement procedures can benefit by first reviewing the basic phenomenology of the application of interest. The following section briefly addresses the detection of land cover disturbances in arid environments.

5.1 Background Phenomenology

The detection of land cover disturbances with visible, reflective infrared, and thermal infrared energy depends on many surface and subsurface characteristics. These factors interact and change in relative importance making the net spectral effect difficult to predict. In addition, the potential range of background conditions that might be present must also be considered. Fortunately, the arid climate and sparse vegetation at TTR are conditions where MSS image enhancement techniques have proven especially useful for detecting soil disturbances.

TONOPAH TEST RANGE

TONOPAH, NEVADA

21, 22 AUGUST 1993

5,000 FEET AGL

RUN/LINE 27/-35

TIME 12:36

RUN/LINE 25/-30

TIME 12:26

RUN/LINE 22/-25

TIME 12:18

RUN/LINE 20/-20

TIME 12:08

RUN/LINE 17/-15

TIME 11:59

RUN/LINE 15/-10

TIME 11:39

RUN/LINE 13/-5

TIME 11:40

RUN/LINE 11/0

TIME 11:30

RUN/LINE 45/+5

TIME 10:03

RUN/LINE 47/+10

TIME 10:11

TONOPAH TEST RANGE

TONOPAH, NEVADA

21, 22 AUGUST 1993

5,000 FEET AGL

RUN/LINE 43/+15
TIME 09:54

RUN/LINE 41/+20
TIME 09:44

RUN/LINE 39/+25
TIME 09:34

RUN/LINE 37/+30
TIME 09:24

RUN/LINE 35/+35
TIME 09:08

RUN/LINE 33/+40
TIME 08:58

RUN/LINE 31/+45
TIME 09:00

RUN/LINE 29/+50
TIME 08:48

RUN/LINE 27/+55
TIME 09:03

RUN/LINE 25/+60
TIME 08:48

TONOPAH TEST RANGE

TONOPAH, NEVADA

22 AUGUST 1993

1.000 FEET AGL

DOUBLE TRACKS

RUN 29 TIME 12:54

AREA 9

RUN 37 TIME 13:06

RUN 35 TIME 13:03

RUN 39 TIME 13:10

NEDS LAKE

RUN 33 TIME 13:00

ROLLER COASTER DECON

RUN 31 TIME 12:59

AREA 3

RUN 47 TIME 13:23

RUN 50 TIME 13:26

ARTILLERY ROUND 38

RUN 45 TIME 13:18

The act of burying an object or material typically involves clearing any vegetation cover, removing some soil, placement of the object or material, and replacing the soil. Since this process is normally accomplished by scraping the earth over the top of the site, areas that have been scraped and are completely clear of vegetation are often readily apparent. Even the most arid areas usually have some vegetation that will be affected by the burying of an object. Soil removal may result in slow recovery and/or long-term vegetation stress. Conversely, however, it may actually improve vegetation growth by aerating the soil and/or changing drainage and soil moisture conditions. The new vegetation may also involve a different species mix. In either case, MSS sensing techniques have been developed that will often detect these types of changes in vegetation conditions.

Many soils are vertically stratified and the mixing of soils by digging will change their surface appearance (color, composition, texture, and moisture content). These types of changes will usually modify the observed spectral reflectance of the soil. The mineral elements of many soils have distinct spectral characteristics in the middle infrared region that affect their discrimination. The disturbance of even homogeneous soils can still affect the geometry of the surface. Rough soils are generally darker than smooth soils and directional reflectance differences will be larger. As a result, many differences that are not apparent visually or on color photography can become readily apparent in MSS imagery.

As indicated by this brief review of relevant factors, man-made disturbances to the soil regime can affect the soil and vegetation cover in many ways. This can result in various spectral response changes indicative of soil disturbance. Remote sensing techniques are available to detect and enhance these spectral responses.

5.2 Contrast Enhancements

When a digital image is created, the quantizing process defines a discrete range of values which is often termed gray or brightness levels. For Daedalus AADS1268 digital imagery, the available brightness levels range from 0 (black, or no signal available) to 255 (white, maximum signal). Sensor gain levels are usually set to span the full range of conditions that might be present on each flightline of data collection, resulting in no clipping (low end) or saturation (high end).

The apparent contrast (or relative difference in brightness values) between specific scene features can often be improved by applying digital contrast enhancement, which takes a narrow range of the raw

data and stretches it to cover the full potential range of the display device. This allows subtle differences in tone between different features on the ground to be emphasized and become more visually apparent. All of the examples shown in the following sections have been contrast enhanced.

5.3 MSS Color Composites

The visual perception of color is usually more acute than for shades of gray. Computer monitors and film recorders use three color signals to create color composite images. Various image processing procedures are available to select and combine MSS imagery into color composites.

5.3.1 Standard Color Composites

A standard color composite image is a three-channel combination of different MSS channels. The color of features in a standard composite image is a function of relative radiance differences in the spectral channels selected for the composite. When the Daedalus AADS1268 channels equivalent to the red, green, and blue wavelengths (channels 5, 3, and 2) are combined and displayed in the corresponding colors, the result is analogous to a color photograph. In this composite, the colors of scene features are similar to colors as they would appear visually or in color photography.

