PRELIMINARY

ASSESSMENT OF REMOTE SENSING TECHNOLOGIES TO DISCOVER AND CHARACTERIZE WASTE SITES

Prepared by
Environmental Research Institute of Michigan

11 March 1992

Preliminary Report 242900-3-T on Subcontract 9-XC2-Y9152-1 with Los Alamos National Laboratory

PRELIMINARY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

AD

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

PRELIMINARY

**ASSESSMENT OF REMOTE SENSING TECHNOLOGIES
TO DISCOVER AND CHARACTERIZE
WASTE SITES**

Table of Contents

1.0 THE PROBLEM	3
2.0 EXISTING CAPABILITIES	6
3.0 A SYSTEMS APPROACH	19
4.0 SPECIAL SENSOR TECHNOLOGY/PROCESSING	27
5.0 CASE STUDIES	31
6.0 SUMMARY OF RECOMMENDATIONS	34
APPENDIX: REQUIREMENTS ANALYSIS	36

**ASSESSMENT OF REMOTE SENSING TECHNOLOGIES
TO DISCOVER AND CHARACTERIZE
WASTE SITES**

1.0 THE PROBLEM

The Department of Energy (DOE) has initiated an effort to remediate waste sites at all of its facilities, in a campaign of environmental restoration. The effort includes all available means to identify, reclaim and restore these lands to as close to their original state as can be expected. Once the sites and problems have been located and characterized and an achievable restoration/remediation program has been established, efforts to reclaim the environment will begin.

The individual DOE waste sites can vary from plant discharge outfall sites, which can be as small as 10 square meters, to land fills ranging in size from 1,000 to 10,000 square meters. DOE waste sites are distributed throughout the U.S., where climatic and vegetative conditions vary from humid and sub-tropical, as at the Savannah River Site in South Carolina, to arid, as at the Hanford site in Washington State. Soils range from silt and clay, as at the Fernald site in Ohio, to alluvial fill at Sandia National Laboratory in Albuquerque, to basaltic sheet flows at Hanford. Depths of ground water vary from zero to 600 meters. Wastes include organics such as solvents and lubricating oils, heavy metals such as chromium, mercury, and lead, and radioactive materials, including uranium and transuranic materials. Special problems to be considered are:

- concentrated waste forms such as in buried tanks and pits,
- soil and groundwater contamination
- ground safety hazards for workers
- intrusive nature of some current methods
- high cost of drilling holes
- requirement for long-term monitoring.

The sequence of activities anticipated for DOE waste site restoration are listed in the 1989 Applied Research, Development, Demonstration, Testing and Evaluation (RDDT&E) draft plan as:

- strategic planning
- characterization
- assessment

PRELIMINARY

- remediation
- compliance monitoring.

This report concerns the Characterization phase and provides suggestions for non-invasive methods to discover and characterize waste sites, focusing on remote sensing technologies.

Remote sensing methods can be utilized in a comprehensive approach with historical and ancillary data, traditional ground-based methods, and a plan for coordinated coverage. Remote sensing methods are especially attractive in that they involve no safety hazards to workers on the ground and do not destroy evidence nor damage the environment any further. They can be cost-effective because some currently available methods are readily applied and relatively inexpensive to the user.

DOE has called for special innovative technologies in the RDDT&E plan, recognizing that many of these problems cannot be solved in a conventional way. Transferring technology from DOD and other applications, upgrading existing sensors/methods and developing new technology are all appropriate; technology that is now available should be demonstrated to determine its utility.

The Los Alamos National Laboratory has been asked by DOE's Office of Technology Development to assess the capabilities of current technology and then make recommendations. A workshop was hosted by Los Alamos in Dallas, Texas, August 29-30 to review current technology and then make recommendations for use of noninvasive ground-based geophysical technology to characterize waste sites. Technologies were presented and ranked in terms of the development needed. The technology development areas that were expected to have the most benefit to DOE for the least cost are (with highest benefit to cost ratio first):

- data fusion
- electromagnetic methods
- ground penetrating radar
- seismic methods
- gravity methods
- magnetic methods.

PRELIMINARY

The Environmental Research Institute of Michigan (ERIM) has been asked by Los Alamos to prepare this report as input to their effort. It is a preliminary assessment of current and proposed non-invasive technology that was not fully covered at the Dallas workshop. Recommendations are summarized at the end of this report.

PRELIMINARY

2.0 EXISTING CAPABILITIES

The report starts with a catalogue of existing data sources, descriptions of current systems and a selected bibliography of remote sensing.

2.1 Catalogue of Existing Data Sources

Data archives/bases exist for a number of satellite imagery sources. Data on broad area coverage by low resolution systems such as AVHRR is generally available and imagery will be especially useful with maps in a GIS-type of system. It is highly likely that mid-level resolution satellite systems such as LANDSAT and SPOT will be important contributors to detecting waste sites and monitoring them for indicators of change. Data bases for these are quite easy to access and are discussed below.

A number of airborne systems offer better resolution than is available from the majority of satellite systems and some archives exist back to the 1940s. However, these data are harder to access than that from satellite systems. One needs to rely heavily on word-of-mouth as most information from airborne systems has not been well-documented. Some specific sources are discussed below.

2.1.1 Multispectral Data

A data search was made for this project covering the period 1977-1992. The search provided data that exemplifies the kind of information available. Data bases for three systems were searched, the LANDSAT TM (Thematic Mapper) database maintained by EOSAT, SPOT Image Customer Service and ERIM's own database of multispectral aircraft collections.

ERIM is a frequent user of LANDSAT and SPOT so it has on-line access to these data base systems; however, these sensor data are also commercially available to anyone via customer service representatives: for LANDSAT contact EOSAT Customer Services Department 800/344-9333 or 301/522-0537 and for SPOT contact SPOT Image Corporation Customer Service 703/620-2200. ERIM's aircraft multispectral information file is one that has been generated from a number of projects, and includes information archived at ERIM, those of other contractors and the government. Many of these images are relatively high resolution. More information is available about these data bases but is not presented here.

PRELIMINARY

Table 2-1 shows the number of "cloud free" (< 10%) LANDSAT images found over several DOE sites since TM data was available in 1982. It also shows the number of SPOT images taken regardless of cloud cover since 1986 when images first became available. ERIM's estimate is that about half of the SPOT imagery would be acceptable in terms of cloud cover. The MS aircraft data are the number of collections made. Usually about 25 image scenes are made for each collection.

A LANDSAT scene covers about 185 x 185 km on the ground and SPOT, 60 x 60 km. Most aircraft scenes cover a smaller area on the ground than a SPOT scene. The area usually depends on the image resolution. Details about all of these data are available.

Table 2.1. Multispectral Images from LANDSAT, SPOT and Aircraft as of March 1992

DOE Facility	# of LANDSAT-TM Scenes (Cloud-Free)		# of SPOT Scenes (Any)		# of MS Scanner Collections (about 25 scenes per collection)	
	1982-1992	1990-1992	1986-1992	1990-1992	1977-1992	1990-1992
Hanford, Washington	27	6	10	6	4	0
Idaho Falls, Idaho	25	2	18	8	1	0
Oak Ridge, Tennessee	14	2	7	3	2	0
Paducah, Kentucky	19	5	21	13	2	1
Portsmith, Ohio	16	4	10	1	1	0
Savannah River, S. Carolina	26	3	16	11	21	1

2.1.2 Aircraft Data

A variety of other historical data elements are available. World War II aerial photos (some of which may still be classified) can be obtained from the National Archives. One may have to obtain authority to review the image data. The US Department of Agriculture (USDA) Solid Conservation Service (SCS) and the Agricultural Stabilization and Conservation Service (ASCS) both possess image repositories that range back into the 1950s through the 1980s.

PRELIMINARY

Even if those data do not cover the DOE sites, the USDA agencies may have data that could help define the properties of the surrounding areas. Photographic data is available through the USDA Aerial Photographic Field Office in Salt Lake City, Utah at 801/524-5856. They have color IR, and black and white available of the US at between 1:20K and 1:60K scale. Prices are \$5 per photo index and \$4 per line index. Currently, it takes about 4-6 weeks to process a request.

More recent photo image data can be obtained from the National High Altitude Photography (NHAP) and the National Aerial Photography (NAP) repositories. Both of these photo repositories are maintained by the EROS Data Center (EDC), US Geological Survey. Many of the states and local authorities also may have image data of the areas surrounding the DOE reservations/restricted sites and possibly within the boundaries of the sites as well.

To locate NHAP 1:40K scale black and white and color IR products acquired between 1980 and 1987, contact the EDC in Sioux Falls, South Dakota, 605/594-6969. They also have NAP Program Imagery which is mostly black and white flown between 1987 and present at 1:20K scale. NAP is not complete so it may not be available for specific areas. The EDC also has NASA Large Format Camera and Skylab S-190B photographic data. It acts as the agent for acquisition of Soviet data for federal agencies, but no other foreign data. Prices are \$6 for a black and white contact print, and up to \$65 for a 40" x 40' color enlargement. Normally it requires two to three weeks to comply with request.

The EPA is known to have flown several photo collection missions in the early 1970s using the RF-4C with all photo cameras loaded with different color films to reveal pollutants being dumped into major waterways. One of the authors of this report personally flew one such mission from Puget Sound to Lake Washington waterways in 1974 and knows of collections in the San Francisco Bay area. There may be others, thus, the data source should be examined further.

For more information, contact EPA's Environmental Photographic Interpretation Center (EPIC) at Vint Hill Farms Station, near Warrenton, Virginia at 703/349-8970. It has a limited coverage of 1:3K to 1:12K scale imagery. This can be relatively expensive but they can do a search of the data base to tell whether they have coverage quickly. The contracting and copying of data will take additional time. They have color and color IR products and the data collected by one of the authors of this report is also available.

