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MIL-HDBK-1200 (EA)
16 NOVEMBER 1992

MILITARY HANDBOOK

CHEMICAL AND BIOLOGICAL (CB) AGENTS DETECTION AND MONITORING SYSTEMS

AMSC N/A

FSC 6665

FOREWORD

1 This military handbook is approved for use by all Activities and Agencies of the Department of the Army and is available for use by all Departments and Agencies of the Department of Defense

2 Beneficial comments (recommendations, additions, deletions) and any pertinent data that may be of use in improving this document should be addressed to Commander, US Army Chemical Research, Development, and Engineering Center, ATTN SMCCR-PET-S, Aberdeen Proving Ground, MD 21010-5423, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3 This handbook was developed under the auspices of the US Army Materiel Command's Engineering Design Handbook Program, which is under the direction of the US Army Industrial Engineering Activity Research Triangle Institute was the prime contractor for the preparation of this handbook, which was prepared under Contract No DAAA09-86-D-0009

4 This handbook provides military design engineers, scientists, analysts, and planners with a guide to research of chemical and biological detection systems It provides a consistent and thorough approach to evaluating the technical options available for design and development of detection and monitoring systems

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LIST OF ACRONYMS AND ABBREVIATIONS

ABC = autonomous background compensation
AC = hydrogen cyanide
ac = alternating current
ACAA = automatic chemical agent alarm
ACADA = automatic chemical agent detector alarm
ALAD = automatic liquid alarm detector
ALO = authorized levels of organization
AMC = US Army Materiel Command
Ao = operational availability
ASAP = Army Streamlined Acquisition Process
ASP = ammunition supply points
B = biological
BATEK = biological agent test kit
BDWS = biological detector and warning system
BOI = basis of issue
BW = biological warfare
C = chemical
CAM = chemical agent monitor
CAU = central alarm unit
CB = chemical and biological
CBT = chemical, biological, and toxin
CG = phosgene
CIDS = circular intensity differential scattering
CK = cyanogen chloride
CMLS = US Army Chemical School
CPE = collective protective equipment
CRDC = US Army Chemical Research and Development Center
CRDEC = US Army Chemical Research, Development, and Engineering Center
CS = combat support
CSL = US Army Chemical Systems Laboratory
CSS = combat service support
CWS = US Army Chemical Warfare Service
CWSA = chemical warfare scanning alarm
CX = phosgene oxime
DA = Department of the Army
DA = diphenylchloroarsine
DC = diphenylcyanoarsine
dc = direct current
DIA = dichloroindophenyl acetate
DIAL = differential absorption LIDAR
DISC/DIAL = differential scattered/differential absorption LIDAR
DISC = differential scatter
DM = adamsite
DM1 = adamsite variation
DMMP = dimethyl methylphosphonate
DNA = deoxyribonucleic acid
DoD = Department of Defense
DP = diphosgene
DS = direct support
DS2 = decontaminating solution No 2
DT = development test
DT/OT = developmental testing and operational testing
DT&E = developmental test and evaluation
E coli = *Escherichia coli*
ED = ethyldichloroarsine
EMI = electromagnetic interference
EMP = electromagnetic pulse
EOD = explosive ordnance disposal
ESR = electron spin resonance
FAST = fluorescence antibody staining technique
FFT = fast Fourier transform
FLOT = forward line of own troops
FMECA = failure mode, effects, and criticality analysis
FOV = field of view
FSDWS = Fixed Site Detection and Warning System
FSI = fixed site installation
G = nonpersistent nerve agent family
GA = tabun
GAO = General Accounting Office
GB = sarin
GD = soman
GEMS = German mass spectrometer
GMBU = ground-mobile breadboard unit
GS = general support
H = mustard or Levenstein mustard
HC = hexachloroethane (smoke)
HD = distilled mustard
HFE = human factors engineering
HL = mustard-lewisite mixture
HN = nitrogen mustards
HS = mustard ("hot stuff"), a form of undistilled mustard
HT = mustard mixture
IBA = isonitrosobenzoylacetone
ICAD™ = individual chemical agent detector
IFOV = instantaneous field of view
ILS = integrated logistic support
ILSP = integrated logistics support plan
IME = international materiel evaluation
IMS = ion mobility spectrometry
IMS/MS = ion mobility spectrometer/mass spectrometer
I/O = input/output
IPE = individual protective equipment
IR = infrared
KB = killer bursa
L = lewisite
LAD = liquid agent detector
LCC = logistic control code
LIBS = laser-induced breakdown spectroscopy
LIDAR = light detection and ranging