Any three MSS channels, including the thermal channel, can be used to produce an MSS color composite. A standard approach is to select a channel combination that produces the most color separation between the features of interest and the background. Several techniques have been developed to facilitate this process of channel set selection.

Figures 6 and 7 present three MSS color composites which were selected to differentiate features contained in dry lake beds (NEDS Lake and Pedro Lake, respectively). The enhanced color composites were selected by visual examination of various channel combinations on the computer monitor.

The left half of Figure 6 is a standard color composite of channels 5, 3, and 2 for the same area; this composite is provided as a basis for comparison of the enhanced imagery. The right half of the figure is a composite of channels 10, 7, 5. Due to the nature of solar illumination and atmospheric conditions, different contrast enhancements were applied to the lake and the surrounding background. The result is the

TONOPAH TEST RANGE

MSS Color Composite Channels 10, 7, 5 (R, G, B)
1,000 feet AGL

MSS Natural Color Composite Channels 5, 3, 2 (R, G, B)
5,000 feet AGL

NEDS LAKE

22 AUGUST 1993

- Known Disturbance
- Unknown Disturbance

TONOPAH TEST RANGE

PEDRO LAKE

22 AUGUST 1993

MSS Color Composite Channels 9, 7, 5 (R, G, B)
5,000 feet AGL

“halo” effect seen on the background data. The addition of the middle infrared (channel 10) brings out detail that is not available in the standard color composite. The input imagery was enhanced to show details of interest and the difference is striking. Vehicular tracks, various targets, and other disturbances are clearly visible.

The second color composite (Figure 7), for Pedro Lake, consists of channels 9, 7, and 5. This composite also shows greater detail in the dry lake bed than is possible with color aerial photography. A middle infrared channel (channel 9) was once again responsible for much of the feature enhancement.

5.3.2 Geologic Enhancement

A useful image enhancement for sparsely vegetated areas, such as the TTR, is commonly referred to as a geologic ratio enhancement. This enhancement brings out subtle differences in mineral types by ratioing appropriate pairs of MSS channels. The enhancement used was generated by: 1) dividing channel 9 by channel 10 and displaying the result as the red signal, 2) dividing channel 9 by channel 7 and displaying the result as green, and 3) dividing channel 5 by channel 2 and displaying the result as blue. Each image was then contrast stretched to further enhance subtle details. Figures 8 and 9 represent examples of this geologic enhancement.

Although the disturbance on Figure 8 is seen in color aerial photographs, the extent of the disturbance is not as apparent. The disturbed areas appear as shades of purple in this enhancement. The purple area extends out from both sides of the road as expected, since the area was disturbed by the building of the road.

Figure 9 is a mosaic of the three 1,000-foot flightlines over Area 9 with the geologic enhancement applied. The Area 9 landfill, a previously known feature, clearly appears as a purple area consistent with the results in Figure 8. Other purple areas are indicative of additional disturbances. The available site information gives no indication that these are disposal sites. Further investigation of the areas is warranted. The dark green areas correspond to concrete road surfaces, while the bright orange areas indicate asphalt road surfaces. Graded road surfaces are denoted in shades of purple.

TONOPAH TEST RANGE

Geologic Enhancement Channels 9/10, 9/7, 5/2 (R.G.B.)
1,000 feet AGL

ROLLER COASTER DECON

22 AUGUST 1993

TONOPAH TEST RANGE

Geologic Enhancement Channels 9/10 9/7 5/2 (R G B)
1 000 Feet AGL

- Known Disturbance
- Unknown Disturbance

AREA 9

22 AUGUST 1993

5.3.3 Optimal Composite

With 11 distinct spectral channels available, there are 990 possible three-channel combinations of the data. The process of selecting combinations that maximize statistical separability is called feature selection. A commonly accepted measure of statistical separability is the transformed divergence criteria.⁵ This technique involved gathering statistics for a known disturbed area and a homogeneous background for the 11 channels. These statistics were then used for all three-channel combinations of the 11 possible channels and the transformed divergence for each combination was calculated.

The results were tabulated and sorted such that the combinations with the largest divergence were ranked highest. The top twenty ranked channel combinations were investigated by displaying them on the monitor and selecting the best combination for visual separation of the disturbed area from the background. The optimum channel combination is represented by an MSS color composite of channel 10 (mid-infrared), channel 7 (red), and channel 9 (near-infrared) as red, green, and blue, respectively.

The results of this process are shown in Figure 10. The disturbed areas are dark green in color and match previously known areas. Although this technique does not discriminate between man-made and natural disturbance, it does give an indication where to search and was used in the analysis of the 5,000-foot (1,524-meter) data.

6. IMAGE ANALYSIS AND AERIAL PHOTO INTERPRETATION

The previously mentioned techniques were applied to the MSS data and each flightline was reviewed for signs of disturbance. The optimal channel combination was displayed on the monitor and various contrast stretches were applied as appropriate. Since there was a large illumination effect, it was necessary to continually update the stretch to respond to these variations.

The aerial photography was cross-referenced during the data reviews to assist verification of the disturbance sites. When interpretations indicated a site was the result of a naturally-occurring phenomenon, such as stream runoff caused by flash flooding, it was removed from the list of potential sites.