PRELIMINARY

2.1.3 Needed Work

For the satellites systems mentioned in 2.1.1, a computerized data search should be done using the coordinates of each DOE site. This should yield enough relevant information to decide which images to view. For aircraft data, the participants in collections should be consulted to obtain a list of dates and sites. Making a list will be relatively easy, but obtaining detailed information may be difficult.

Having located image sources, the next step is to focus on image content. It is important to make clear what is expected to be extracted from images to "discover" and "characterize" waste sites. The following definitions could be used:

Discover

- to detect waste sites
- to estimate areal extent of waste sites;

Characterize

- to locate pit or trench boundaries
- to estimate depth of disturbed (excavated and backfilled) soil
- to locate buried containers in three-dimensions
- to estimate container contents
- to determine whether containers are leaking
- to locate contaminants from leaking containers in three-dimensions
- to estimate environmental impact of waste sites upon adjoining lands
- to estimate geological structure and hydrological properties of the waste sites and their immediate vicinity, including depth to ground water.

It is essential that image analysts and phenomenologists visually sample each type of data to assess potential value in terms of these definitions. Based on their recommendation, an acquisition of imagery should proceed.

2.2 Current Capabilities Description

This section provides an exemplary description of remote sensing systems. First, LANDSAT and SPOT are discussed; they are now being used for a number of environmental assessments including waste site discovery and characterization.

PRELIMINARY

2.2.1 LANDSAT and SPOT

LANDSAT and SPOT are multispectral systems that operate in the spectral regions shown on Table 2-2. This table, taken from the Remote Sensing Handbook, gives a convenient reminder of what bands of the spectrum give what environmentally relevant information. Table 2-3 (also from the handbook) shows the seven bands of the Thematic Mapper (TM) sensor on LANDSAT 4 and 5, along with GSD in meters. Table 2-4 gives comparative information, LANDSAT TM versus SPOT.

As presented in section 2.1 of this report, historical LANDSAT TM and SPOT data can be easily obtained. The data from the two systems can be merged to produce composite images having the benefits of the spectral and spatial characteristics of each system. Change detection can also be performed with each system's imagery and between LANDSAT and SPOT. Algorithms are available for land use categorization/classification with special features such as seasonal corrections and routines to emphasize changes of interest.

There are a number of other multispectral systems, mostly with coarser resolution than LANDSAT and SPOT. These are discussed next, along with satellites having other types of sensors such as radar. Airborne systems are also discussed.

2.2.2 Catalogue

This section contains some catalogues of data from currently available systems. They are not all inclusive having been gathered only from information sources readily available to ERIM. It is recommended that these types of charts be completed, along with a search for imagery discussed in Section 2.1. This is not a large effort, especially if approached "top down" so that details are only gathered for some systems that have more promise for remote sensing of waste sites.

Table 2-5 shows LANDSAT and SPOT, as well as other multispectral imaging satellite systems. Table 2-6 is a catalogue of radar imaging satellite systems. There are also a number of airborne systems both multispectral and radar. Table 2-7 is a catalogue for airborne radar. Such a table could be prepared for airborne multispectral systems. A number of satellites and aircraft carry film cameras and a few examples are given on Table 2-8.

Table 2-2. Spectral Regions

Region	Wavelength (Mm)	Detectors	Phenomenology
Ultraviolet	0.3-0.4	Photographic film, bird and insect vision	Vegetation, especially flowers, shadows filled in by diffuse illumination
Visible	0.4-0.7	Human vision, silicon detectors, photographic film	Natural/true color composite images, water penetration, chlorophyll reflection/absorption
Near Infrared	0.7-1.0	Silicon detectors, IR sensitive film	Reflection from internal cell structure of plant cells, health and vigor or stress of plants
Short-Wave IR (SWIR)	1.0-2.5	Lead Sulfide, Platinum Silicide Schottky barrier diodes	Water content, snow/ice/cloud discrimination, geology, emission from hot (450 K or more) objects, wide range of other applications
Mid-Wave IR (MWIR)	3.0-5.0	Indium Antimonide, Mercury Cadmium Tellurium	Mixture of reflected and emitted radiation from warm objects
Long-Wave IR (LWIR)	8.0-14.0	Mercury Cadmium Tellurium	Emission from warm (300 K) objects, some geology

Table 2-3. LANDSAT Thematic Mapper Bands

Band	Wavelength (μm)		GSD (m)
	Lower	Upper	
1 - blue	0.45	0.52	30
2 - green	0.52	0.60	30
3 - red	0.63	0.69	30
4 - NIR	0.75	0.90	30
5 - SWIR	1.55	1.75	30
6 - LWIR	10.4	12.5	120
7 - SWIR	2.08	2.35	30

Table 2-4. Comparison of LANDSAT Thematic Mapper & SPOT

LANDSAT Thematic Mapper

Spectral Range: 0.45 to 13 μm
Number of Spectral Bands: 7 (3 V, 1 NIR, 2 SWIR, 1 LWIR)*
Spectral Bandwidth: 0.06 μm (V) to 4.5 μm (LWIR)
Ground Spatial Dimension Resolution: 30 meter* (120m for LWIR)
Ground Swath Width: 185 km
Radiometric Resolution: 8 bits*
Data Rate: 85 Mbps
Platform: LANDSAT Spacecraft (705 km altitude)

*Plus an additional Panchromatic band (0.4 to 0.9 μm)
with 15 meter ground resolution on LANDSAT 6

SPOT

Spectral Range: 0.50 to 0.90 μm
Number of Spectral Bands: 3 (2 V, 1 NIR) plus Panchromatic
Spectral Bandwidth: 0.08 μm to 0.21 μm
Ground Spatial Dimension Resolution: 20 meter (spectral) and 10m (panchromatic)
Ground Swath Width: 60 km
Radiometric Resolution: 8 bits
Data Rate: 48 Mbps
Platform: SPOT Spacecraft (832 km altitude)

PRELIMINARY

Table 2-5. Example Catalogue of Spectral Imaging Satellite Systems in the World

PRELIMINARY

Name	Country	Band/Spectral Characterization		Resolution	Average Ground Coverage/Image	Part of World Covered	Repeat Rate at any Point on Earth
SPOT HRV	France	1 or 3	Panchrom VNIR	10m 20m	60 x 60 km	all	24 da nadir 1-2 da off nadir
--	India	--	(LANDSAT MSS-like)	--	--	all	44 da
JERS-1 (scheduled launch 2/92, research satellite)	Japan	8 1	VNIR (4) SWIR (4) (one pair stereo) SAR (L band)	18 x 24 m 18 m	75 x 75km	all	44 da
MOS - 1 (MESSR)	Japan	4	VNIR	50 m	100 x 100 km	all	17 da
MOS - 1 (VTIR)	Japan	4	V (1) TIR (3)	900 m 2700 m	1500 x 1500 km	all	1-2 da (?)
AVHRR	USA	5	VNIR (2) TIR (3)	1.1 km	1500 x 1500 km	all	1-2 da
LANDSAT MSS	USA	4	VNIR	80m	185 x 185 km 100 x 100 nmi	all	16 da
LANDSAT TM	USA	7	VNIR (4) SWIR (2) TIR (1)	30m 30m 120m	185 x 185 km 100 x 100 nmi	all	16 da
--	"Soviet"	--	(LANDSAT MSS-like)	--	--	--	--

PRELIMINARY

Table 2-6. Example Catalogue of Radar Imaging Satellite Systems in the World

PRELIMINARY

Name	Country	Band/Spectral Characterization	Resolution	Average Ground Coverage/Image	Part of World Covered	Repeat Rate at any Point on Earth
Radarsat	Canada	HH-5.30 GHz	--	--	--	--
ERS-1	European Space Agency	L-band/VV-5.3 GHz	25-28 m	99.6w (km)	--	--
JERS-1	Japan	HH-1.275 GHz	--	--	--	--
Almay-I	"Soviet"	HH-3.0 GHz	15-30 m	20-350/40 L (km)	--	--
COSMOS 1870	"Soviet"	S-Band SAR	25-30 m	--	--	--
EORSAT	"Soviet"	passive used with RORSAT	--	--	--	--
OKEAN-1	"Soviet"	SLR, VV, 9.56 GHz	1.5 km	460 km swath	--	--
RORSAT	"Soviet"	active non-SAR	40 m	--	--	--
EOS-SAR	USA	Polar 1.20 GHz VV,HH 5.0 GHz VV,HH 9.0 GHz	--	--	--	--
Magellan	USA	2.385 GHz	--	--	--	--
SEASAT	USA	HH-1.275 GHz	--	--	--	--
SIR-A	USA	L-band / HH-1.275 GHz	20-30m	--	--	--
SIR-B	USA	L-band / HH-1.275 GHz	20-30m	--	--	--
SIR-C/X-SAR	USA	Polar - 1.25 GHz Polar - 5.30 GHz VV - 9.606 Hz (X-SAR)	30 m	15-90 w (km) 15-40 w (km) for X-SAR	--	--
SIR-D	USA	--	--	--	--	--
ERS-2	USA	--	--	--	--	--
Cassini/Titan	--	HH 13.8 Hz	--	--	--	--
Polyus-V	--	--	--	--	--	--

