New Detection Approaches

—for chemical and biological defense

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The military threat posed by chemical and biological agents is marked with the case in which they can be produced. Standard chemical processing technology has expanded to allow for large-scale production that is both economical and efficient. Commercial pesticide plants and pharmaceutical production facilities bear witness to this trend. Corresponding large-scale production of chemical and biological warfare agents would be a relatively easy process.

In addition to the classical chemical threat, emerging biotechnologies have compounded the biological threat considerably. Protein engineering fermentation and gene cloning provide opportunities for more diverse threat agents. Viruses and bacteria, in particular, can be rendered more lethal by genetic engineering techniques, and many toxins can now be mass produced.

Although the 1972 Biological and Toxin Weapons Convention bans the development, production, and stockpiling of biological agents and toxins for hostile purposes, neither the types nor the quantities of these materials are specified. Moreover, the treaty permits research, production, and modification of a biological agent or toxin for declared prophylactic, protective, and other peaceful purposes.

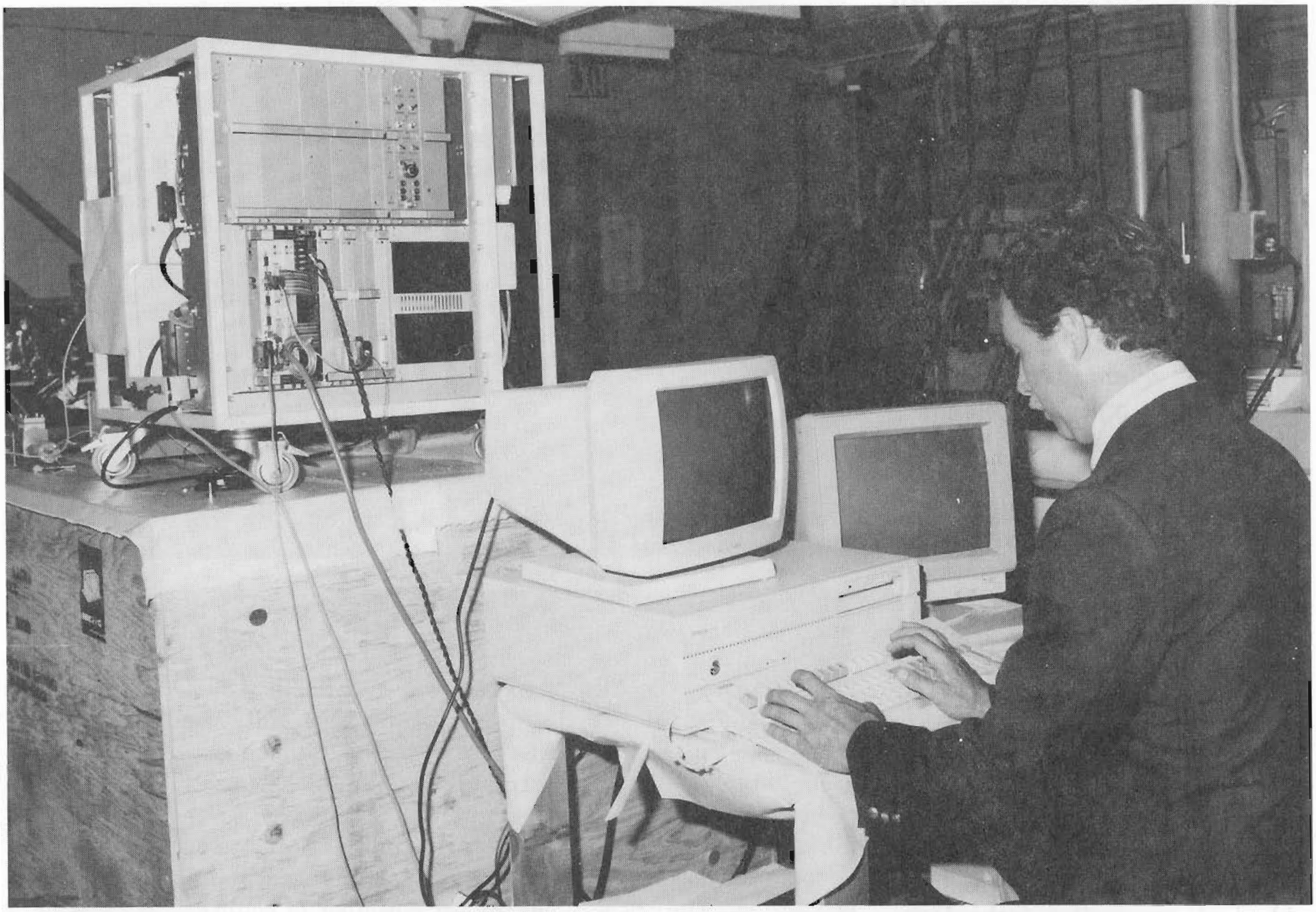
With no verification provisions included in the convention, the agents produced or modified could be used militarily or covertly with antagonistic intent. The shortcomings of the treaty render it vulnerable to broad and adverse interpretations of provisions that would otherwise minimize the risk of hostile use of biological agents and toxins. Given the political reality of an unverifiable convention and the dynamic menace of chemical and biological agents, a strong defense posture is necessary to counter a diversifying threat.