The potential sites for man-made disturbances were logged (Appendix A) and their locations annotated on the color aerial photography. Next, these locations were transferred to 7.5-minute USGS topographic maps. These data were reviewed by a second analyst to verify the locations of the identified disturbances. The locational data were then coordinate digitized using the ARC/INFO GIS, available from

TONOPAH TEST RANGE

MSS Color Composite Channels 10 7 9 (R G B)
1 000 feet AGL

MSS Natural Color Composite Channels 5 3 2 (R G B)
1 000 feet AGL

- Known Disturbance
- Unknown Disturbance

AREA 3

22 AUGUST 1993

Environmental Systems Research Institute (ESRI; Redlands, California). For final presentation, the data were plotted as an overlay on the TTR site map described earlier (Figure 11).

A total of 358 disturbance sites were identified. Of these sites, 326 were within the boundaries of the TTR, while the remainder were outside. The locations outside the TTR boundaries were identified on the MSS and aerial photography without regard to location and can easily be eliminated by the ARC/INFO GIS. The disturbance sites were visually classified according to probable source and estimated map locational accuracy using a 5-digit ID number. The accuracy of placement and frequency of occurrence are indicated in Table 4. For example, the first number in Appendix A is 00113.

The first three digits are the unique point identifier. **00113**

The fourth digit is an estimate of the accuracy of point placement. **00113**

The fifth digit is the type of disturbance. **00113**

Table 4. Accuracy and Disturbance Area Key and Summary		
Accuracy Code	Limits	Frequency
1	± 75 meters	140
2	± 150 meters	145
3	± 300 meters	73
Disturbance Code	Disturbance Type	Frequency
1	Facility	75
2	Berm	3
3	Bomb crater	5
4	Suspect area	161
5	Scraped earth	95
6	Equipment/Debris	18

116°35'0" 116°30'0" 116°25'0"

Tonopah Test Range Potential Disturbance Locations

37°50'0"

37°45'0"

37°40'0"

37°35'0"

Tonopah Test Range Boundary

Class 3 Roads

Class 4 Roads

Wash

Dry Lake or Pond

Disturbed Earth Sites

TTR Site Location Map

2500 0 2500 5000 7500 10000 METERS

NTS-94-003

7. SUMMARY AND CONCLUSIONS

The Multispectral Remote Sensing Department* of the Remote Sensing Laboratory conducted an airborne MSS survey of a portion of the Tonopah Test Range, Nevada, and the surrounding area. The survey was initiated as part of an interim and limited investigation conducted by DOE/NV. The focus of this effort is to gather preliminary information regarding historical hazardous material release sites which could have environmental impacts. The overall investigation includes an inventory of environmental restoration sites, a ground-based geophysical survey, an aerial radiological survey, and this aerial MSS and photographic survey.

The MSS survey was conducted on August 21 and 22, 1993. Twelve-channel daytime MSS data were collected using a Daedalus AADS1268 MSS system. Flight altitudes were 1,000 and 5,000 feet (304 and 1,524 meters) above ground level. Simultaneous color aerial photography was acquired with the scanner data.

The MSS imagery and coincident aerial photography were analyzed for the detection, identification, and mapping of man-made disturbances such as landfills. MSS imagery provided key spectral discriminants, while aerial photography provided higher spatial resolution and stereo-viewing capability.

Several standard image enhancement techniques were applied to the data to assist image interpretation. A geologic ratio enhancement and a color composite consisting of AADS1268 channels 10, 7, and 9 (mid-infrared, red, and near-infrared spectral bands) proved most useful for detecting soil disturbances.

A total of 358 disturbance sites were identified on the imagery and mapped using a geographic information system. The geometric fidelity of the aerial photography proved useful during the final mapping of disturbance sites. The high spatial resolution and stereo-viewing of the photography significantly assisted the image analysis process.

Of the sites mapped, 326 were found to be located within the Tonopah Test Range. The remaining sites were present on the imagery but were located outside of the boundary adjacent to the site. The mapped site locations are being used to support ongoing field investigations for identifying historical hazardous material release sites which could have environmental impacts.

A major conclusion of this study was that the spectral response characteristics of MSS imagery can provide a unique capability for detecting man-made soil disturbances in an arid environment. Digital enhancement of the MSS data provided results not attainable from conventional aerial photographic systems.

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* Now designated the Spectral Imaging and Geographic Information Systems (SIGIS) Section.

APPENDIX A
DISTURBANCE AREAS

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
00113	7521-1	27	N/A	Pack Rat Cyn	Bomb Craters
00213	7521-1	27	10122	Pack Rat Cyn	Bomb Craters
00313	7521-1	27	9893	Pack Rat Cyn	Bomb Craters
00425	7521-3	27	9667	Pack Rat Cyn	Scrape at road junction
00515	7521-4	27	9477	Civet Cat Cv	Area at rd. jct (target?)
00616	7521-5	27	9004	Pack Rat Cyn	Equipment/Debris
00726	7521-5	27	8897	Cactus Spring	Array of equipment
00836	7521-9	27	7846	White Patch Dr	Equipment (target?)
00933	7521-12	27	6954	White Patch Dr	Installation
01035	7521-12	27	6868	White Patch Dr	Scraped Area
01134	7521-12	27	6764	White Patch Dr	Suspect Area (equipment)
01235	7521-12	27	6794	White Patch Dr	Scraped Area
01334	7521-13	27	6606	White Patch Dr	Suspect Area (mining?)
01434	7521-15	27	6232	White Patch Dr	Structure
01521	7521-35	27	1614	E of Cactus Pk	Mountain top installation
01633	7523-197	25	8123	Cactus Spring	Bomb Crater
01731	7523-194	25	7203	White Patch Dr	Fenced Area
01834	7523-191	25	6378	White Patch Dr	Suspect Area (mining?)
01924	7523-180	25	4463	E of Cactus Pk	Natural?
02015	7523-180	25	4311	E of Cactus Pk	Scrape at end of road
02125	7523-164	25	388	Reeds Ranch	Scrape & trailer
02234	7523-167	25	819	E of Cactus Pk	Rd junction w/wash
02334	7523-168	25	1289	E of Cactus Pk	Suspect area at rd. & wash junction
02424	7523-123	22	N/A	Civet Cat Cv	Suspect Area (trench or bomb?)