LIF = laser-induced fluorescence
LOPAIR = long path infrared
LORA = level of repair analysis
LOS = line of sight
LSA = logistic support analysis
MAA = mission area analysis
MANPRINT = manpower and personnel integration
MLRS = multiple launch rocket system
MMD = mass median diameters
MNS = Mission Needs Statement
MOPP = mission-oriented protective posture
MOS = military occupational specialty
MS = mass spectrometry
MS/MS = tandem mass spectrometer
MTBF = mean-time-between-failure
MTBFA = mean-time-between-false-alarms
MTBS = mean-time-between-stoppage
NBC = nuclear, biological, and chemical
NBCRS = nuclear, biological, and chemical reconnaissance system
NBCWRS = nuclear, biological, and chemical warning and reporting system
NDI = nondevelopmental item
NMR = nuclear magnetic resonsance
O&O = operational and organizational
ORD = Operational Requirements Document
O&S = operations and support
OWG = optical waveguide
PACT = particchrome analyzer
PAS = photoacoustic spectroscopy
PD = phenyldichloroarsine
PHA = preliminary hazard analysis
PPI = preplanned product improvement
PMD = program management documentation or documents
POL = petroleum, oils, and lubricants
ppb = parts per billion
ppm = parts per million
PS = chloropicrin
PSA = particle size analyzer
RAM = reliability, availability, and maintainability
RAST = radioactive-labeled antibody staining technique
R&D = research and development
RDI = reconnaissance detection, and identification
RDIMP = Reconnaissance, Detection, and Identification Master Plan
RDT&E = research, development, test, and evaluation
RECON = reconnaissance
RF = radio frequency
RFI = radio frequency interference
RNA = ribonucleic acid
ROC = Required Operational Capability
ROM = read-only memory
rpm = revolutions per minute
RPV = remotely piloted vehicles
RSCAA = remote sensing chemical agent alarm
RTM = real-time monitor
SA = arsine
SAW = surface acoustic wave
SDS = standard data set
SNR = signal-to-noise ratio
SPART = single particle aerodynamic relaxation time
STB = supertropical bleach
SUREVAP = surface evaporation
T = toxin
T = sulfur and chlorine compound
TDP = technical data package
T&E = test and evaluation
TECOM = US Army Test and Evaluation Command
TEMP = test and evaluation master plan
TFFEC = thin-film field emission cathode
TGD = thickened soman
THD = thickened distilled mustard
TMDE = test, measurement, and diagnostic equipment
TRADOC = US Army Training and Doctrine Command
TV = tidal volume
U S = United States
UV = ultraviolet
UVIF = ultraviolet-induced fluorescence
V = persistent nerve agent family
VG = persistent and nonpersistent nerve agent families
VGH = persistent nerve agent, nonpersistent nerve agent, and mustard
VX = persistent nerve agent

CHAPTER 1
INTRODUCTION

The purpose and scope of the this handbook are described The history of chemical and biological (CB) warfare and development of CB detection and monitoring in CB defense on the battlefield are discussed The contents of each of the remaining chapters are summarized

1-1 PURPOSE

The purpose of this handbook is twofold (1) to provide design engineers with a guide to research and development of chemical and biological (CB) agents detection systems and (2) to provide a consistent and thorough approach to evaluating the technical options available for the design and development of detection and monitoring systems

The continuous, massive buildup of CB weapons capabilities and the periodic, alleged use of CB weapons by potential enemies of the United States require rapid detection, warning, identification, and monitoring of the presence of CB agents by our armed forces To meet this requirement, the US Army is developing a wide variety of CB detection and monitoring systems based on many new concepts and technologies

Designing CB detection and monitoring systems that can be used effectively in this context involves application of complex technology This handbook was written with the following intentions