The use of chemical and biological warfare agents in international conflicts must also be incorporated in the threat assessment. It has been widely reported that chemical weapons have been used extensively in Afghanistan by the Soviet Union, in the Iran–Iraq war, and in Angola. Toxins have also reportedly been used in Laos and Kampuchea.

While the use of such weapons has aroused some international indignation, little action has been taken to curb their use. Yet the number of countries possessing a chemical and biological weapons capability continues to grow. Together, these observed trends indicate changing attitudes toward the deployment and use of these weapons. They gauge the tolerance of such aggression and underscore the expanding chemical and biological threat.

The US chemical and biological defensive program must constantly keep pace with ever–shifting political trends and emerging new technologies that may be applied to adversarial materials and their delivery systems. This pursuit must be balanced with the demand for provisional solutions to immediate problems. Stopgap measures cannot detract, however, from the overall advancement of the program.

Chemical and biological defense research and development encompasses detection, physical protection,



Dr. William Lagna, a physical scientist at CRDEC enters data into the chemical and biological mass spectrometer. The device has a potential for applications to environmental monitoring, medical diagnostics, and industrial process control.

and decontamination. In supporting these objectives, the program must respond to significant defense challenges. Detection is particularly encumbered by exacting and complex requirements necessary for effective battlefield operation.

Successful physical protection and decontamination are predicated on accurate detection capabilities. Detectors, for instance, must be capable of identifying a broad spectrum of chemical and biological agents having incredibly diverse physical, chemical, and biological characteristics. They must also exhibit high sensitivity and specificity along with a quick response time under rigorous battlefield conditions.

Master Plan

Recognizing these defense challenges, the US Army Chemical Research, Development, and Engineering Center (CRDEC) and the US Army Chemical School developed a reconnaissance detection and identification master plan. This plan serves as a strategy for acquisition of point and standoff detectors. It is based on battlefield–driven information needs and the appropriate technologies available to address them. Three agent detector–sensor systems were targeted in the plan because of their versatility, high sensitivity, and quick response time. These devices are the chemical and biological mass spectrometer, the bio–chemical detector system, and the laser standoff detection system. They constitute the three major technology thrusts of CRDEC's chemical and biological detection initiative.

The technologies are being concurrently pursued because of their inherent capabilities as well as discrete intended applications. No single technology can fulfill all the desired performance criteria in every combat scenario. Each one, however, possesses distinct advantages. The mass spectrometer, for example, has been identified as the foremost method for specific identification of known and unknown agents. It allows for unique characterization of chemical and biological agents and other toxic but non–warfare agents that may be present on the battlefield. The microsensor–based bio–chemical detector is most amenable to miniaturization for tactical operations and for such specialized applications as in-place filter, garment, and contamination monitors. For standoff detection, laser radar is the most promising technology because of the ability to perform look-ahead and scanning reconnaissance. In concert, these technologies strive to satisfy chemical and biological battlefield information needs.