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
02514	7523-127	22	8589	Civet Cat Cv	Dump (?) on road to target
02624	7523-137	22	5977	Cactus Spring	Scrape on side of road
02724	7523-142	22	5102	Cactus Spring	Discolored at side of rd. - natural?
02826	7523-145	22	4417	E of Cactus Pk	Cleared area with debris
02915	7523-147	22	4063	E of Cactus Pk	Scraped Area near bend in road
03025	7523-147	22	4011	E of Cactus Pk	Scraped area off road
03114	7523-158	22	1151	E of Cactus Pk	Pit and evidence of digging
03211	7523-160	22	807	Reeds Ranch	Facility and scrape
03314	7521-67	20	6543	Cactus Spring	Suspect mine (horses?)
03414	7521-65	20	6171	Cactus Spring	Suspect area (scrape/mining?)
03515	7521-57	20	4231	E of Cactus Pk	Scrape on road offshoot
03611	7521-56	20	4001	E of Cactus Pk	Installation & scrapes
03711	7523-119	17	338	Reeds Ranch	Installation (scrape & box)
03822	7523-118	17	813	E of Cactus Pk	Berms near pond
03914	7523-117	17	1292	E of Cactus Pk	Hilltop pit (scrape)
04025	7523-117	17	1109	E of Cactus Pk	Scrape on road to hilltop
04124	7523-107	17	3512	E of Cactus Pk	Suspect area at roadside
04224	7523-107	17	3413	E of Cactus Pk	Suspect area at roadside
04335	7523-114	17	1820	E of Cactus Pk	Scrape (older area?)
04411	7523-100	17	5108	Cactus Spring	Installation at Cactus Spring
04534	7523-43	15	N/A	Reeds Ranch	Pond and scrapes
04611	7523-44	15	144	Reeds Ranch	Power Substation
04712	7523-47	15	903	E of Cactus Pk	Equipment Array & scrape
04824	7523-48	15	1020	E of Cactus Pk	Suspect Area
04924	7523-48	15	1040	E of Cactus Pk	Suspect Area
05024	7523-48	15	1045	E of Cactus Pk	Suspect Area
05121	7523-53	15	2317	E of Cactus Pk	Airport (construction)

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
05221	7523-53	15	2427	E of Cactus Pk	Airport (construction)
05321	7523-53	15	2493	E of Cactus Pk	Airport (construction)
05421	7523-53	15	2555	E of Cactus Pk	Airport (construction)
05521	7523-53	15	2619	E of Cactus Pk	Airport (construction)
05621	7523-53	15	2678	E of Cactus Pk	Airport (construction)
05721	7523-53	15	2257	E of Cactus Pk	Facility near airport
05821	7523-53	15	2264	E of Cactus Pk	Scrape near airport
05921	7523-53	15	2412	E of Cactus Pk	Scrape near airport
06021	7523-53	15	2466	E of Cactus Pk	Scrape near Airport
06121	7523-53	15	2433	E of Cactus Pk	Airport (construction)
06221	7523-53	15	2553	E of Cactus Pk	Airport (construction)
06321	7523-53	15	2889	E of Cactus Pk	Airport (construction)
06421	7523-53	15	2937	E of Cactus Pk	Airport (construction)
06521	7523-53	15	3076	E of Cactus Pk	Airport (construction)
06621	7523-57	15	3519	E of Cactus Pk	Large pit (lots of dist.)
06724	7523-57	15	3634	E of Cactus Pk	Suspect area on side of rd.
06814	7523-61	15	4714	Cactus Spring	Suspect area on side of rd.
06915	7523-61	15	4809	Cactus Spring	Scraped area at end of rd.
07011	7523-61	15	4911	Cactus Spring	Facility with long scrape
07114	7523-61	15	4896	Cactus Spring	Suspect area on side of rd.
07214	7523-61	15	4876	Cactus Spring	Suspect area on side of rd.
07314	7523-61	15	4933	Cactus Spring	Scrape at bend in rd.
07414	7521-121	13	85	Reeds Ranch	Scrape at end of rd on hill
07514	7521-121	13	243	Reeds Ranch	Scrape at road junction
07615	7521-121	13	238	Reeds Ranch	Scrape along roadside
07715	7521-121	13	405	Reeds Ranch	Borrow pit
07825	7521-120	13	534	Reeds Ranch	Scrape near facility