PRELIMINARY

Table 2-7. Example Catalogue of Radar Imaging Aircraft Systems in the World

PRELIMINARY

Name	Country	Band/Spectral Charac	Resolution	Average Ground Coverage/Image	Part of World Covered	Repeat Rate at Any Pt on Earth
AuSAR	Australia	X-band	--	--	--	--
CCRS/(CV-580)	Canada	HH/VV?/5.3 GHz Polar/X-band	5-20 m	16.4-63 (km)	--	--
IRIS	Canada	X-Band SAR	--	--	--	--
CASSAR	China	Polar/X-band	--	--	--	--
VARAN-S	France	HH/VV/9.375 GHz	3 m	11.9 (km)	--	--
E-SAR (D0228)	Germany	Polar?/L, C&X-band	2 m	3 km	--	--
AMRS/Soviet (IL-18)	"Soviet"	Polar/L-band SAR-25 Polar/.167 GHz SAR 180 VV/X-band SLR-3 HH/VV Ku-band SLR-0.8	15-25 m	30-120 (km)	--	--
RSRE - SAR	U-K	X-band	--	--	--	--
DCS/ERIM (CV-580)	USA	Ku-band	--	--	--	--
NADC/ERIM (P-3)	USA	Polar/1.25 GHz Polar/5 GHz Polar/10 GHz	2.4 m	--	--	--
NASA/JPL (CV-990)	USA	Polar/1.224 GHz	10-13 m	7 w (km)	--	--
NASA/JPL (DC-8)	USA	Polar/0.44 GHz Polar/1.25 GHz Polar/5 GHz	10-13 m	10 w (km)	--	--
SARLAB (CV-580)	USA	--	--	--	--	--
PHARUS/Delft U of T		Polar/C-band	--	--	--	--

PRELIMINARY

Table 2-8. Example Catalogue of Film Camera Imaging Satellite or Aircraft Systems in the World

PRELIMINARY

Name	Country	Band/Spectral Charac	Resolution	Average Ground Coverage/Image	Part of World Covered	Repeat Rate at Any Pt on Earth
Film Cameras Available via Soyazkarta	"Soviet"	--	5 m line pair	--	--	--
S-190B Skylab 1973	USA	Color CIR B&W	10 m	--	--	--
S-192 Skylab 1973	USA	13 bands, blue - 2.2 μ +LWIR	80 m	40 mile swath	--	--
National High Altitude Photographic Program (NHAP) on U-2 type	USA	Natural Color CIR	2 feet	10 x 10 miles	USA	3 years
Large format camera on Space Shuttle 1985	--	Color CIR	Best is 5 m line-pair	--	--	--

2.2.3 Availability

The number of systems listed points to an important fact: there are a number of standard remote sensing systems available and, as has been previously stated, they frequently collect imagery that can be obtained by the public. However, only if the imagery can be used in waste discovery and characterization is it relevant to the discussion here. Section 3 develops a method for determining what is useful. To complete the information provided in Section 2, a brief bibliography of ERIM's selected readings on remote sensing for environment is included next.

2.3 JOURNAL'S/TEXTS ON REMOTE SENSING - A SELECTED BIBLIOGRAPHY LIST

A Guide to Remote Sensing: Interpreting Images of the Earth. S.A. Drury, Oxford University Press, 1990

Applied Remote Sensing. C.P. Lo. Longman, 1986.

Classification of Remotely Sensed Images. Ian L. Thomas. Adam Hilger, 1987

Geocarto International. ISSN 1010-6049.

Geographic Information Systems. Aster Publishing. ISSN 1051-9858.

GIS World. ISSN 0897-5507.

IEEE Transactions on Geoscience and Remote Sensing. (ISSN 0196-2892)

Image Interpretation in Geology. S.A. Drury. Allen and Unwin, 1987.

International Journal of Remote Sensing. Taylor DeFrancis. ISSN 0143-1161.

International Journal of Remote Sensing. Taylor DeFrancis. ISSN 0269-3798.

Introduction to Remote Sensing. James B. Campbell. Guilford Press, 1987.

Introduction to the Physics and Techniques of Remote Sensing. Charles Elachi, Wiley, 1987.

Introductory Digital Image Processing: A Remote Sensing Perspective. John R. Jensen. Prentice-Hall, 1986.

Manual of Remote Sensing, 2nd Edition. American Society of Photogrammetry. ISBN 0-937294-41-1
(Volume 1). ISBN 0-937294-42-X (Volume 2).

Photogrammetric Engineering and Remote Sensing. American Society of Photogrammetry and Remote
Sensing. ISSN 009-1112.

Physical Fundamentals of Remote Sensing. Erwin Shanda. Springer-Verlag, 1986.

Physical Principles of Remote Sensing. W.G. Rees. Cambridge University Press, 1990.

Principles of Remote Sensing. Paul J. Curran, Longman, 1985.

Remote Sensing and Image Interpretation. Thomas M. Lillesand. Wiley, 1987.

Remote Sensing Digital Image Analysis: An Introduction. J.A. Richards. Springer-Verlag, 1986.

Remote Sensing in Hydrology. E.T. Engman. Chapman and Hall, 1991.

Remote Sensing in Soil Science. Michel A. Mulders. Elsevier, 1987.

Remote Sensing of Environment. Elsevier. ISSN 0034-4257.

Remote Sensing of Ice and Snow. Dorothy K. Hall. Chapman and Hall, 1985.

Remote Sensing: Methods and Applications. Michal R. Hord, 1986.

Remote Sensing: Principles and Interpretation. Floyd F. Sabins. Elsevier, 1987.

3.0 A SYSTEMS APPROACH

It is ERIM's opinion as well as that of most others who have considered sensor capabilities to address this problem, that there is no one "magic" trick. Much is available to contribute, but the real task is to decide which sensors to use and how. There is a real need for a systems analysis of the problem; that is, what are the problems, what can solve them, how well and for how much effort? The systems analysis discussed here involves just the non-invasive methods. At most sites, invasive techniques will be used as well, so an additional study should be conducted on the trade-offs indicated and sampling procedures that result from the entire job.

A critical element in the systems study is comparing the actual components of the problem that sensors can address, to the specific sensor that provides the solution. Section 3.1 gives an example of matching problems to sensors and Section 3.2 discusses a cost benefit methodology to compare alternative acceptable solutions. Section 3.3 outlines a plan for systematically characterizing a site. Section 3.4 addresses a time schedule for the plan.

3.1 EXAMPLE OF MATCHING PROBLEMS TO SENSORS

An example assessment was made by a group of ERIM sensor technologists to demonstrate the need to match problems to sensor solutions. Table 3-1 shows one of many "matrices," generated in the assessment. The first column lists "DOE Problem Set" or problems listed in its RDDT&E document, (2.2.1.6 being the need for remote, in situ, or other on-site methods for local characterization of contaminants). The "problem elements" are the topics listed earlier in this report as problems to be addressed at waste sites. The next column on the table gives "information elements" that represent specific information which is needed to provide answers/inputs to the problem elements. Table 3-1 focuses on subsurface contaminants (problem element) and location of tanks (information element).

The "target observables" were selected by ERIM as being those that represent the physical target phenomena which may be used to locate buried tanks. These were matched to "signature observables" or the information provided by the sensor. The "sensor" column shows typical sensors that could provide the information. A ground rule for this exercise was that sensors had to be currently operational with products demonstratable now or expected to be so within two years. Sensors selected were meant to be illustrative, not necessarily preferred.

PRELIMINARY

Definitions of sensor codes are given on Table 3-2. Details of this work and all matrices are given in the appendix.

PRELIMINARY

Table 3-1. Example of Matching Target Observables to Signature Observables to Sensors

PRELIMINARY

Table 3-2. Definitions of Sensor Codes listed in the far right column of Table 3-1

AVIRRIS	Airborne Visible & InfraRed Imaging Spectrometer. An image-forming multispectral scanner, operated on an aircraft by JPL, having over 100 spectral channels. One of the first "hyperspectral scanners."
Comm. SAR, P3	Any of a number of commercially available SAR sensors such as the one flown by DOD's P3 aircraft.
Daedalus	Daedalus scanners are a line of multispectral scanners for airborne operation manufactured by Daedalus Enterprises.
Hyper	Hyperspectral scanners. A generic imaging scanner that operates with about a hundred to a few hundred spectral channels, compared to a Multispectral scanner which has two to a few tens of channels.
IWT	A Convair 580T aircraft operated by ERIM as an Intelligent Weapons Technology testbed.
M7	A multispectral scanner of 16 channels developed by ERIM. The channels are located in the UV-visible near IR, short-wave IR, and thermal IR regions of the spectrum. A large measure of flexibility is allowed to shift/relocate the spectral location of the channels. Currently flown on ERIM aircraft.
Pan E-O	A generic panchromatic E-O camera on aircraft platform.
PRT5/10	Hand-held radiometers. The designation PRT 5 of PRT 10 are for "Precision" infrared Radiometric Thermometers. They were manufactured by Barnes, but are no longer available.
SPOT	The SPOT Multispectral satellite.
TM	The LANDSAT Thematic Mapper (TM).
3-D Laser	A generic 3-D Laser.

It is essential that this type of logic be exercised to make useful recommendations about a sensor suite for waste site problems. The type of matrix shown on Table 3-1 identifies the sensors that can provide the "benefit". Next, the cost of sensors is discussed.

3.2 A COST-BENEFIT METHODOLOGY

Having identified the sensors that address the problems, the cost-benefit analysis should proceed. This requires that benefits and costs be quantified. Often the quantifications of benefits and costs seem artificial or contrived and at best, approximate. Yet, ERIM has found that this type of analysis is very useful in providing a framework to make decisions about what future technologies to give priority funding.

PRELIMINARY

To do the analysis, the designated sensor solutions to each problem are assigned a benefit rating and cost value. Some examples of benefit are: percentage of the problem that would be expected to be solved by the sensor; or categorical ratings of good/OK/bad when compared to other possible sensor use; or amount in square meters of waste site area "characterized." Cost can also be very approximate; orders of magnitude dollars are often adequate for decision making. Sometimes even categories such as high/medium/low are adequate. However, both development and operational costs need to be considered for technology development comparisons.

