AN OVERVIEW OF ARMY SENSOR TECHNOLOGY APPLICABLE TO FIELD SCREENING OF ENVIRONMENTAL POLLUTANTS

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ABSTRACT

The Army has under development a number of technologies directed toward the field detection and identification of chemical and biological (CB) agents. This includes not only specific sensors, but the technology required to integrate these sensors into effective field detection systems. Much of this technology can be adapted to materials of environmental concern. In particular, there are technologies in various stages of development which are applicable to vapor and aerosol clouds, as well as to contaminated surface water and terrain. These include both point sampling and monitoring systems, as well as remote sensing systems capable of providing rapid wide area coverage. This paper will provide an overview of Army programs applicable to field screening methods, with particular emphasis on mass spectrometric, infra red, and aerosol sampling technologies.

INTRODUCTION

Technologies which can be utilized for the detection of chemical warfare agents in the field may also be applicable to the field detection, classification and identification of various substances of environmental interest. Although Army detection programs, particularly those in the early stages of development, focus on biological as well as chemical detection, and much of the technology is applicable to both. In this paper, the emphasis will be on chemicals in the form of vapors or aerosols. The two main areas which will be covered are standoff detection and point detection. Standoff detection has sometimes been referred to as remote detection. However, remote detection is defined here as the use of point detectors which are located at the site to be monitored, which may be of some distance from the main monitoring station or base, and connected to it by hard wire or telemetry. Standoff detection refers to the use of equipment located at the monitoring base which can sense chemicals at a distant location. The point detection technology to be discussed in this paper is pyrolysis-mass spectrometry. There will also be some discussion of aerosol sampling, since this is pertinent to point detection of aerosolized particulates, liquid or solid. It is not the aim of this paper to present detailed experimental results but rather to provide an overview of the technology and its range of applicability.

DISCUSSION

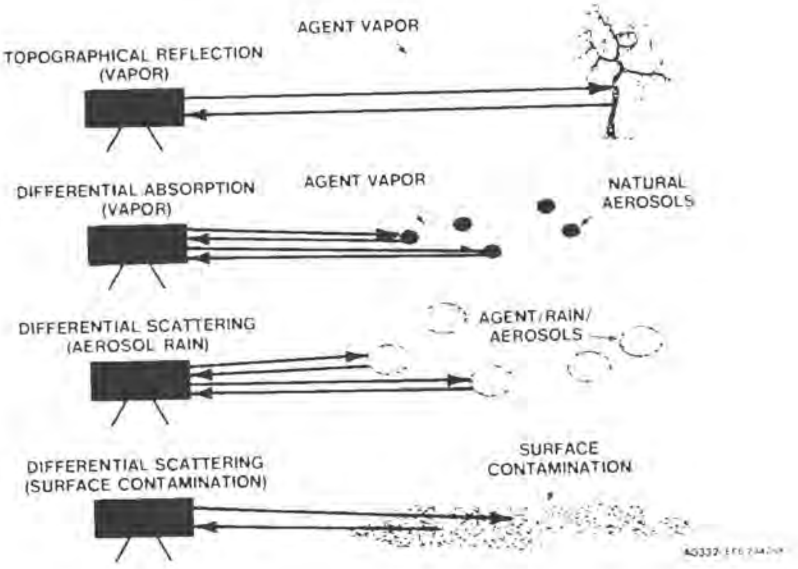
STANDOFF DETECTION: The U.S. Army Chemical Research, Development and Engineering Center (CRDEC) is currently engaged in an extensive multi-year exploratory development program to exploit laser radar for Chemical Biological (CB) Standoff Detection. At present, the only near term capability for the detection of chemical agents at a distance is the use of passive infrared sensors. These sensors can detect only chemical vapors. Active (laser) infrared

(IR) systems employing Differential Scattering and Absorption Lidar (DISC/DIAL) are being developed for the detection of chemical agents in all physical forms: vapors, aerosols, and rains, as well as liquid surface contamination. In addition, an ultraviolet (UV) system employing laser-induced fluorescence is being developed for the detection of biological clouds consisting of organisms, toxins and related materials. The principles of operation of these systems and the background of their development will be briefly discussed. The IR and UV breadboard systems have recently been used in an extensive field test employing various non-toxic chemicals and interferents with excellent results. These data will be discussed along with the necessary development efforts required to adapt the DISC/DIAL technology to practical field use.