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
07925	7521-120	13	626	Reeds Ranch	Scrape off side of road
08022	7521-120	13	660	Reeds Ranch	Berms
08114	7521-118	13	1269	E of Cactus Pk	Target?
08234	7521-116	13	1672	E of Cactus Pk	Fenced area at road inter.
08334	7521-116	13	1908	E of Cactus Pk	Suspect areas in dry lake beds
08434	7521-115	13	2097	E of Cactus Pk	Suspect area
08534	7521-115	13	2128	E of Cactus Pk	Suspect area
08634	7521-115	13	2100	E of Cactus Pk	Suspect area
08735	7521-112	13	2730	E of Cactus Pk	Pits and scrapes
08835	7521-112	13	2780	E of Cactus Pk	Pits and scrapes
08935	7521-112	13	3039	E of Cactus Pk	Pits and scrapes
09034	7521-111	13	3076	E of Cactus Pk	Fenced in area at airport
09134	7521-109	13	3379	E of Cactus Pk	Suspect area near airport
09224	7521-109	13	3447	E of Cactus Pk	Suspect area near airport
09324	7521-109	13	3675	E of Cactus Pk	Suspect area near airport
09434	7521-109	13	3648	E of Cactus Pk	Suspect area near airport
09526	7521-106	13	4105	E of Cactus Pk	Equipment & scrapes
09626	7521-106	13	4177	E of Cactus Pk	Equipment & scrapes
09721	7521-106	13	4280	E of Cactus Pk	Installation
09834	7521-100	13	5495	Cactus Springs	Suspect discolored area
09934	7521-100	13	5610	Cactus Springs	Suspect area (natural?)
10034	7521-98	13	6213	Cactus Springs	Suspect area (old mine?)
10134	7521-98	13	6246	Cactus Springs	Suspect area (old mine?)
10234	7521-98	13	6452	Cactus Springs	Suspect area (natural?)
10324	7523-1	11	N/A	Reeds Ranch	Suspect site (off imagery)
10425	7523-1	11	N/A	Reeds Ranch	Scrape north of trans. line
10515	7523-3	11	532	Stinking SP SW	Scrape at road intersection

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
10611	7523-5	11	843	E of Cactus Pk	Installation w/scrapes
10724	7523-5	11	795	Stinking Sp SW	Suspect area near road
10824	7523-7	11	1106	Stinking SP SW	Suspect area at end of road
10924	7523-7	11	1210	Stinking SP SW	Disturbance in dry lake bed
11034	7523-7	11	1202	Stinking SP SW	Suspect area at bend in road
11134	7523-7	11	1318	Stinking SP SW	Suspect area west of rd. int.
11231	7523-7	11	1304	Stinking SP SW	Installation E of rd. int.
11324	7523-7	11	1455	Stinking SP SW	Suspect area at bend in rd.
11425	7523-7	11	1476	E of Cactus Pk	Scrape at edge of rd. (both sides)
11525	7523-8	11	1759	Stinking SP SW	Scrape along roadside
11625	7523-8	11	1771	E of Cactus Pk	Older scrape
11711	7523-9	11	2045	Stinking SP SW	Installation
11811	7523-9	11	2065	Stinking SP SW	Installation
11914	7523-9	11	2073	Stinking SP SW	Suspect area at end of road
12034	7523-12	11	2654	E of Cactus Pk	Suspect area near road int.
12121	7523-14	11	2970	E of Cactus Pk	Installation
12224	7523-14	11	3094	E of Cactus Pk	Suspect area
12311	7523-14	11	3161	E of Cactus Pk	Installation
12421	7523-14	11	3322	E of Cactus Pk	Pond & trees at end of road
12525	7523-14	11	3087	Stinking SP SW	Scrape
12626	7523-14	11	3165	Stinking SP SW	Scrape (small) end of road
12734	7523-15	11	3408	E of Cactus Pk	Numerous scrapes
12824	7523-17	11	4097	Stinking SP SW	Suspect area at side of road
12934	7523-22	11	5093	Cactus Spring	Suspect area near stream corridor
13024	7523-22	11	5182	Cactus Spring	Suspect area
13124	7523-22	11	5274	Cactus Spring	Suspect area w/trailers
13211	7523-22	11	5467	Cactus Spring	Installation with scrape

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
13314	7522-158	45	234	Stinking Sp NW	Turnaround & ?
13414	7522-158	45	464	Stinking Sp NW	Suspect area at side of road
13524	7522-160	45	1065	Stinking SP SW	Suspect areas(2) off road
13624	7522-160	45	1051	Stinking SP SW	End of road turnaround
13714	7522-163	45	1792	Stinking SP SW	Suspect area south of dry lake
13814	7522-163	45	1834	Stinking SP SW	Suspect area south of dry lake
13914	7522-163	45	1748	Stinking SP SW	Suspect area south of dry lake
14014	7522-163	45	1784	Stinking SP SW	Suspect area south of dry lake
14134	7522-169	45	3808	Stinking SP SW	Numerous scrapes along rd.
14234	7522-174	45	5123	Roller Coaster	Suspect area (natural?)
14334	7522-174	45	5196	Roller Coaster	Suspect area (natural?)
14431	7522-174	45	5213	Roller Coaster	Installation & scrapes
14521	7522-174	45	5344	Roller Coaster	Installation & scrapes
14626	7522-174	45	5257	Roller Coaster	Debris/Eq at end of road
14715	7522-176	45	5441	Roller Coaster	Roller Coaster scrape
14815	7522-176	45	5600	Roller Coaster	Pit and scrapes
14915	7521-124	47	482	Stinking SP NW	Borrow pit
15011	7521-128	47	1390	Stinking SP SW	Installation on road side
15111	7521-128	47	1505	Stinking SP SW	Master launcher installation
15224	7521-128	47	1400	Stinking SP SW	Suspect area
15324	7521-128	47	1353	Stinking SP SW	Suspect area
15411	7521-128	47	1473	Stinking SP SW	Installation
15514	7521-128	47	1533	Stinking SP SW	Suspect area at road intersection
15634	7521-128	47	1270	Stinking SP SW	Suspect area north of road
15711	7521-129	47	1769	Stinking SP SW	Command Post?
15815	7521-129	47	1774	Stinking SP SW	Scrape & pit
15925	7521-130	47	2004	Stinking SP SW	Scrape at side of road