Mass Spectrometer

The chemical and biological mass spectrometer was identified by the master plan as the next generation point detector for reconnaissance and fixed site applications. It is designed to detect, identify, and determine concentrations of threat materials that are present in the air as vapors, aerosols, or liquid droplets. The device, now in exploratory development, is intended for man-portable field deployment and will be capable of 24- to 72-hour unattended missions.

A systems engineering approach has been taken to develop and integrate components of the mass spectrometer for sample acquisition and pretreatment, ionization, mass analysis, ion detection, signal processing, and data display. These components have been assembled in a prototype detector comprising the mass analyzer module, the aerosol collection and sampler module, and the computer-power module. This modular format was created to accommodate technology advances in detection as well as changes in the chemical and biological threat.

The mass spectrometer's proficiency will be demonstrated, using a variety of chemical agents and model biological materials. While mass spectrometry makes detection of chemical agents fast and easy, biological agents present a more formidable challenge. As they typically exceed the molecular weight range of most conventional mass spectrometers, these biomaterials must be broken down into compounds that are readily recognized by the device. Pyrolysis mass spectrometry allows for such analysis. Using this approach, complex materials are heated in a controlled manner. This results in characteristic chemical signatures easily analyzed by the spectrometer. These signatures are then compared with a large data base of known chemical signatures to identify the material.

Designed to operate in a nuclear, biological, and chemical (NBC) environment, the new mass spectrometer is intended to replace the German mass spectrometer (GEMS) currently used in the Fuchs NBC reconnaissance vehicle. The new design will provide for ease of decontamination and future incorporation of nuclear-hardened components.

The system will detect, identify, and monitor chemical and biological agent contamination while on the move. It will be portable for dismounted operations and for use as a point alarm at fixed sites, such as air bases and aboard ships. It may also be used in airborne operations and for low mobility combat service support.

Because of enhanced detection capabilities and reduced size, the mass spectrometer surpasses the GEMS in application and deployment possibilities. For instance, the GEMS can only detect chemicals whereas the new mass spectrometer can detect chemicals, biologicals, toxins, and polymers. Moreover, it can identify over 120,000 compounds with substantially higher selectivity than the German MS. The device will take no more than 15 seconds to detect the presence of any threat material as compared to one minute for the GEMS. Identification of the threat material and quantitative determination of the concentration will occur within two minutes.

The new mass spectrometer will occupy less than four cubic feet and weigh only 40 pounds, an order of magnitude less than the GEMS. In addition, the device will auto-tune, auto-calibrate, and self-diagnose. Last July, the first demonstration model was delivered to the Army. Its capabilities will not only benefit military applications, but will enhance medical, environmental, and systems process monitoring as well.

Bio-Chemical Detector

Perhaps the most challenging endeavor in the area of detection is the development of an extremely lightweight, automatic detector that will be adaptable to changes in technology and the threat. The master plan identified the need for such a system to sample, detect, and classify chemical and biological hazards in air and surfaces. The bio-detector is envisioned to meet these objectives.

CRDEC is currently applying emerging microsensor technologies to develop a modular, mini-detector. Once completed, it will provide continuous automatic air