The Army is making a significant investment in standoff technology because it is the only technology known that can provide rapid wide area surveillance capability while simultaneously reducing the total number of detectors required. At CRDEC there are three phases to the Standoff Detection program; the XM21 Passive Remote Sensing Chemical Agent Alarm, along with technology upgrades; the Laser Radar (LIDAR) CB Standoff Detection System; and, for the future, combining these technologies with other electro-optic systems in integrated sensor suites.

First to be discussed is chemical detection portion of laser radar project called IR DISC/DIAL. The objective is to provide chemical laser Standoff detection systems for CB defense applications. The planned systems capabilities are to scan surrounding atmosphere and terrain, operate in fixed or mobile mode, detect chemical contamination in all its physical forms, and range resolve, quantify and map data. The purposes of the current program are to demonstrate concept feasibility, establish capabilities and limits, complete science base, determine effectiveness in field situations and establish basis for rapid transition to mature development. The IR DISC/DIAL system can develop data in four ways (as shown in Figure 1):

FIGURE 1



Topographic reflection DIAL: By transmitting different IR frequencies and detecting their topographic return, chemical vapor clouds can be identified by their selective absorption of some of the IR frequencies. This measurement detects the presence of the cloud and its total concentration times path length (CL); however, it does not tell how far away the cloud is or its density (concentration).

Aerosol backscatter DIAL: By the same technique, but with higher laser power, the normally occurring atmospheric aerosol begins to reflection IR energy back to the detector. This distributed reflector can be "range resolved" by gate timing the returning signal just as radar systems do. In this way, average concentrations and ranges can be developed for many cells (range lines) down the LIDAR path. By scanning the system spatially, a map can then be made of vapor chemical agents.

Agent backscatter DISC: In the same manner, chemical agent aerosols and agent rains can be detected by the selective frequencies that they directly backscatter to the detector.

Surface reflection: The fourth mode of detection is the detection of selective IR frequencies backscattered from agents on surfaces. This measurement is dependent on the amount of material located on the surface of dirt, grass, trees or equipment.

Figure 2 shows that, for each of the detection modes, the return signals are different so that all measurements can be made simultaneously. This is important because there are no significant hardware design constraints to add aerosol rain and surface detection to an aerosol backscatter DIAL system. The first objective of the DISC/DIAL project was to build a Ground Mobile Breadboard (GMB) system to demonstrate the feasibility of DISC/DIAL chemical detection. The system was mounted in a van and tested. Based on these tests, the GMB was upgraded. The current specifications of the Ground Mobile Breadboard Upgrade (GMBU) are given in table 1.

The GMBU along with other devices was then exposed to extensive U.S. Army Dugway Proving Ground (DPG) field testing. The goals of these tests were:

(1) Investigate effects of reducing system size, weight and power on detection performances. This was because the Army's near term use was a ground mobile vehicle application for reconnaissance.

(2) Obtain quantifiable data on vapors, aerosols, and liquid detection and on interferences to prove feasibility.

(3) Use more realistic field scenarios to develop workable use concepts.

FIGURE 2

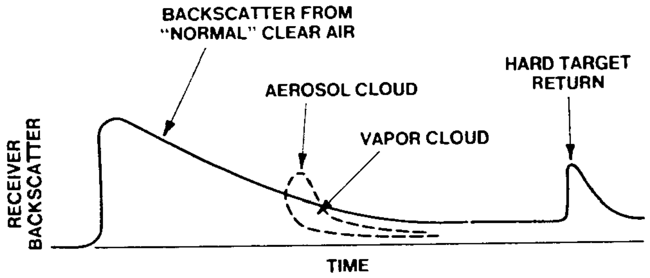


TABLE I. DISC/DIAL Specifications

Transmitter	
Lasers	Four CO_2 TEA Laser
Tunability	Line-Tunable by Grating
Wavelengths	9.2 to 10.8 Microns
Energy (on 10P20)	2.0 J/Pulse
Pulse-to-Pulse Power Stability	± 3 Percent
Pulsewidth (3dB)	90 ns
Repetition Rate	20 Hz
Beam Divergence	3.5x4.0 MRAD
Mode	Multimode or TEMoo
Timing Jitter	2 NS Pulse-to-Pulse