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
16034	7521-130	47	2016	Stinking SP SW	Scrape
16134	7521-130	47	2008	Stinking SP SW	Scrape
16234	7521-130	47	2207	Stinking SP SW	Scrape
16334	7521-132	47	2499	Stinking SP SW	Suspect area off road
16414	7521-132	47	2634	Stinking SP SW	Suspect area at end of road
16515	7521-136	47	3622	Stinking SP SW	Scrape at road intersection
16634	7521-143	47	5567	Roller Coaster	Suspect area on spur
16711	7521-145	47	6174	Roller Coaster	Installation with scrapes
16816	7521-151	47	7441	Roller Coaster	Equipment and scrape
16914	7521-151	47	7581	Roller Coaster	Suspect area at road bend
17015	7521-151	47	7622	Roller Coaster	Large scrape
17111	7522-154	43	397	Stinking SP NW	Suspect area at road intersection
17211	7522-151	43	1225	Stinking SP SW	Installation
17334	7522-153	43	426	Stinking SP NW	Suspect area off road
17424	7522-153	43	684	Stinking SP NW	Suspect area off road
17534	7522-152	43	928	Stinking SP SW	Suspect area off road
17624	7522-150	43	1703	Stinking SP SW	Suspect area off road
17724	7522-150	43	1720	Stinking SP SW	Suspect area off road
17834	7522-149	43	1863	Stinking SP SW	Suspect area at turnaround
17921	7522-142	43	3912	Stinking SP SW	Installation
18024	7522-142	43	3905	Stinking SP SW	Septic sludge pits
18124	7522-141	43	4308	Stinking SP SW	Suspect area
18221	7522-141	43	4350	Stinking SP SW	Installation
18324	7522-136	43	5390	Roller Coaster	Pit/Scrape
18424	7522-136	43	5674	Roller Coaster	Scrape/mound
18524	7522-132	43	6764	Roller Coaster	Older disturbance
18614	7522-130	43	7320	Roller Coaster	Suspect area at roadside

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
18715	7522-130	43	7486	Roller Coaster	Turnaround?
18811	7522-130	43	7494	Roller Coaster	Installation
18925	7522-128	43	7865	Roller Coaster	Scrape at road side
19024	7522-125	43	8862	Trappman Hills	Suspect area
19115	7522-125	43	8988	Trappman Hills	Scrape
19214	7522-86	41	192	Stinking SP NW	Borrow pit
19324	7522-87	41	698	Stinking SP SW	Turnaround
19434	7522-90	41	1448	Stinking SP SW	Suspect area
19531	7522-91	41	1999	Stinking SP SW	Station?
19611	7522-96	41	3080	Stinking SP SW	Installation
19725	7522-96	41	3144	Stinking SP SW	Scrape near "chevron" roads
19825	7522-96	41	3593	Stinking SP SW	Scrape near "chevron" roads
19925	7522-96	41	3709	Stinking SP SW	Scrape near "chevron" roads
20025	7522-96	41	3342	Stinking SP SW	Scrape near "chevron" roads
20124	7522-98	41	4080	Stinking SP SW	Suspect area
20224	7522-100	41	4625	Roller Coaster	Suspect area
20324	7522-100	41	4701	Roller Coaster	Suspect area
20424	7522-103	41	5176	Roller Coaster	Suspect digging in dry lake
20524	7522-103	41	5257	Roller Coaster	Suspect digging in dry lake
20625	7522-103	41	5324	Roller Coaster	Scrape
20724	7522-103	41	5431	Roller Coaster	Suspect area
20825	7522-104	41	5668	Roller Coaster	Scrape
20925	7522-104	41	5671	Roller Coaster	Scrape
21014	7522-105	41	6033	Roller Coaster	Suspect area
21111	7522-113	41	8311	Roller Coaster	Installation - tower
21225	7522-113	41	8379	Roller Coaster	Scrape
21315	7522-116	41	8971	Trappman Hills	Scrape on side of road