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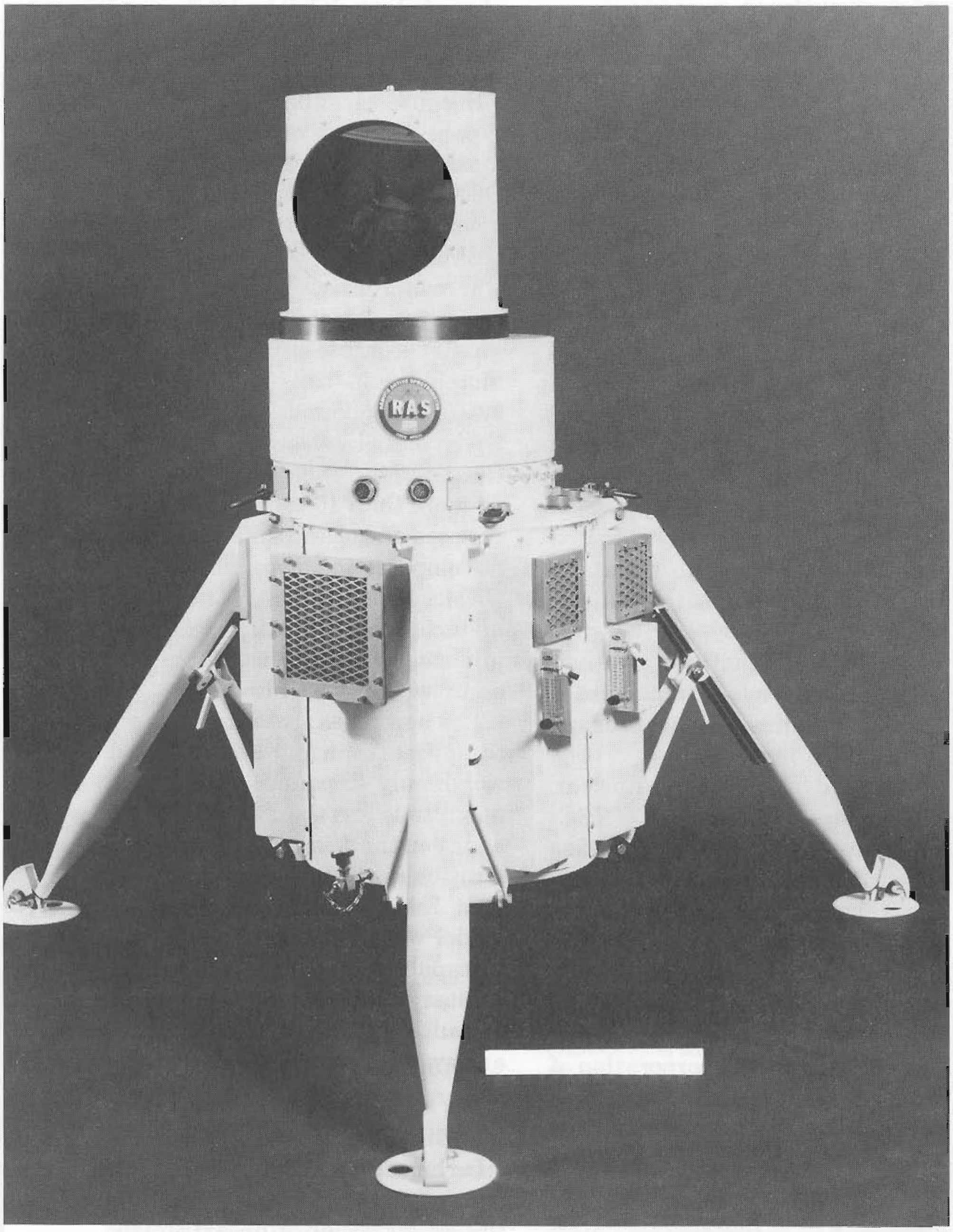

The mass spectrometer now in exploratory development at CRDEC.

sampling over a 24–hour period and will be capable of detecting a wide variety of chemical and biological materials in the air. The detector is principally intended to serve as a tactical point alarm.

In addition to visual and audible alarms, the system will indicate the agent class and determine the concentration level of the detected material. All data will be transmitted to a battlefield information network for dissemination.

The bio–chemical detector comprises sample acquisition as well as sample sensing, and signal processing elements. The system is designed to be compact and lightweight. Upon completion, the detector will occupy one cubic foot of space and weigh about 10 pounds. Three state–of–the–art electronic approaches to detection will be incorporated into the device. The fiber optic waveguide, the light–silicon sensor, and the miniature electrochemical detector are the candidate technologies being evaluated for eventual use in the device. Together, these methods will allow for the detection of nerve agents, blister agents, pathogens, and toxins.

The fiber optic waveguide is an electro–optical approach to point detection. It comprises a thin quartz rod coated with enzymes, antibodies, or biological receptor molecules specific for certain threat agents or classes of agents. Upon surface contact, the chemical and biological threat material will displace fluorescent analogues from the coated quartz rod or compete with the fluorescent analogue for a limited amount of binding sites.