1 To give design engineers and other users the benefit of past experience, current concepts, and projected technological advancements in the detection of CB agents

2 To conserve time, materials, and funds by outlining approaches to solving the problems that are most likely to be encountered in the design of detection and monitoring systems for CB agents

3 To provide a source of fundamental design information not readily available elsewhere that will facilitate the evolution of new designs for CB detection and monitoring systems

4 To generate, compile, and document an up-to-date set of equations, tables, and physical values useful in the design of CB detection and monitoring systems

5 To preserve unique technical knowledge that would otherwise be lost when design engineers are reassigned or leave Government service This consideration applies particularly to CB detection and monitoring research and development because many members of the Army's experienced engineering design work force in this field have retired or will reach retirement age within a few years

6 To provide a source of information for orientation, guidance, and training of new Government personnel and Army contractors involved in the design of CB detection and monitoring systems

7 To communicate concisely to design engineers the requirements for military operations and of related scientific, technical, and materiel acquisition disciplines that must be considered during development of CB detection and monitoring systems

8 To permit the design of CB detection and monitoring systems to accelerate under mobilization or other emergency conditions during which experienced engineers may be inundated with emergency requirements

1-2 SCOPE

This handbook is a design tool that provides the following knowledge

1 A basic understanding of the operational effects of CB agents

2 A description of the required operational environment and the requirements for CB detection and monitoring systems

3 An explanation of past technologies explored and current technologies being explored to meet CB detection and monitoring requirements

4 An explanation of CB detection system design components and criteria

Because there are major differences between chemical and biological agents and their required detection technologies, most information on chemical agents and detection systems is presented separately from the information on biological agents and detection systems

The information in this handbook is presented at a technical level considered suitable for augmenting the basic skills and knowledge of the following target audiences

1 Army design engineers, scientists, and analysts, i e , personnel with a bachelor's degree and experience in the field, who participate in the design of CB detection and monitoring systems

2 Specialists in various fields of Army design who have only superficial knowledge of the allied technical fields required for the design of CB detection and monitoring systems

3 Design engineers and systems analysts employed by contractors to research and develop CB detection and monitoring systems for the Department of the Army

4 Personnel concerned with procurement, production, inspection, drawings, specifications, testing, main-

tenance, and administration of CB detection and monitoring systems

1 3 BACKGROUND

This paragraph discusses the history of CB warfare, the history of the development of CB detection and monitoring devices, and the role and application of detection and monitoring systems in relation to other areas of CB defense It also defines the terms relating to CB detection and monitoring systems

The key terms defined in this paragraph and used throughout this handbook are based on definitions appearing in approved Army doctrinal publications and regulations The basic terms that follow apply specifically to this handbook

1 *Chemical Agents* Chemical agents are chemical substances intended for use in military operations to kill, seriously injure, or incapacitate humans through physiological effects Excluded are riot control agents, herbicides, and smoke

2 *Biological Agents* Biological agents are either microorganisms with disease-producing properties or toxins intended for military use that produce lethal, incapacitating, or damaging effects to humans, livestock, or plant life

3 *Toxins* Toxins are nonliving, poisonous chemical substances produced by living organisms When inhaled, swallowed, or injected into man or animals, they cause injury or death Toxins also can be produced synthetically by genetic engineering

4 *Detection* Detection is the determination of the presence or absence of a chemical or biological agent at a specific point in time and at a specific location

5 *Monitoring* Monitoring is the continuous or periodic act of determining whether a chemical agent or a biological agent is present

There have been frequent reorganizations and realignments of the responsibilities for CB defense materiel development Thus the current responsible organization the US Army Chemical Research Development, and Engineering Center (CRDEC), has been known by a variety of names and acronyms References may name one or more of these organizations

1-3.1 HISTORY

Chemicals and biological materials have been used in warfare for many centuries, but CB warfare was not well documented until the twentieth century To prevent casualties, it is essential that the presence and identity of CB agents be established quickly A responsive CB detection and monitoring capability is the solution to this problem For a more thorough understanding of the CB detection problem, it is necessary to examine the following points