Receiver	
Telescope Diameter	16 Inches
Detector	HgCdTe Quadrant
Size	1x1 mm Per Element
Detectivity	4x10 cm/$Hz^{1/2}$w
Field of View	8 MRAD
Overall Electronic Bandwidth	10 Hz to 7 MHz

These tests involved large scale simulant clouds created by a special 100 meter long spray system as well as aircraft spray. Also, aerosols were generated by spray from a high ranger boom, and surfaces (such as dirt, grass, concrete, trees, or vehicles) were coated with simulants. The many accomplishments of these large scale tests were:

- Demonstrated feasibility of ISC/DIAL technology
- Demonstrated high sensitivity
- Demonstrated operation in motion, scanning and mapping
- Detected cloud through a cloud
- Detected collocated DMMP and SF_6
- Detected DMMP (dimethyl methylphosphorate)
  - up to 5 Km (range resolved)
  - up to 10 Km (column-content)
  - in presence of all interferents (fog, rain, dust and military smokes)
  - on ground by secondary vapor
  - at night and in reduced visibility
  - in calibrated chamber
- Detected SF96 - as an aerosol
  - as ground contamination on six surfaces
- Detected other volatile and non-volatile simulants
- Validate emulation and simulation models

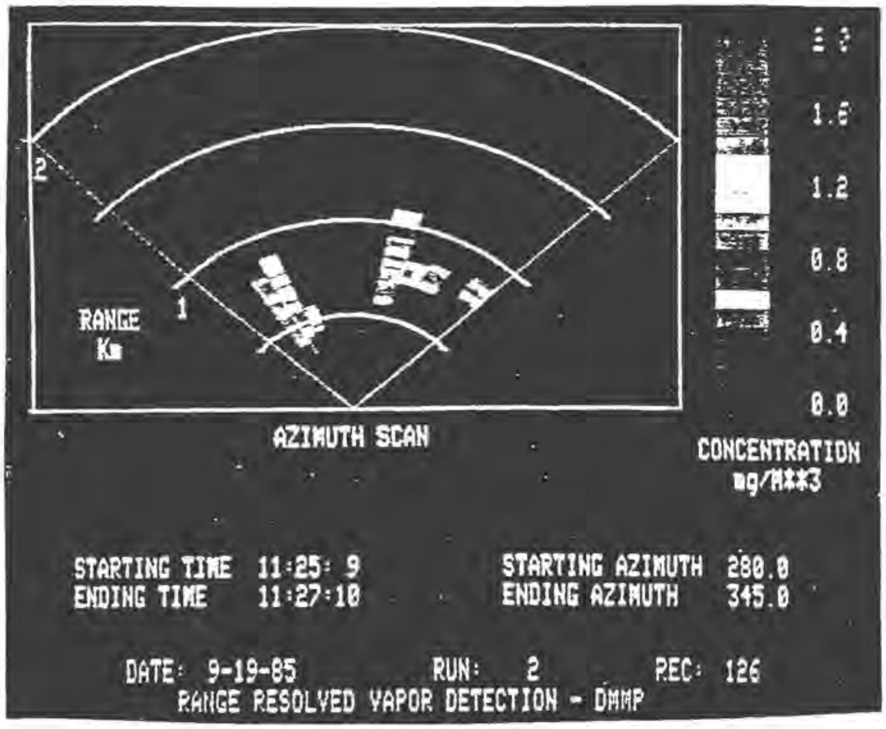
Figure 3 shows a typical GMBU map of a simulant vapor cloud. Although not evident in this black and white illustration, the range cells are colored to show the average concentration from 0.1 to 2.0 mg/m^3.