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
21411	7522-116	41	9142	Trappman Hills	Installation - radio tower
21514	7522-116	41	9247	Trappman Hills	Suspect area
21624	7522-116	41	9265	Trappman Hills	Suspect area
21724	7521-196	39	N/A	Stinking Sp SW	Borrow pit?
21821	7521-196	39	N/A	Stinking Sp SW	Installation
21911	7521-194	39	596	Stinking Sp SW	Installation
22024	7521-190	39	1398	Stinking Sp SW	Turnaround?
22125	7521-190	39	1536	Stinking Sp SW	Scrape
22224	7521-190	39	1537	Stinking Sp SW	Turnaround?
22315	7521-188	39	2126	Stinking Sp SW	Scrapes at road intersection
22425	7521-179	39	4532	Roller Coaster	Scrape - evidence of burial
22524	7521-179	39	4541	Roller Coaster	Suspect area
22634	7521-175	39	5484	Roller Coaster	Suspect area in dry lake bed
22734	7521-175	39	5503	Roller Coaster	Suspect area in dry lake bed
22834	7521-174	39	5875	Roller Coaster	Suspect area in dry lake bed
22914	7521-170	39	6756	Roller Coaster	Suspect area (borrow pit?)
23015	7521-170	39	6830	Roller Coaster	Scrape/cleared area
23115	7521-167	39	7607	Trappman Hills	Scrape
23216	7521-164	39	8433	Trappman Hills	Equipment/turnaround
23315	7521-164	39	8454	Trappman Hills	Scrape
23436	7524-182	37	1620	Stinking SP SW	Equipment/debris
23531	7524-182	37	1883	Stinking SP SW	Installation
23625	7524-178	37	2621	Stinking SP SW	Scrape & pit
23725	7524-174	37	3716	Stinking SP SW	Scrape
23815	7524-174	37	4049	Stinking SP SW	Suspect area (digging)
23924	7524-172	37	4305	Stinking SP SW	Suspect area
24015	7524-172	37	4444	Roller Coaster	Scrape

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
24124	7254-171	37	4652	Roller Coaster	Suspect area
24225	7522-20	37	4998	Roller Coaster	Scrape
24334	7522-26	37	6860	Roller Coaster	Suspect area
24424	7522-29	37	7771	Roller Coaster	Suspect area
24534	7522-33	37	8708	Trappman Hills	Suspect area
24634	7522-33	37	8740	Trappman Hills	Suspect area
24726	7522-83	35	N/A	Stinking SP NW	Equipment/scrape
24824	7522-81	35	515	Stinking SP SW	Questionable suspect area-natural?
24936	7522-75	35	2187	Stinking SP SW	Equipment/scrape
25024	7522-74	35	2519	Stinking SP SW	Suspect discoloration
25124	7522-72	35	3174	Stinking SP SW	Suspect area
25211	7522-69	35	3913	Stinking SP SW	Installation/scrape
25315	7522-69	35	3863	Stinking SP SW	Scrape/borrow pit?
25416	7522-69	35	3840	Stinking SP SW	Debris/scrape
25511	7522-69	35	3900	Stinking SP SW	Building
25615	7522-69	35	3966	Stinking SP SW	Scrape
25714	7522-67	35	4152	Stinking SP SW	Suspect area (discolored)
25814	7522-64	35	5330	Roller Coaster	Suspect area (older or natural)
25914	7522-64	35	5276	Roller Coaster	Suspect area (older or natural)
26014	7522-64	35	5306	Roller Coaster	Suspect area (older or natural)
26124	7522-63	35	5624	Roller Coaster	Suspect area
26224	7522-61	35	6171	Roller Coaster	Suspect area
26315	7522-61	35	6220	Roller Coaster	Scrape
26421	7522-60	35	6659	Roller Coaster	Installation w/scrapes
26521	7522-60	35	6729	Roller Coaster	Installation w/scrapes
26621	7522-60	35	6678	Roller Coaster	Installation w/scrapes
26725	7522-60	35	6515	Roller Coaster	Scraped area

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
26825	7522-60	35	6836	Roller Coaster	Scrape/long trench
26921	7522-60	35	6821	Roller Coaster	Installation w/scrapes
27035	7520-160	33	1614	Breen Creek	Scrape/pit
27115	7520-152	33	3576	Breen Creek	Scrape on side of road
27214	7520-152	33	3678	Breen Creek	Suspect older scrape
27324	7520-142	33	6437	Roller Coaster	Suspect area between runways
27415	7520-142	33	6294	Mellan	Scrape (crosses runway)
27525	7520-137	33	7599	Mellan	Scrape
27624	7520-134	33	8390	Triangle Mtn	Suspect area near target
27724	7520-130	33	9374	Triangle Mtn	Suspect area on road to tower
27811	7520-130	33	9222	Trappman Hills	Suspect area on road to tower
27914	7520-66	13	2315	Breen Creek	Suspect area off road
28014	7520-66	13	2533	Breen Creek	Suspect area at turn in road
28124	7520-66	13	2670	Breen Creek	Suspect area
28214	7520-66	13	2593	Breen Creek	Suspect area
28314	7520-66	13	2617	Breen Creek	Suspect area (offshoot from 28214)
28414	7520-61	13	3876	Breen Creek	Suspect row of 13 disturbances
28511	7520-61	13	3938	Breen Creek	Walls & a berm (scraped)
28614	7520-61	13	3838	Breen Creek	Gully (both sides of road)
28711	7520-60	13	4166	Breen Creek	Structure & scrapes
28815	7520-60	13	4213	Breen Creek	Scrapes (excavation?)
28924	7520-60	13	4231	Breen Creek	Suspect area
29014	7520-55	13	5673	Mellan	Suspect area (pit)
29114	7520-55	13	5702	Mellan	Suspect area
29211	7520-55	13	5843	Mellan	Installation (tower) & pits
29315	7520-54	13	6028	Mellan	Open pit
29415	7520-51	13	6781	Mellan	End of runway