Having assigned each problem such as "tank location indicated by soil moisture content change" and each sensor solution such as "characteristic spectral signature from M7" a benefit and cost, then a DOE "scenario" would be chosen. The scenario is based on knowledge of the site problems, policies and priorities and represents the relative value of each of the various waste site problems. One way of quantifying the scenario is to assign a percentage of the total problem that each problem represents. A priority ranking for each problem can also be used. Again, these only need to be approximate to help guide the analysis.

To compare one sensor suite against another, quantities like percentage of the total problem solved is compared to cost, for each suite. To assess the benefit/cost of new technology, the expected benefit of some new development is compared to that for existing technology being sure to include operational plus development costs. To evaluate more than one new technology, their relative benefit/cost ratios are compared.

3.3 PLAN FOR DETERMINING SENSOR USE IN DISCOVERY AND CHARACTERIZATION OF WASTE SITE

The following plan is an implementation of systems methodology that allows intervention at selected intervals to determine whether the activity should proceed. It is recommended that this type of procedure be implemented as a "test characterization." The plan is organized in nine steps.

Step 1 - Select a suitable GIS. Because it is likely that data will be forthcoming from a number of sources, it is suggested that a GIS be the central receiver of all data. In this way, information can be geo-coded and tracked over time. Information will include historical data on waste site disposals and other events, geological/hydrological profiles, cultural features, imagery and maps. A modest image processing set-up to produce change detection images would be very useful. Analysis of restoration personnel's requirements should be conducted to determine what features would be useful for them.

PRELIMINARY

Step 2 - Select sites for test cases. Selection of several sites is preferred because the process should be demonstrated on a wide variety of contaminant and contaminant storage problems. Also, the site selection should include site(s) where the contaminant and storage media are already well understood and site(s) where where contaminants are only believed to be stored. To minimize cost for this test, these sites should be relatively close to each other. Nearly contiguous sites would be ideal, separated enough to avoid interaction among the sites. A separate group(s) of such sites should also be tested where the geographical background is different.

Step 3 - A comprehensive analysis of the potential observables. This analysis would be conducted through discussions with the specialists on the site in addition to specialists on the contaminant/storage containers and specialists on sensors. The purpose of this effort is to identify those phenomena that a sensor may interrogate/collect that could be used as evidence that a contaminant and/or its container are present.

Step 4 - Collect all historical data. Data from interviews with old-timers and others at the sites is needed to obtain historical knowledge. It should be entered into the GIS to generate a time sequenced analysis of the sites. This, along with hydrological, topographical and geological data should yield a substantial understanding of sites and their differences.

Step 5 - Check. At this point, an assessment of the results of the preceding activities should be conducted. The purpose is to review the usefulness of what has been accomplished and whether there is sufficient motivation to continue.

Step 6 - Comprehensive evaluation of sensor characteristics and sensitivities. At this point, consider and then select the particular sensors that demonstrate capability for discovering and characterizing contaminants and containers present at the test sites. The actual mix will be based on expected cost/benefit criteria.

Step 7 - Second check. A second assessment is suggested because in the next step, data are collected and the cost of collecting data with sensors is relatively high compared to the previous activities.

Step 8 - Collect the data necessary to evaluate the current capabilities. In this step, data are collected. If possible, historical imagery and other information can be used. If not, new collection may be needed. In this step, the process of comparing problems to sensor solutions is verified and validated. The effectiveness of the

PRELIMINARY

sensors is assessed individually and in concert with others to provide evidence of newly discovered problems or provide information about known problems.

Step 9 - Implement the process at more sites, as required. It is likely that the test sites do not include some waste problems of interest and do not include all representative geographical areas. The process should be repeated, as required, to include these. Also, another test at a similar facility would be appropriate to evaluate repeatability.

3.4 TIME SCHEDULE

In theory, the systems plan just presented assumes that there is adequate time to stop to test a new sensor concept, attempt to collect and merge data to check for practical problems, etc. In this way, maximum information goes forward to select a sensor suite or decide to improve a technology. It is rare and certainly not true in this case, that the community can wait one to two years to do the solid study needed.

There is a need for specialized field experiments to test new proposed sensor-application relationships and for research into sensor/image processing modifications to current technology. There is also a need to demonstrate practical aspects of sensor tasking and to try innovative data merging. Ideally, these activities would follow and be guided by the systems study just described. However, in the interest of time, it is recommended that special sensor investigations and case study demonstrations be done in parallel with the assessment of current sensor systems.

Thus, it is essential that the results of sensor technology work, systems studies and case study demonstrations be continually integrated. All three types of work have already been initiated and it may be reasonable to merge them about one year from now for an integrated site demonstration (See Figure 3-1).

Section 4.0 contains some of ERIM's ideas about what technologies may be fruitful and Section 5.0 contains recommendations for case study demonstrations. Section 6.0 summarizes report recommendations.

Figure 3-1. Interplay of Studies

PRELIMINARY

4.0 SPECIAL SENSOR TECHNOLOGY/PROCESSING

It is recommended that a cross-section of the remote sensing community and sensor developers/phenomenologists be contacted to suggest and prioritize sensor approaches for this problem. Of particular interest is what sensors would be particularly useful, what new development is needed and what new data analysis might be suggested. Because of the time-critical nature of the problem it should be limited to sensors already available or in development but not "blue sky" approaches.

4.1 AN EXAMPLE

Table 4-1 shows an example of input from ERIM specialists. The observables shown on the table were presented to the specialists and they were asked to suggest "good" sensor solutions, noting whether the technology was available now and noting their confidence in the suggestion. They were told to consider the following observables:

- detection of waste sites
- estimation of the planar dimensions of waste sites
- location of pit or trench boundaries
- estimation of depth of disturbed (excavated and backfilled) soil
- three-dimensional location of buried containers
- determination of whether containers are leaking
- estimation of environmental impact of waste sites upon adjoining lands.

The specialists were most confident or certain that existing multispectral systems could contribute to all observables except those requiring ground penetration. They were also certain about the capability to do the various tasks shown on the table with differential absorption LIDAR as available now and with laser-induced fluorescence and multispectral LIDAR which are still in development.

The specialists suggested SAR texture analysis, use of multiple frequencies and multiple polarizations to detect sites, estimate site dimensions and locate boundaries as well as evaluate surrounding environmental impact. The specialists were moderately confident that these radar currently available technologies would work

PRELIMINARY

Table 4-1. Example of Method for Comparing Sensor Alternatives

PRELIMINARY

	OBSERVABLES							Available Now	Confidence in Expected Performance
	Detect Site	Est. Site Dimensions	Locate Pit Boundaries	Est. Depth of Dist. Soil	3-D Container Location	Detect Container Leaks	Surrounding Env. Impact		
Multispectral Passive Sensor (vis to IR)	X	X	X			X	X	X	MOST
Multispectral LIDAR	X	X							MOST
Differential Absorption LIDAR	X	X						X	MOST
Laser Induced Fluorescence	X	X	X			X	X		MOST
SAR Image Texture Analysis (segment.)	X	X	X				X	X	
Multifrequency SAR segment	X	X	X				X	X	
Polarimetric SAR	X	X	X				X	X	
Airborne UHF Wideband Ground Penetrating Radar	X	X	X	X	X	X			
LWIR (thermal)	X	X	X	X	X	X		X	
Active LIDAR (3-D)		X	X					X	LEAST

PRELIMINARY

but not certain. They also commented that ground penetrating radar could perform the first three observables while also determining the depth of disturbed soil, 3-D location of containers and detecting container leaks. However, such a radar is not commercially available at this time. Again, they were moderately confident but felt that controlled experiments are needed to confirm their conjecture.

The specialists were also moderately confident that LWIR (thermal) could contribute to the detection and location tasks, with technology available now. They were the least certain of all about currently available active (3-D) LIDAR sensitivity to estimate dimension and locate pit boundaries.

These are just examples of the utility of the recommended approach. A comprehensive survey of the community should be conducted as is currently being planned for DOE workshops.

In the process of preparing this report, a number of suggestions have come forward from ERIM specialists. They are presented next, in no particular order of presentation.

4.2 OTHER SUGGESTIONS

- Develop special FLIR processing to detect change in emitted radiance due to leaking buried tanks.
- Measure changes in the thermal behavior of the area surrounding buried tanks with developing multispectral or hyperspectral sensors.
- Measure differences in the thermal inertia of different waste sites as compared to background.
- Detect areas of heavy metal contamination by multispectral analysis (from aircraft); if area large enough use LANDSAT or SPOT.
- Detect changes in land contours by repeating surveys using interferometric SAR systems that are being developed.
- Improve data processing from currently available ground penetrating radar to determine whether the sensor has potential to detect buried objects.
- Develop a robotics platform to test for changes in gaseous emissions from tanks.
- Develop an aircraft testbed with multiple sensors especially for waste problems.
- Test the HYDICE or other hyperspectral scanners for detection of a number of chemicals.
- Retrofit sensitive invasive ground-based chemical detectors on aircraft or other platforms and use existing soil sample holes.
- Implement sub-pixel analysis or other pattern recognition/target detection methods.

PRELIMINARY

- Review current LANDSAT and SPOT data processing, automatic or supervised classification to see what enhancements might be appropriate for waste problems.
- Use change detection and image fusion with LANDSAT, SPOT, maps and other imagery (radar, optical).
- Use a GIS to update maps, categorize and merge data from multiple sensors and data bases.

Much more detail is available on all of these suggestions and the ones on Table 4-1. More detail can be provided on request.