Additionally, this field work was backed up with an extensive emulation and simulation program which was able to show excellent correlation between predicted and actual performance. For example, the DMMP and SF_6 1 Km range resolved predicted and measured values are identical. Using this excellent agreement, one can infer the following sensitivities to chemical vapors with strong absorptions in the 9-10 micron region of the infrared.

Column Content		Range Resolved
2 Km	10 Km	1 Km
10 mg/m^2	12 mg/m^2	0.5 mg/m^3

The minimum detectable concentration of liquid simulants on the ground were measured at 0.5-5.0 g/m^2 depending on the porosity of the surface. Also very encouraging is the

FIGURE 3 GMBU MAP



STARTING TIME 11:25: 9
ENDING TIME 11:27:10

STARTING AZIMUTH 280.0
ENDING AZIMUTH 345.0

DATE: 9-19-85 RUN: 2 REC: 126
RANGE RESOLVED VAPOR DETECTION - DMMP

fact that one four wavelength set (1/20 sec data) can provide a high amount of information about the situation. An example:

Accuracy of Prediction (Range Over All Data)	Information
97.2-100 percent	1 simulant on any 1 of 5 surfaces
87.4-87.8 percent	1 simulant on any 5 of 5 surfaces
66.2-74.1 percent	3 simulants on any 6 of 6 surfaces

This demonstrates that a real time surface detection algorithm can be developed.

The UV LIF based laser radar was also successfully tested at DPG for detection of biological and toxin materials. While not nearly as far along in development as the IR system, this system demonstrated significant detections at ranges up to 1.2 Km. The system, which measures the laser induced fluorescence of tryptophane, a compound occurring in all living material, can sense the presence of biological/toxin clouds but cannot as yet uniquely identify the material. Relative optical discrimination between biological simulants and interferents/backgrounds of UV/LIF are below:

	Scattering Signal Level 248 nm	Fluorescence Signal Level 280-410 nm
Tryptophane	None	Strong
BG	None	Strong
Egg Albumen	None	Strong
Diesel Exhaust	Small	Strong
Auto Exhaust	Small	Weak
Road Dust	Strong	None
Trees	Strong	Strong

Other optical concepts based on Mueller Matrix scattering are currently being investigated to add additional identification capabilities to UV/LIF system.

Passive IR. The standoff detection and identification of chemical vapor clouds is currently achieved by recording the IR spectrum in the 8-12 micron wavelength region by means of an interferometer. This is the XM21 Remote Chemical Agent Sensing Alarm. It is a tripod-mounted device weighing approximately 55 pounds, exclusive of the source power. It scans a 1.5^{o} field of view (FOV) for 2 seconds, co-adding eight scans. If the cloud fills the entire FOV, the sensitivity is on the order of a concentration-path length product of 150 mg/m^2, the precise value depending upon the strength of the absorption bands. The interferogram, taken in the time domain, is converted to a frequency domain spectrum in the microprocessor by means of a fast Fourier transform. A background spectrum of the FOV must be obtained and stored, and then subtracted from the sample scan prior to further signal processing. Because of the relatively slow scan speed, and the requirement of the current algorithm for a background subtract, it cannot be operated from a moving platform.

A lightweight (20 lbs), fast scan interferometer is under development. In addition, recent developments in direct signal processing in the time domain have both reduced demands on the microprocessor and relieved the requirement for a background scan. Since results equivalent to those on the XM21 can be achieved in a single scan without a pre-determined background spectrum, this device can be operated from a moving platform such as a ground vehicle or airframe. Thus, if only vapor detection is required, passive technology represents an attractive method for rapid survey of an area, particularly by air.

In summary, CRDEC has demonstrated the feasibility of IR DISC/DIAL technology for the detection of chemical agents in all forms, as well as passive IR for chemical vapor detection. Prototypes for ground mobile, fixed site and test facility application are beginning to be developed. The potential exists for modifying these systems to mount on helicopters, RPVs, and even satellites, and to add the capability of detecting biologicals and toxins, as well as chemicals.