1 The effect of the introduction of new agents to the battlefield or into national stockpiles, as related to CB defense

2 The evolutionary development of CB equipment to detect and identify these agents

3 The application of various technologies to the problem of detection

The modern history of toxic chemical warfare began in World War I when the Germans employed chlorine gas, a choking agent, against the French on the western front on 22 April 1915 at Ypres, Belgium The unprotected French troops suffered about 15,000 nonfatal casualties and 5000 fatalities from this chemical attack

During the war, many new "war gases" were introduced by both sides and resulted in about 1,205,000 nonfatal casualties and 92,000 fatalities The Russians suffered the most casualties about 420,000 nonfatal casualties and 56,000 fatalities In 1918, the United States suffered 71,345 nonfatal casualties and 1462 fatalities from chemical attacks (Ref 1)

The first "war gases" used were experimental chemicals that affected the respiratory system and had to be inhaled to be effective By 1917 the gas mask had been so improved that it fully protected the individual against these agents, and the only chemical casualties were those troops who could not don their masks in time or who removed their masks too soon after the attack To counter this development, in July 1917 the Germans began employing mustard "gas", which could not be protected against solely by the improved gas masks

Mustard is a liquid that not only damages the respiratory system but also blisters the skin and burns the eyes (Ref 2) The first large-scale mustard attack by the Germans occurred at Nieuport, France, between 21 and 29 July 1917 Gas masks alone did not protect the soldiers from mustard, which not only blistered exposed skin but was readily absorbed through boots and uniforms to cause additional casualties (Ref 3)

Early chemical agent detection methods used during World War I consisted mainly of identifying the agents by sight and odor By 1918, however, most of the European armies had developed vesicant gas detector paints, crayons, and powders that contained dyes which changed color in the presence of blister agents such as mustard The only "gas alarms" consisted of man-activated bells, gongs, sirens, and Klaxon® horns

In June 1918 the Chemical Warfare Service (CWS) at Edgewood Arsenal, MD, was assigned total responsibility for research, development, and procurement of chemical materiel Shortly thereafter, American University developed an improved detector paint that incorporated a British-developed dye Drops of mustard on the paint were detected by the chemical reaction with the dye, which changed the color from olive drab to red (Ref 4)

Although large-scale military use of biological warfare

has not been experienced in modern times. Germany reportedly used glanders on a small scale to infect French and Rumanian cavalry horses during World War I. Biological agent research was active in Germany and Japan in the 1930s. The US National Academy of Sciences studied these incidents and concluded that biological warfare was technically feasible. In 1942 the US Army Biological Defense Research Program was established, and early in 1943 the CWS implemented this program at Camp Detrick, MD (Ref. 5).

The only reported uses of chemical agents between World War I and World War II were mustard attacks by Italy on the Ethiopians in 1935 and 1936 and limited chemical attacks by Japan against the Chinese in the late 1930s. Both of these Axis powers employed chemical warfare to gain local tactical advantages against foes that could not retaliate in kind (Ref. 6).

Meanwhile, unknown to US intelligence sources, the Germans had developed the first nerve agent, tabun (GA), in 1936. Germany built the first pilot production plant in 1939 and had manufactured 12,000 tons of GA by 1945 (Ref. 6). GA and the follow-on family of nerve agents (called G-agents), such as sarin (GB) and soman (GD), also developed by the Germans, possess many of the ideal characteristics for chemical agents. They were highly toxic, clear, and odorless liquids. Although impurities introduced during the production process initially gave GA a characteristic sweet, fruity, or chocolate odor, breathing a nerve agent sufficiently to detect the odor could lead to incapacitation or death.

As early as 1940, the CWS recognized that almost complete reliance for detecting chemical agents had been placed on human sensory methods. Realizing that these methods were unreliable and hazardous, Edgewood Arsenal immediately started a research program that led to development, type classification, production, and issue of a number of chemical agent detector items by 1942. Among these were the M5 liquid vesicant detector paint, M6 liquid vesicant detector paper, M7 vesicant detector crayon, and M4 HS (mustard) detector kit. These detectors, however, were effective only for detection of liquid or high vapor concentrations of blister agents, such as mustard, lewisite (L), nitrogen mustards (HN), and certain arsenicals (Ref. 4).