4.3 TAKING ADVANTAGE OF OTHER STUDIES

Many environmental surveys based on airborne and satellite-based data have been conducted for county land use/waste disposal inventories, wildlife population studies, disease/infestations in forests, agricultural land monitoring and the like. Other studies have been made by DOD and NASA looking for buried objects. These studies have observables similar to those for waste site discovery characterization, so individuals who have been involved in these studies are a resource. It is recommended that selected studies be reviewed and individuals contacted to determine:

- which sensors added what information
- how sensors were used together
- how often to revisit an area
- what resolutions or bands were needed

PRELIMINARY

5.0 CASE STUDIES

Two case studies are recommended next. One uses historical data and one involves new data collection.

5.1 CASE STUDY - HISTORICAL DATA

A recent review of historical imagery, ground truth data and auxiliary information has shown that good historical information is available for Los Alamos waste sites. Imagery is available from the time the sites began to be used and documentation is good for the historical period. The purpose of a historical case study at Los Alamos would be to demonstrate data fusion methods, that is, how a GIS system could be used to fuse a number of data sources to monitor the sites, detect changes and begin site characterization.

Sources of data are:

- Multispectral, IR imagery
- Photography
- Radar imagery
- Gamma and chemical detection data
- Ground truth
- Meteorological, geographical and hydrological data
- Soil samples
- Conversations with "old-timers" about waste disposal locations
- Los Alamos remediation project data files
- Any relevant scientific experiments that have taken place at the site.

The difficulty here is likely to be which data to include, rather than a lack of data. Special studies should include:

- Demonstrations of use of GIS for site characterization
- Creative processing of existing imagery to highlight waste problems
- Image fusion
- Suggestions of useful graphic output
- Indicators of change.

PRELIMINARY

It should be mentioned that among DOE facilities, Los Alamos does not have the most serious waste problems. However, there are numerous interesting features at the sites, more than are likely to be covered in any case study. As a demonstration of data fusion technology it is an excellent choice because of the good quality of ground truth. Also, since the Los Alamos remediation team is available on a daily basis, the demonstration can be authentic and current.

A preliminary look at the data indicate that there is enough coverage from the various sources to piece together some typical trends over time to adequately demonstrate a methodology. However, to study true synergistic applications, new imagery will have to be collected in a coordinated fashion. To obtain geographic and waste type variation, several sites will have to be considered. The next case study addresses that.

5.2 CASE STUDY - NEW COLLECTION

There are numerous reasons for new collection and many purposes can be served by a well-planned one. New collections are needed to obtain:

- time coincident coverage by different sensors
- use of new experimental sensors
- additional ground truth data
- digital data forms that are not normally saved, such as radar phase histories
- imagery that is collected frequently enough to observe the changing phenomena
- imagery that is of the appropriate type to observe the phenomena.

The result of new collection would be to:

- determine what sensors can measure which phenomena
- demonstrate the benefit of data fusion
- provide a demonstration of a proposed multisensor/multisource characterization methodology.

A few recommendations for the collection are as follows:

- Good historical data will be important to be able to demonstrate any new change.
- Ground truth is also very important to be able to understand the remote sensing data.
- Existing satellite systems can be tasked cheaply; if budget permits, adding aircraft collection would give flexibility of collection times and opportunities to add new experimental sensors.

PRELIMINARY

- Collection should cover all seasons of the year.
- Once set in place, some parts of the collection effort could continue each year.

Finally, each DOE facility offers unique geography and physical plant description with numerous waste sites to be observed. The collection should task a small subsample of waste sites very frequently to observe phenomena that require frequent coverage. A larger sample of waste site can be tasked less frequently to observe geographic variation.

5.3 SCHEDULE

The demonstration using Los Alamos historical data can begin immediately and could be completed in 2-3 months. The new collection should take one year to cover all seasons and then repeat. About one month should be allocated to solicit collection requests from the various collection participants with an additional month allocated for planning and data requests. The initiation time depends on the availability of sensors used.

PRELIMINARY

6.0 SUMMARY OF RECOMMENDATIONS

It is unlikely that there is a single remote sensing technique that alone can discover and characterize waste sites. However, it is expected that some requirements can be met using a suite of appropriate sensors along with other collateral information. Data fusion, especially based on GIS systems, will likely have high payoff.

At this time, the community has not verified a sensor strategy for the waste site problem. Rather than concentrating on advanced sensor technology development, it is recommended that existing sensor systems be emphasized including improved packaging and processing. Environmental agencies and the military/intelligence community have studied similar problems; it is recommended that DOE obtain their input and involvement.

A systems study is recommended; observables must be defined, matched to sensor capabilities and a cost-benefit analyses made. An inventory of sensors and historical imagery is essential but it needs to be selective. "Old-timers" at the sites are also valuable information sources of information on site locations and history. First-cut recommendations need to be made about

- what sensor/processing technologies should be evaluated
- what GIS systems should be used to combine information
- what case study collections should be made.

A recommended approach includes an element of overall area monitoring at relatively low resolution, followed by focussed overhead collection at higher resolution and ground data collection. For area monitoring, improved processing and change detection algorithms for LANDSAT and SPOT are expected to have high payoff. GIS-created maps from all information and image fusion are also likely to be of benefit.

Sensor solutions that are recommended as having the most promise for the observables discussed in this report are:

- multispectral, especially IR or hyperspectral, for thermal effects, vegetative change, leaks and contaminants
- radar for depth, dimension and texture
- LIDAR, laser fluorescence and hyperspectral for chemical effluents.

PRELIMINARY

The value of some of these needs to be validated. ERIM also recommends that some thought be given to platforms. While traditional sensors on low flying aircraft, high flying aircraft, satellites and other means are all possibilities, there is much room for innovation such as

- robotics for sensitive (unsafe) areas
- chemical detectors on aircraft
- specially designed aircraft platforms to collect simultaneous signatures of various kinds.

Two case studies are recommended. The first is a Los Alamos historical data study to demonstrate the merging of information to yield new inferences. The second is a new collection to demonstrate sensor capabilities and develop integrated strategies. These practical demonstrations can provide feedback to on-going systems studies and other special sensor experiments or research.

From the two case studies, systems studies and the knowledge gained through pooled data/information/experiments sponsored by all interested agencies, sufficient experience should have been gathered to apply the lessons to an actual site characterization. Following a plan similar to the one suggested in section 3.3, trial characterization should be implemented at selected DOE sites.

PRELIMINARY

APPENDIX: REQUIREMENTS ANALYSIS

AVIRRIS	Airborne Visible & InfraRed Imaging Spectrometer. An image-forming multispectral scanner, operated on an aircraft by JPL, having over 100 spectral channels. One of the first "hyperspectral scanners."
Comm. SAR, P3	Any of a number of commercially available SAR sensors such as the one flown by DOD's P3 aircraft.
Daedalus	Daedalus scanners are a line of multispectral scanners for airborne operation manufactured by Daedalus Enterprises.
Hyper	Hyperspectral scanners. A generic imaging scanner that operates with about a hundred to a few hundred spectral channels, compared to a Multispectral scanner which has two to a few tens of channels.
IWT	A Convair 580T aircraft operated by ERIM as an Intelligent Weapons Technology testbed.
M7	A multispectral scanner of 16 channels developed by ERIM. The channels are located in the UV-visible near IR, short-wave IR, and thermal IR regions of the spectrum. A large measure of flexibility is allowed to shift/relocate the spectral location of the channels. Currently flown on ERIM aircraft.
Pan E-O	A generic panchromatic E-O camera on aircraft platform.
PRT5/10	Hand-held radiometers. The designation PRT 5 of PRT 10 are for "Precision" infrared Radiometric Thermometers. They were manufactured by Barnes, but are no longer available.
SPOT	The SPOT Multispectral satellite.
TM	The LANDSAT Thematic Mapper (TM).
3-D Laser	A generic 3-D Laser.

DOE Problem Description

2.2.1.1 Need for Better Characterization of Subsurface Geohydrologic Features and Properties - Characterization of subsurface geology, hydrology, geochemistry/geophysics, and biological activity.

2.2.1.2 Need for Better Characterization and Sampling Strategy - Site characterization, strategic planning for data collection (sampling) and data utilization. Includes geostatistical analyses.

2.2.1.3 Need for Characterization of Inactive Facilities - Design, construction features, current physical condition and contamination levels of facilities.

2.2.1.4 Need for Characterization of Underground Storage Tanks - Mixed wastes stored in underground storage tanks (single-shelled storage tanks (SSTs)).

2.2.1.5 Need for Better Analytical Procedures for Some Radionuclides and Complex Organic Mixtures - Site characterization -> soil, water, geo-phase samples, waste samples.

2.2.1.6 Need for Remote, In Situ, or Other Onsite Methods for Local Characterization of Contaminants - Subsurface contamination -> buried concentrated waste forms (ex. tanks, trenches) dispersed contaminants in soil & water. Real-time monitoring of ambient volatile organics & toxic metals.

2.2.1.7 Need for Understanding Contaminant Distribution and Behavior in Subsurface Environment - Develop ways to optimize characterization of a given site; Develop sufficient understanding of subsurface processes; Basis for measuring and demonstrating that remediation measures are effective.