POINT DETECTION: There are two specific technologies which form the basis of recently fielded and developmental Army point detectors; namely, ion mobility and mass spectrometery.

Ion Mobility Spectrometry. This is a technology which operates at atmospheric pressure. The air sample containing the vapor(s) to be detected are drawn through a permselective membrane into an ionization region where reagent gas ions react with the (polar) compounds to be detected and form cluster ion species. These are gated into a drift tube where the ions migrate under an applied electric field, and are separated according to their mobility as measured by their time of arrival at the collection at the end of the drift tube. These may be operated in both a positive and negative mode. The U.S. Army currently has fielded a hand-held monitor, the Chemical Agent Monitor (CAM), and has a point alarm system (XM22) under development. These relative low weight, man portable, field hardened devices are quite sensitive and should be quite useful for field screening and monitoring of a wide variety of environmentally hazardous vapors. Since this technology and its applications will be discussed extensively in the symposium, it will not be considered further here.

Mass Spectrometry. A mass spectrometer system which can provide sensitive, effectively real time detection and identification of chemicals in the form of vapors, aerosols, and ground surface contamination, is currently under development by CRDEC. Since this system also has the potential to detect materials of biological origin, it is referred to as the Chemical Biological Mass Spectrometer (CBMS).

The CBMS consists of two major components, the biological probe and the mass analyzer chassis. An artist's concept is shown in figure 4. The biological sampling probe contains the virtual impactor and infrared pyrolyzer. The mass analyzer chassis contains the mass analyzer, instrument computer, data processing computer and display, alarm and communication modules.

The virtual impactor block of the biological sampling probe consists of a 1000 l/min pump and a four stage virtual impacter concentrator. This device separates the aerosol particles from the air by virtue of their inertia and directs them onto a quartz wool matrix. The quartz wool is mounted inside of the infrared pyrolyzer assembly. Periodically this assembly is heated to

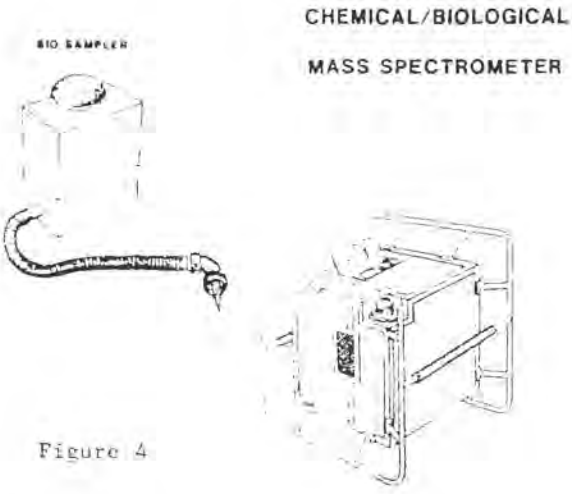


Figure 4

temperatures near 600 C. As a result, any biological material collected on the quartz wool is pyrolyzed. Although the focus is on biological aerosols, any aerosol particle in the applicable size range will also be collected and analyzed in the same way. This includes liquid or solid chemical aerosols, or chemicals adsorbed on or attached to other aerosol particles of network or anthromorphic origin. These pyrolysis products are then drawn into a heated 3 meter long, 1mm O.D. capillary column and pulled to the mass analyzer chassis. Any chemical vapors in the air are also drawn into this capillary and pulled to the mass analyzer.

The pyrolysis products and/or chemical vapors enter the mass analyzer by permeating through a silicone membrane. This membrane separated the high vacuum mass analyzer from the ambient pressure sample. After the sample enters the mass analyzer, it is ionized using an electron gun and the mass spectra taken of the ionized components.

The instrument control computer controls the mass analyzer, the pyrolysis event, and all other instrument related functions including temperature settings, electron gun current, and rf/dc voltages and frequencies. The data processing computer interprets the mass spectra and generates the necessary system responses. The display, alarm and communications modules are the primary interfaces to the operator. A block diagram is shown in figure 5.