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
29514	7520-45	13	8206	Mellan	Road intersection
29625	7520-39	13	N/A	Triangle Mtn.	Scrape
29715	7520-39	13	N/A	Triangle Mtn.	Scrape
29825	7520-39	13	N/A	Triangle Mtn.	Scrape
29925	7520-176	31	2277	Breen Creek	Scrapes
30014	7520-182	31	3938	Breen Creek	Discolored area
30116	7520-182	31	3984	Breen Creek	Equipment/fence/scraped
30225	7520-182	31	3628	Breen Creek	Scrape
30321	7520-182	31	3633	Breen Creek	Buildings and scrapes
30424	7520-182	31	3918	Breen Creek	Suspect area north of other scrape
30524	7520-190	31	5759	Mellan	Suspect area (mining?)
30614	7520-190	31	5915	Mellan	Suspect area (mining?)
30714	7520-190	31	5925	Mellan	Suspect area (mining?)
30824	7520-192	31	6139	Mellan	Suspect area - discolored
30925	7520-195	31	7012	Mellan	Scrape
31025	7520-198	31	7753	Mellan	Scrape
31125	7520-198	31	7966	Mellan	Scrape
31236	7520-198	31	7913	Mellan	Equipment
31316	7520-199	31	8306	Mellan	Debris
31414	7520-199	31	8489	Mellan	Multiple suspect areas (targets?)
31515	7520-199	31	8594	Mellan	Two large scrapes
31635	7520-203	31	9193	Triangle Mtn.	Scrape on side of new road
31735	7520-203	31	9428	Triangle Mtn.	Scrape on side of new road
31835	7520-203	31	9532	Triangle Mtn.	Scrape on side of new road
31935	7520-203	31	9698	Triangle Mtn.	Scrape on side of new road
32015	7529-206	31	N/A	Triangle Mtn.	Scrape
32115	7529-206	31	N/A	Triangle Mtn.	Scrape

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
32215	7529-206	31	N/A	Triangle Mtn.	Scrape
32315	7529-206	31	N/A	Triangle Mtn.	Scrape
32411	7529-206	31	N/A	Triangle Mtn.	Installation
32534	7520-87	15	2559	Breen Creek	Suspect area near dry wash
32611	7520-91	15	3577	Breen Creek	Installation w/scrape
32715	7520-91	15	3620	Breen Creek	Borrow Pit/scrape
32835	7520-93	15	4176	Mellan	Scrape
32915	7520-96	15	4793	Mellan	Scrape
33011	7520-96	15	4890	Mellan	Installation w/scrape
33124	7520-97	15	5164	Mellan	Suspect area (ring of debris?)
33224	7520-97	15	5175	Mellan	Suspect area at rd intersection
33334	7520-103	15	6827	Mellan	Suspect area - turnaround?
33431	7520-104	15	7162	Mellan	Installation on mtn w/scrape
33525	7520-104	15	7258	Mellan	Scrape (target?)
33625	7520-104	15	7330	Mellan	Scrape
33716	7520-113	15	N/A	Triangle Mtn	Equipment
33811	7520-113	15	N/A	Triangle Mtn	Installation w/scrapes
33911	7520-113	15	N/A	Triangle Mtn	Installation w/scrapes
34014	7520-113	15	N/A	Triangle Mtn	Suspect area on road to mtn top
34111	7520-9	11	1436	Breen Creek	Installation w/scrapes (near edge)
34211	7520-10	11	1660	Breen Creek	Installation w/scrapes
34311	7520-10	11	1705	Breen Creek	Installation w/scrapes & pit
34411	7520-10	11	1966	Breen Creek	Installation w/scrapes & berm
34525	7520-16	11	3517	Breen Creek	Scrape at edge of road
34614	7520-18	11	4088	Mellan	Suspect area rd int w/wash
34715	7520-38	11	N/A	Triangle Mtn	Scrape
34815	7520-38	11	N/A	Triangle Mtn	Scrape at top of hill

ID	Photo #	MSS Run	MSS Line	Quad Sheet	Comment
34911	7520-38	11	N/A	Triangle Mtn	Installation w/scrape
35015	7520-38	11	N/A	Triangle Mtn	Scrape
35124	7520-38	11	N/A	Triangle Mtn	Suspect area at road end
35225	7520-38	11	N/A	Triangle Mtn	Scrape
35335	7520-38	11	N/A	Triangle Mtn	Scrape
35434	7520-21	11	4892	Mellan	Suspect area on road side
35534	7520-21	11	4982	Mellan	Suspect area on road side
35624	7521-35	27	1618	E of Cactus Pk	Suspect area
35724	7521-35	27	1631	E of Cactus Pk	Suspect area at road intersection
35811	7521-115	13	2276	E of Cactus Pk	Facility

APPENDIX B
SURVEY PERSONNEL

J.E. Shines	Mission Manager
T.L. McCreary	Acquisition Scientist
G.E. Menkel	MSS Technician
V.A. Young	MSS Technician
J.M. Roed	Photo Technician
S.L. Bartley	Pilot-In-Command
I.L. Hopkins	Pilot
C.E. Peterson	Aircraft Mechanic

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