DOE Problem Set vs. Problem Element

Problem Element	DOE Problem Set						
	2.2.1.1	2.2.1.2	2.2.1.3	2.2.1.4	2.2.1.5	2.2.1.6	2.2.1.7
Site Location			X			X	
Soils-Basin/Ponds Containing LLW and Hazardous Wastes							X
Contaminated Soils - Mixed Wastes				X		X	X
Burial Grounds Containing Radioactive and Hazardous Wastes			X			X	X
Sludges in Tanks				X		X	
Ground Water Contaminated with Radionuclides, Organics, and Inorganics							X
Subsurface Contaminants			X			X	X

Problem Elements vs. Information Elements

Problem Elements

Information Elements	Site Location	Soils-Basin/Ponds Containing LLW & Hazardous Wastes	Contaminated Soils - Mixed Wastes	Burial Grounds Containing Radioactive & Hazardous Wastes	Sludges in Tanks	Ground Water Contaminated w/ Radionuclides, Organics and Inorganics	Subsurface Contaminants
Location of Tanks	X			X	X		X
Characterization of Tanks				X	X		X
3-D Mapping of Tanks					X		X
Identify Concentrated Wastes in Trenches			X	X			X
Locate Contaminants in Ground Water		X		X		X	X
Track Migration of Contaminants in Soils		X	X	X		X	X
Characterize Soils (contaminants/distrib.)			X				X
Location of Berms, Fences, LOCs	X	X		X			X
Detect/Id. Cultural Liner, Scrap	X			X			X

Information Elements vs. Target Observables

Information Elements

[illegible]

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor
2.2.1.1	Site Location				
2.2.1.2					
2.2.1.3	Soils-Basin/Ponds Containing LLW and Hazardous Wastes				
2.2.1.4					
2.2.1.5	Contaminated Soils - Mixed Wastes				
2.2.1.6	Burial Grounds Containing Radioactive and Hazardous Wastes				
2.2.1.7	Sludges in Tanks				
	Ground Water Contaminated with Radionuclides, Organics, and Inorganics				
	Subsurface Contaminants				

DOG Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Se near
2.2.1.1 2.2.1.2 2.2.1.3 2.2.1.4 2.2.1.5 2.2.1.6 2.2.1.7	<p>Site Location</p> <p>Soils-Bush/Ponds Containing LLW and Hazardous Wastes</p> <p>Contaminated Soils - Mixed Wastes</p> <p>Burial Grounds Containing Radioactive and Hazardous Wastes</p> <p>Sludges in Tanks</p> <p>Ground Water Contaminated with Radionuclides, Organics, and Inorganics</p> <p>Subsurface Contaminants</p>	<p>Location of Tanks</p> <p>Characterization of Tanks</p> <p>3-D Mapping of Tanks</p> <p>Identify Concentrated Waste in Trenches</p> <p>Locate Contaminants in Groundwater</p> <p>Track Migration of Contaminants in Soils</p> <p>Characterize Soils (constituents/dists)</p> <p>Location of Berms/Fences/LOCs</p> <p>Detected Cultural Litter/Scrap</p>			

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Barriers
2.2.1.1 2.2.1.2 2.2.1.3 2.2.1.4 2.2.1.5 2.2.1.6 2.2.1.7	<p>Site Location</p> <p>Soils-Bash/Ponds Containing LLW and Hazardous Wastes</p> <p>Contaminated Soils - Mixed Wastes</p> <p>Burial Grounds Containing Radioactive and Hazardous Wastes</p> <p>Sludges in Tanks</p> <p>Ground Water Contaminated with Radionuclides, Organics, and Inorganics</p> <p>Subsurface Contaminants</p>	<p>Location of Tanks</p> <p>Characterization of Tanks</p> <p>3-D Mapping of Tanks</p> <p>Identify Concentrated Waste in Trenches</p> <p>Locate Contaminants in Groundwater</p> <p>Track Migration of Contaminants in Soils</p> <p>Characterize Soils</p> <p>Location of Berms/Fences/LCOs</p> <p>Detect/Id. Cultural Litter/Scrap</p>	<p>Vegetation Stress</p> <p>Soil Moisture Content Changes</p> <p>Soil Compaction Changes</p> <p>Desert "Varnish" Disruption</p> <p>Anomalous Vegetative Growth</p> <p>Exothermic Heat Sources</p> <p>Tank/Soil Thermal Indicators</p> <p>Local Surface Contour Indicators</p> <p>Soil/Mineral Discoloration</p>		

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor
2.2.1.1	Site Location	Location of Tanks	Vegetation Stress	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM, SPOT, AVIRRIS, Daedalus, M7, Hyper. Daedalus, M7, PRT5/10 IWT, Comm. SAR, P3
2.2.1.2		Location of Berms/Fences/LOC			
2.2.1.3	Soils-Basin/Ponds Containing				
2.2.1.4	LLW and Hazardous Wastes	Detect/Id. Cultural Litter/Scrap	Soil Moisture Content Changes	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM, SPOT, AVIRRIS, Daedalus, M7, Hyper. Daedalus, M7, PRT5/10 IWT, Comm. SAR, P3
2.2.1.5					
2.2.1.6	Contaminated Soils - Mixed Wastes		Soil Compaction Changes	Sensible Temperature Anomaly RCS/Clutter Signature Change	Daedalus, M7, PRT5/10 IWT, Comm. SAR, P3
2.2.1.7	Burial Grounds Containing Radioactive and Hazardous Wastes		Desert "Varnish" Disruption	Characteristic Spectral Signature	TM, SPOT, AVIRRIS, Daedalus, M7, Hyper.
	Sludges in Tanks				
	Ground Water Contaminated with Radionuclides, Organics, and Inorganics		Anomalous Vegetative Growth	Characteristic Spectral Signature RCS/Clutter Signature Change E-O/SAR Signature Texture Change	TM, SPOT, AVIRRIS, Daedalus, M7, Hyper. IWT, Comm. SAR, P3 Pan E-O
	Subsurface Contaminants		Exothermic Heat Sources	Sensible Temperature Anomaly	Daedalus, M7, PRT5/10
			Tank/Soil Thermal Indicators	Sensible Temperature Anomaly	Daedalus, M7, PRT5/10
			Local Surface Contour Indicators	Height/Relief (E-O/SAR) Pan Contrast Change	IWT, Comm. SAR, P3, 3-D Laser Pan E-O
			Soil/Mineral Discoloration	Characteristic Spectral Signature Pan Contrast Change	TM, SPOT, AVIRRIS, Daedalus, M7, Hyper. Pan E-O
			Ambient/Diurnal Thermal Change	Sensible Temperature Anomaly	Daedalus, M7

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor	
2.2.1.1 2.2.1.2 2.2.1.3 2.2.1.4 2.2.1.5 2.2.1.6 2.2.1.7	Site Location	Location of Tanks	Vegetation Stress	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM,SPOT,AVIRRIIS, Daedalus,M7,Hyper. Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3	
	Soils-Basin/Ponds Containing LLW and Hazardous Wastes	Location of Berms/Fences/LOC				
		Detect/Id. Cultural Litter/Scrap	Soil Moisture Content Changes	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM,SPOT,AVIRRIIS, Daedalus,M7,Hyper. Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3	
	Contaminated Soils - Mixed Wastes					
		Burial Grounds Containing Radioactive and Hazardous Wastes		Soil Compaction Changes	Sensible Temperature Anomaly RCS/Clutter Signature Change	Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3
	Sludges in Tanks			Desert "Varnish" Disruption	Characteristic Spectral Signature	TM,SPOT,AVIRRIIS, Daedalus,M7,Hyper.
		Ground Water Contaminated with Radionuclides, Organics, and Inorganics		Anomalous Vegetative Growth	Characteristic Spectral Signature RCS/Clutter Signature Change E-O/SAR Signature Texture Change	TM,SPOT,AVIRRIIS, Daedalus,M7,Hyper. IWT,Comm.SAR,P3 Pan E-O
	Subsurface Contaminants					
			Ambient/Diurnal Thermal Change	Sensible Temperature Anomaly	Daedalus, M7	
			Soil/Mineral Discoloration	Characteristic Spectral Signature Pan Contrast Change	TM,SPOT,AVIRRIIS, Daedalus,M7,Hyper. Pan E-O	
			Fences/Posts/Footings	Point/Extended Signatures	IWT,Comm.SAR,P3	

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observables	Sensor
2.2.1.1	Site Location	Location of Tanks	Soil Compaction Changes	Sensible Temperature Anomaly	Deedalus, M7, PR TS/10
2.2.1.2	Soils-Basin/Ponds Containing LLW and Hazardous Wastes	Location of Berms/Fences/LOC	Desert "Vanish" Disruption	RCS/Cluster Signature Change	WT, Comm, SAR, P3
2.2.1.3	Contaminated Soils - Mixed Wastes	Detectable Cultural Layer/Borep		Characteristic Spectral Signature	TM, SPOT, AVIRIS, Deedalus, M7, Hyper.
2.2.1.4	Burial Grounds Containing Radioactive and Hazardous Wastes		Anomalous Vegetative Growth	Characteristic Spectral Signature	TM, SPOT, AVIRIS, Deedalus, M7, Hyper.
2.2.1.5	Sludges in Tanks			RCS/Cluster Signature Change	WT, Comm, SAR, P3
2.2.1.6	Ground Water Contaminated with Radionuclides, Organics, and Inorganics			E-O/SAR Signature Texture Change	Pan E-O
2.2.1.7	Subsurface Contaminants			Pan Contrast Change	Pan E-O
			Surface/Subsurface Metal	Point/Extended Signature	WT, Comm, SAR, P3