At the quartz–sample interface, light penetrates a short distance into the sample and excites the fluorescent probes. The 100 nonometer field of excitation permits an effective partitioning of surface–bound fluorophores from those which are free in solution. This separation allows for analytical measurements of the analyte (agent material) in picogram quantities.

The silicon sensor is a microsensor–based method for detecting chemical and biological threat compounds. It is a light–modulated silicon device containing a 25mm 2 planar silicon wafer with a silicon oxide–nitride layer on the surface. When alternating current is applied to an infrared light emitting diode, a photocurrent is produced that is dependent on the surface chemical potential. Changes in ph level or redox potential are reflected in the magnitude of the photocurrent illumination of the diode. The silicon surface layer can be readily adapted to include acetylcholinesterase–based assays for the detection of chemical nerve agents, as well as enzyme-labelled immunoassays and receptor-based assays for detection of biological threat materials.

The miniature electrochemical detector operates via a differential pulse voltammeter in an electrochemical cell. Direct electrochemical oxidation of the chemical agent produces an electric signal. This device is readily applicable to the detection of blister agents such as mustard and Lewisite. Work is also underway to modify the approach so that nerve agents may be detected.

These and other technologies form the basis for the miniaturized bio-detector. Together they hold promise for threat agent detection in combat. Following their integration in a hand-held, portable device, they will be used in highly mobile combat and combat support operations and contamination monitoring.

"The ground-based system detected chemical clouds at distances up to seven kilometers."

Laser Radar

Standoff detection capabilities are necessary for fixed-site chemical defense, ground and air reconnaissance, and contamination avoidance. The master plan identified laser radar as having the most potential in detecting chemical vapors, aerosols, liquids on surfaces, and agent rains. Specifically, two types of radar were addressed—differential scattering for aerosol rain and surface contamination detection, and differential absorption for vapor detection. Combined, both technologies provide for detection of chemical aerosols and agent rains by their unique spectral backscatter patterns. They may also afford a basis for early warning of chemical attacks.

While infrared (IR) laser radar systems are employed for the detection of chemical agents, a corresponding ultraviolet system using laser-induced fluorescence is being developed to detect biological clouds. The IR system interprets data in several ways. Via topographic reflection, different IR frequencies are transmitted and detected by their topographic return. If chemical clouds are present, they will selectively absorb some of the IR frequencies, thus allowing for their detection as well as determination of concentration and path length.

Aerosol backscatter laser radar employs lasers with greater intensity. Following transmission of different IR frequencies, ambient atmospheric aerosols reflect the IR signals back to the detector. The returned signals are gate-timed for range resolution. Vapor concentrations and ranges can then be calculated for anything in the laser radar path.

Agent backscatter laser radar works in a similar fashion. If chemical agent aerosols or rains are present, they can be detected by the particular frequencies that are backscattered to the detector. Surface reflection permits the detection of chemical agents on soil, foliage, or equipment surfaces via interpretation of select IR frequencies that are backscattered by the agent material.

In 1985, both laser radar systems were incorporated into a demonstration model. It comprised two CO_2 transverse excited atmospheric laser transmitters, an optical receiver, and control, signal processing, and diagnostic equipment. A corresponding airborne system was also designed to operate in a twin-engine plane. Both systems have undergone extensive testing at Dugway Proving Ground. The ground-based system detected chemical clouds at distances up to seven kilometers, while the airborne system detected chemical clouds at the same distance downwind from the vapor source.

In 1986, the differential absorption laser radar was reduced in size. This compact, lightweight system served as a remote active spectrometer for the detection of chemical agents from a standoff position. It was the first step taken to reduce the size of the system without compromising the operational capabilities. It is anticipated that future laser radar applications will involve detection from helicopters and remotely plotted vehicles.

Conclusion

The technologies being developed represent a new generation of chemical and biological agent field detectors. Their development is in response to the demand for increased operational capabilities on the battlefield. They will continue to be refined to accommodate future changes in the threat as well as new battlefield requirements.