A QUISTOR (Quadrupole Ion Storage Device) mass analyzer is used in the CBMS. (Figure 6) This mass analyzer consists of two end caps and a ring electrode. An ion getter pump or molecular drag pump can be used to produce the required vacuum. An electron gun is mounted on the sample inlet side. Selected masses are either trapped within the QUISTOR or expelled out through the end caps depending on the voltages and frequencies applied to the caps and ring. The masses of the ions that are expelled are directly correlated to the voltages and frequencies applied to the rings and caps.

In principle, a mass analysis is made as follows. First a vapor sample enters the QUISTOR. This sample is then ionized using the electron gun. The voltages and frequencies applied to the rings and end caps cause these ions to become trapped within the QUISTOR's internal electric fields. The dc voltage applied to the QUISTOR is then changed at a controlled rate. At specific voltages, certain masses become unstable and are expelled from the QUISTOR and are detected at the electron multiplier. A plot is made of the signal from the electron multiplier as a function of the applied voltage. This voltage is increased until all ions are expelled. The final mass record is then obtained by correlating the applied and plotted voltage to the corresponding masses that should be expelled.

Figure 5

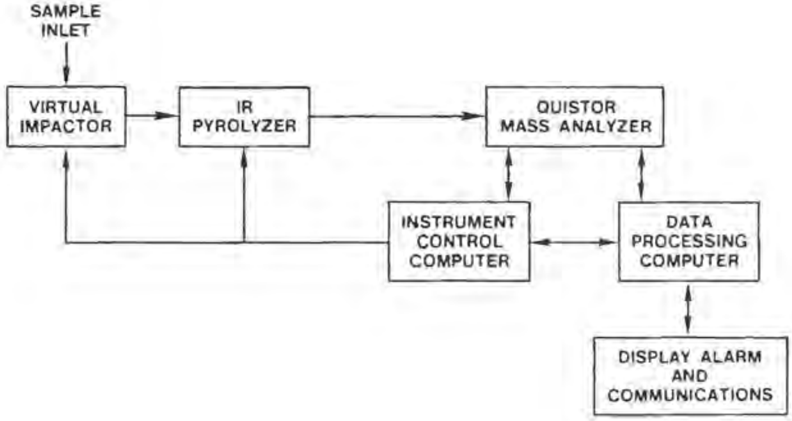
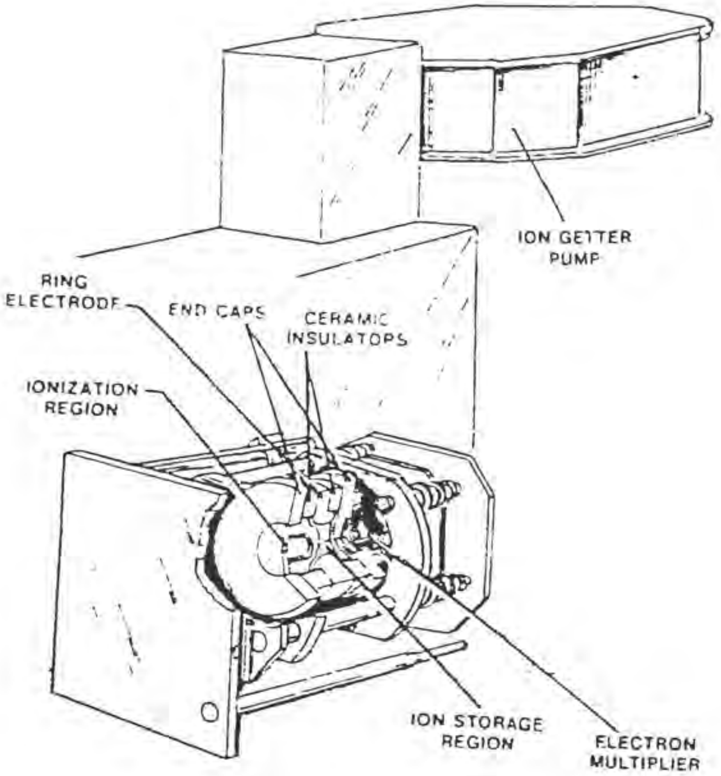


Figure 6. QUISTOR Schematic



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