DOE Problem Sets	22.1.1 22.1.2 22.1.3 22.1.4 22.1.5 22.1.6 22.1.7	Site Location Soils-Basins/Ponds Containing LW and Hazardous Wastes Contaminated Soils - Mixed Wastes Burial Grounds Containing Radioactive and Hazardous Wastes Sludges in Tanks Ground Water Contaminated with Radionuclides, Organics, and Inorganics Subsurface Contaminants	Problem Element	Information Element	Target Observables	Signature Observables	Sensor
		Loose Contaminants in Ground Water		Track Migration of Contaminants in Soils	Soil Moisture Content Changes	Characteristic Spectral Signature TM,SPOT,AVIRIS, Daedalus,M7,Hyper, Daedalus, M7,PRTS/10 RCS/Cutler Signature Change RCS/Cutler Signature Change	
					Soil Compaction Changes	Soil Moisture Content Changes	
					Desert "Vernal" Disruption	Characteristic Spectral Signature TM,SPOT,AVIRIS, Daedalus,M7,Hyper, Daedalus, M7,PRTS/10 RCS/Cutler Signature Change	
					Anomalous Vegetative Growth	Characteristic Spectral Signature TM,SPOT,AVIRIS, Daedalus,M7,Hyper, Daedalus, M7,PRTS/10 RCS/Cutler Signature Change E-O/SAR Signature Change	
					Exothermic Heat Sources	Sentinel Temperature Anomaly	
					Local Surface Contour Indicators	Height/Radar (E-O/SAR)	
					Soil/Mineral Discoloration	Characteristic Spectral Signature TM,SPOT,AVIRIS, Daedalus,M7,Hyper, Pan E-O	

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor
2.2.1.1	Site Location	Locate Contaminants in Ground Water	Vegetation Stress	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper. Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3
2.2.1.2	Selle-Basin/Ponds Containing LLW and Hazardous Wastes				
2.2.1.3		Track Migration of Contaminants in Sells	Soil Moisture Content Changes	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper. Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3
2.2.1.4					
2.2.1.5	Contaminated Soils - Mixed Wastes	Location of Berms,Fences,LOC	Soil Compaction Changes	Sensible Temperature Anomaly RCS/Clutter Signature Change	Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3
2.2.1.6			Desert "Varnish" Disruption	Characteristic Spectral Signature	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper.
2.2.1.7	Burial Grounds Containing Radioactive and Hazardous Wastes				
	Sludges in Tanks		Anomalous Vegetative Growth	Characteristic Spectral Signature RCS/Clutter Signature Change E-O/SAR Signature Texture Change	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper. IWT,Comm.SAR,P3 Pan E-O
	Ground Water Contaminated with Radionuclides, Organics, and Inorganics				
	Subsurface Contaminants		Exothermic Heat Sources	Sensible Temperature Anomaly	Daedalus, M7,PRT5/10,
			Soil/Mineral Discoloration	Characteristic Spectral Signature Pan Contrast Change	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper. Pan E-O

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor
2.2.1.1	Site Location	Locate Contaminants in Ground Water	Vegetation Stress/Vigor	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM, SPOT, AVIRIS, Daedalus, M7, Hyper. Daedalus, M7, PRT5/10, IWT, Comm. SAR, P3
2.2.1.2					
2.2.1.3	Soils-Basin/Ponds Containing	Track Migration of Contaminants in Soils	Soil Moisture Content Changes	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM, SPOT, AVIRIS, Daedalus, M7, Hyper. Daedalus, M7, PRT5/10, IWT, Comm. SAR, P3
2.2.1.4	LLW and Hazardous Wastes				
2.2.1.5	Contaminated Soils - Mixed Wastes	Location of Berms, Fences, LOC	Soil Compaction Changes	Sensible Temperature Anomaly RCS/Clutter Signature Change	Daedalus, M7, PRT5/10, IWT, Comm. SAR, P3
2.2.1.6					
2.2.1.7	Burial Grounds Containing Radioactive and Hazardous Wastes		Desert "Varnish" Disruption	Characteristic Spectral Signature	TM, SPOT, AVIRIS, Daedalus, M7, Hyper.
	Sludges in Tanks		Anomalous Vegetative Growth	Characteristic Spectral Signature RCS/Clutter Signature Change E-O/SAR Signature Texture Change	TM, SPOT, AVIRIS, Daedalus, M7, Hyper. IWT, Comm. SAR, P3 Pan E-O
	Ground Water Contaminated with Radionuclides, Organics, and Inorganics				
	Subsurface Contaminants		Ambient/Diurnal Thermal Changes	Sensible Temperature Anomaly	Daedalus, M7
			Soil/Mineral Discoloration	Characteristic Spectral Signature Pan Contrast Change	TM, SPOT, AVIRIS, Daedalus, M7, Hyper. Pan E-O
			Fences/Posts/Footings	Point/Extended Signatures	IWT, Comm. SAR, P3

DOI Problem Sets	Problem Element	Information Element	Target Observables	Signature Observables	Sensor
2.2.1.1 2.2.1.2 2.2.1.3 2.2.1.4 2.2.1.5 2.2.1.6 2.2.1.7	Site Location Soils-Bash/Ponds Containing LLW Contaminated Soils - Mixed Wastes Burial Grounds Containing Radioactive and Hazardous Wastes Sedges in Tanks Ground Water Contaminated with Radionuclides, Organics, and Inorganics Subsurface Contaminants	Identify Concentrated Waste in In Trenches Track Migration of Contaminants in Soils Characterize Soils (concentrations)	Vegetation Stress/Vigor Soil Moisture Content Changes Soil Compaction Changes Desert "Vernal" Disruption Anomalous Vegetative Growth Exothermic Heat Sources Local Surface Contour Indicators Soil/Mineral Discoloration	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Cluster Signature Change TM,SPOT,AVIRIS, Daedalus,M7,Hyper, WT,Comm,SAR,P3 Pan E-O	TM,SPOT,AVIRIS, Daedalus,M7,Hyper, WT,Comm,SAR,P3,3-D Laser Pan E-O

DOE Problem Sets	221.1 221.2 221.3 221.4 221.5 221.6 221.7	Site Location Soils-Basins/Ponds Containing LLW and Hazardous Wastes Contaminated Soils - Mixed Wastes Burial Grounds Containing Radioactive and Hazardous Wastes Wastes Sludges in Tanks Ground Water Contaminated with Radionuclides, Organics, and Inorganics Subsurface Contaminants	Problem Element	Information Element	Target Observable	Signature Observable	Sensor								
<div>Identify Concentrated Waste in Trenches</div> <div>Track Migration of Contaminants in Bells</div> <div>Characteristic Soils (constituents/depth)</div>								Vegetation Stress/Vigor	Characteristic Spectral Signature TM.SPOT.AVIRRIS, Deedalus, M7, Hyper. Sensible Temperature Anomaly Daedalus, M7, PRTS/10 RCS/Cluster Signature Change WT, Comm, SAR, P3						
								Soil Moisture Content Changes	Characteristic Spectral Signature TM.SPOT.AVIRRIS, Deedalus, M7, Hyper. Sensible Temperature Anomaly Daedalus, M7, PRTS/10 RCS/Cluster Signature Change WT, Comm, SAR, P3						
								Soil Compaction Changes	Sensible Temperature Anomaly Daedalus, M7, PRTS/10 RCS/Cluster Signature Change WT, Comm, SAR, P3						
								Desert "Varnish" Disruption	Characteristic Spectral Signature TM.SPOT.AVIRRIS, Deedalus, M7, Hyper.						
								Anomalous Vegetative Growth	Characteristic Spectral Signature TM.SPOT.AVIRRIS, Deedalus, M7, Hyper. RCS/Cluster Signature Change WT, Comm, SAR, P3 E-O/SAR Signature Texture Change Pan E-O						
								Exothermic Heat Sources	Sensible Temperature Anomaly Daedalus, M7, PRTS/10						
								Soil/Mineral Discoloration	Characteristic Spectral Signature TM.SPOT.AVIRRIS, Deedalus, M7, Hyper. Pan Contrast Change Pan E-O						

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Bar near
2.2.1.1 2.2.1.2 2.2.1.3 2.2.1.4 2.2.1.5 2.2.1.6 2.2.1.7	Site Location Soils-Bash/Ponds Containing LLW and Hazardous Wastes Contaminated Soils - Mixed Wastes Burial Grounds Containing Radioactive and Hazardous Wastes Sludges in Tanks Ground Water Contaminated with Radionuclides, Organics, and Inorganics Subsurface Contaminants	Identify Concentrated Waste in Trenches Track Migration of Contaminants in Soils Characterize Soils (constituents/distrib.)	Vegetation Stress/Vigor Soil Moisture Content Changes Soil Compaction Changes Desert "Varnish" Disruption Anomalous Vegetative Growth Exothermic Heat Sources Soil/Mineral Discoloration Principal Chemical Constituents	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change Sensible Temperature Anomaly RCS/Clutter Signature Change Characteristic Spectral Signature Characteristic Spectral Signature RCS/Clutter Signature Change E-O/SAR Signature Texture Change Sensible Temperature Anomaly Characteristic Spectral Signature Pan Contrast Change Characteristic Spectral Signature	TM, SPOT, AVIRIS, Deedalus, M7, Hyper, Deedalus, M7, PRISM/10 WT, Comm. SAR, P3 TM, SPOT, AVIRIS, Deedalus, M7, Hyper, Deedalus, M7, PRISM/10 WT, Comm. SAR, P3 Deedalus, M7, PRISM/10 WT, Comm. SAR, P3 TM, SPOT, AVIRIS, Deedalus, M7, Hyper, Deedalus, M7, Hyper, WT, Comm. SAR, P3 TM, SPOT, AVIRIS, Deedalus, M7, Hyper, WT, Comm. SAR, P3 Pan E-O Deedalus, M7, PRISM/10 TM, SPOT, AVIRIS, Deedalus, M7, Hyper, Pan E-O High Resolution Spectroradiometer, Hyper.

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor
2.2.1.1	Site Location				
2.2.1.2					
2.2.1.3	Soils-Basin/Ponds Containing LLW and Hazardous Wastes				
2.2.1.4					
2.2.1.5					
2.2.1.6	Contaminated Soils - Mixed Wastes	Location of Tanks	Vegetation Stress	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper. Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3
2.2.1.7	Burial Grounds Containing Radioactive and Hazardous Wastes	Identify Concentrated Waste in Trenches	Soil Compaction Changes	Sensible Temperature Anomaly RCS/Clutter Signature Change	Daedalus, M7,PRT5/10 IWT,Comm.SAR,P3
	Sludges in Tanks	Locate Contaminants in Groundwater	Desert "Varnish" Disruption	Characteristic Spectral Signature	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper.
	Ground Water Contaminated with Radionuclides, Organics, and Inorganics	Location of Berms/Fences/LOCs	Anomalous Vegetative Growth	Characteristic Spectral Signature RCS/Clutter Signature Change E-O/SAR Signature Texture Change	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper. IWT,Comm.SAR,P3 Pan E-O
	Subsurface Contaminants	Track Migration of Contaminants in Ground Water	Exothermic Heat Sources	Sensible Temperature Anomaly	Daedalus, M7,PRT5/10
			Tank/Soil Thermal Indicators	Sensible Temperature Anomaly	Daedalus, M7,PRT5/10
			Local Surface Contour Indicators	Height/Relief (E-O/SAR)	IWT,Comm.SAR,P3,3-D Laser Pan E-O
			Soil/Mineral Discoloration	Characteristic Spectral Signature Pan Contrast Change	TM,SPOT,AVIRRIS, Daedalus,M7,Hyper. Pan E-O
			Ambient/Diurnal Thermal Changes	Sensible Temperature Anomaly	Daedalus, M7

[illegible]

DOE Problem Sets	221.1 221.2 221.3 221.4 221.5 221.6 221.7	Site Location Soils-Basins/Ponds Containing LLW and Hazardous Wastes Contaminated Soils - Mixed Wastes Burial Grounds Containing Radioactive and Hazardous Wastes Sludges in Tanks Ground Water Contaminated with Radionuclides, Organics, and Inorganics Subsurface Contaminants	Location of Tanks Identify Concentrated Waste in Trenches (Buried) Contaminants in Groundwater Location of Berms/Fences/LOCs Detect/d. Cultural Litter/Scrap Track Migration of Contaminants In Soils	Intermediate Element	Target Observable	Signature Observable	Sensor
			Vegetation Stress/Vigor	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Cluster Signature Change TM.SPOT.AVIRRIS, Deedalus, M7, Hyper, Deedalus, M7, PRISM10 MT, Comm, SAR, P3			
			Soil Moisture Content Changes	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Cluster Signature Change Deedalus, M7, PRISM10 MT, Comm, SAR, P3			
			Soil Compaction Changes	Sensible Temperature Anomaly RCS/Cluster Signature Change Deedalus, M7, PRISM10 MT, Comm, SAR, P3			
			Desert "Varch" Disruption	Characteristic Spectral Signature TM.SPOT.AVIRRIS, Deedalus, M7, Hyper,			
			Anomalous Vegetative Growth	Characteristic Spectral Signature RCS/Cluster Signature Change E-O/SAR Signature Texture Change TM.SPOT.AVIRRIS, Deedalus, M7, Hyper, MT, Comm, SAR, P3 Pan E-O			
			Exothermic Heat Sources	Sensible Temperature Anomaly Deedalus, M7, PRISM10			
			Local Surface Contour Indicators	Height/Relief (E-O/SAR) MT, Comm, SAR, P3, 3-D Laser Pan E-O			
			Soil/Mineral Discoloration	Characteristic Spectral Signature Pan Contrast Change TM.SPOT.AVIRRIS, Deedalus, M7, Hyper, Pan E-O			

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor
22.1.1 22.1.2 22.1.3 22.1.4 22.1.5 22.1.6 22.1.7	Site Location Soils-Bash/Ponds Containing LLW and Hazardous Wastes Contaminated Soils - Mixed Wastes Burial Grounds Containing Radioactive and Hazardous Wastes Sludges in Tanks Ground Water Contaminated with Radionuclides, Organics, and Inorganics Subsurface Contaminants	Location of Tanks Identify Concentrated Waste in Trenches (Buried) Contaminants in Groundwater Location of Barrels/Fences/LOCa Detect/d. Cultural Litter/Scrap Track Migration of Contaminants In Soils	Vegetation Stress/Vigor Soil Moisture Content Changes Soil Compaction Changes Desert "Vegetation" Disruption Anomalous Vegetative Growth Ambient/Diurnal Thermal Changes Soil/Mineral Discoloration Fences/Posts/Footings	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Cluster Signature Change Deedatus, M7, PRTS/M TM, SPOT, AVIRIS, Deedatus, M7, Hyper. Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Cluster Signature Change Deedatus, M7, PRTS/M TM, SPOT, AVIRIS, Deedatus, M7, Hyper. Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Cluster Signature Change Deedatus, M7, PRTS/M TM, SPOT, AVIRIS, Deedatus, M7, Hyper. Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Cluster Signature Change Deedatus, M7, PRTS/M TM, SPOT, AVIRIS, Deedatus, M7, Hyper. Pan Contrast Change Point/Extended Signatures Deedatus, M7 TM, SPOT, AVIRIS, Deedatus, M7, Hyper. Pan E-O MT, Comm, SAR, P3	Sensor

DOE Problem Sets	221.1 221.2 221.3 221.4 221.5 221.6 221.7	<p>Site Location</p> <p>Soils-Basins/Ponds Containing LLW</p> <p>Contaminated Soils -</p> <p>Mixed Wastes</p> <p>Burial Grounds Containing</p> <p>Radioactive and Hazardous</p> <p>Wastes</p> <p>Sludges in Tanks</p> <p>Ground Water Contaminated with</p> <p>Radionuclides, Organics, and</p> <p>Inorganics</p> <p>Subsurface Contaminants</p>	<p>Location of Tanks</p> <p>Identify Concentrated Waste in</p> <p>Trenches (Buried)</p> <p>Contaminants in Groundwater</p> <p>Location of Berms/Fences/LOCs</p> <p>Detect/Id. Cultural Liter/Borp</p> <p>Track Migration of Contaminants</p> <p>In Soils</p>	<p>Vegetation Stress/Vigor</p> <p>Soil Moisture Content Changes</p> <p>Soil Compaction Changes</p> <p>Desert "Vegetation" Disruption</p> <p>Characteristic Spectral Signature</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Characteristic Spectral Signature</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Sensible Temperature Anomaly</p> <p>RCS/Clutter Signature Change</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Characteristic Spectral Signature</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Sensible Temperature Anomaly</p> <p>RCS/Clutter Signature Change</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Soil Moisture Content Changes</p> <p>Characteristic Spectral Signature</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Sensible Temperature Anomaly</p> <p>RCS/Clutter Signature Change</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Soil Compaction Changes</p> <p>Sensible Temperature Anomaly</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Desert "Vegetation" Disruption</p> <p>Characteristic Spectral Signature</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Characteristic Spectral Signature</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Anomalous Vegetative Growth</p> <p>RCS/Clutter Signature Change</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>E-O/SAR Signature Change</p> <p>Pan E-O</p> <p>Daedalus, M7</p> <p>Sensible Temperature Anomaly</p> <p>Daedalus, M7</p> <p>Characteristic Spectral Signature</p> <p>TM,SPOT,AVIRIS; Daedalus,M7,Hypoc.</p> <p>Daedalus, M7,PRTS/10</p> <p>WT,Comm,SAR,P3</p> <p>Pan Contrast Change</p> <p>Pan E-O</p> <p>Daedalus, M7</p> <p>Point/Extended Signatures</p> <p>WT,Comm, SAR,P3</p> <p>Surface/Subsurface Metal</p>	<p>Target Observable</p> <p>Signature Observable</p> <p>Sensor</p>
------------------	---	--	--	---	--

DOE Problem Sets	Problem Element	Information Element	Target Observable	Signature Observable	Sensor
2.2.1.1	Site Location				
2.2.1.2					
2.2.1.3	Soils-Basin/Ponds Containing LLW and Hazardous Wastes				
2.2.1.4					
2.2.1.5					
2.2.1.6	Contaminated Soils -	Location of Tanks	Vegetation Stress/Vigor	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM,SPOT,AVIRRIS, Deedalus,M7,Hyper. Deedalus, M7,PRT5/10 IWT,Comm.SAR,P3
2.2.1.7	Mixed Wastes	Identify Concentrated Waste in Trenches (buried)			
	Burial Grounds Containing Radioactive and Hazardous Wastes	Contaminants in Groundwater	Soil Moisture Content Changes	Characteristic Spectral Signature Sensible Temperature Anomaly RCS/Clutter Signature Change	TM,SPOT,AVIRRIS, Deedalus,M7,Hyper. Deedalus, M7,PRT5/10 IWT,Comm.SAR,P3
	Sludges in Tanks	Location of Berms/Fences/LOCs	Soil Compaction Changes	Sensible Temperature Anomaly RCS/Clutter Signature Change	Deedalus, M7,PRT5/10 IWT,Comm.SAR,P3
	Ground Water Contaminated with Radionuclides, Organics, and Inorganics	Detect/Id. Cultural Litter/Scrap			
		Track Migration of Contaminants in Soils	Desert "Varnish" Disruption	Characteristic Spectral Signature	TM,SPOT,AVIRRIS, Deedalus,M7,Hyper.
	Subsurface Contaminants		Anomalous Vegetative Growth	Characteristic Spectral Signature RCS/Clutter Signature Change E-O/SAR Signature Texture Change	TM,SPOT,AVIRRIS, Deedalus,M7,Hyper. IWT,Comm.SAR,P3 Pan E-O
			Exo/Endothermic Heat Sources/Sinks	Sensible Temperature Anomaly	Deedalus, M7,PRT5/10
			Soil/Mineral Discoloration	Characteristic Spectral Signature Pan Contrast Change	TM,SPOT,AVIRRIS, Deedalus,M7,Hyper. Pan E-O