By 1941 the U.S. had expended much time and effort in pure research and in practical application to obtain a reliable, simple, and sensitive (less than 4 mg/m^3) method for detecting toxic chemical agent vapors. Chemical reactions based on color change, development of acidity, production of turbidity, and precipitate formation had been studied. Physical detection methods based on spectrographic interferometry, Graham's diffusion law, and measurement of physical constants were studied. Physicochemical methods such as detection of a change in acidity or alkalinity, i.e., pH, conductivity, production of heat from an exothermic reaction, and catalytic reactivity also were investigated. Researchers also studied biological detection methods (other than human sensory detection) involving blood reactions visible under the microscope and reactions using small animals, birds, and fishes (Ref. 6).

Many of these methods proved exceedingly sensitive in the laboratory but could not be adapted to field requirements. Shocks, tremors, and jarring were the chief reasons for mechanical failure of the experimental detectors. Atmospheric conditions affected many of the physical detection methods. The chemical methods failed in the presence of high concentrations of toxic agents, mixtures of agents, or various gases, dusts, and vapors that might be encountered in combat. Also many devices were too complicated for use in the field by soldiers with limited technical training (Ref. 7).

Throughout World War II, US training and doctrine in detection of chemical agents required the soldier to break the seal on his gas mask and use his sense of smell to "test for gas". This procedure was enforced despite the continued attempts by scientists to develop new chemical agents that were highly toxic, immediately effective, colorless and odorless. Furthermore, heavy concentrations of the standard agents could overpower the olfactory sense and thus prevent identification and also increase the possibility of injury.

There were no reports of chemical agent use during World War II (Ref. 6). Although the Germans had over 1.04×10^8 kg of chemical agent munitions in their stockpiles, most of their GA nerve agent stockpile was contained in bombs. The Luftwaffe (German Air Force) had over 40,000 250-kg GA bombs available in its munitions depot in Bavaria. The remainder of the German stockpile was mainly mustards and phosgene (CG) artillery projectiles and bombs (Ref. 8). Germany did not employ these nerve agent munitions on 6 June 1944 (D day), i.e., when the Allied forces were most vulnerable to chemical agent attacks.

Despite hints of the existence of nerve agents during World War II, it was not until April 1945, i.e., when the US Army captured the German stockpile of GA in Bavaria, that this new class of agent was revealed to the Allied forces (Ref. 8). Meanwhile, the Russians captured the GA production facilities in Silesia and data on other nerve agents, such as GB and GD, in development at that time. Many of the current Soviet chemical agent detectors and munitions, e.g., 250-kg bombs, evolved from captured German munitions.

The US Army also captured a variety of German "gas" detection items, such as detector kits, tubes, hand pumps, powder, powder shakers and pumps, papers, crayons, spray cards, and an automatic fortress gas detector. The tubes changed color in a typical Schoenemann reaction when exposed to chemical agents,

and they were capable of detecting Levenstein mustard (H), arsenicals, HN, CG, diphosgene (DP), chloropicrin (PS), cyanogen chloride (CK), phosgene oxime (CX), and hydrogen cyanide (AC) The tubes were marked with colored bands to identify the type or class of agent (Ref 9) Other German agents identified included ethyldichloroarsine (ED), adamsite (DM), diphenylchloroarsine (DA), and diphenylcyanoarsine (DC)

The capture of the German nerve agents and exploitation of this technical intelligence had these effects

1 A major change in doctrine away from detection and identification by the sense of smell

2 Establishment of an urgent requirement for detection devices that could detect and/or identify the nerve agents

3 Establishment of the need for an automatic chemical agent alarm system that would respond immediately and warn of the presence of nerve agents in the atmosphere

The Congressional *Report of the Chemical Warfare Review Commission* (Ref 6) to the President on 11 June 1985 validates previously alleged employment of chemical agents and biological toxins by various nations since World War II The following incidents are examples of such employment

1 The Egyptian attacks in Yemen during the period 1963 to 1967

2 Attacks by the Vietnamese in Laos and Cambodia during the late 1970s

3 Use by the Soviet Union in Afghanistan that began in the early 1980s

4 Use by Iraq in the Iran-Iraq war from 1986 through 1988

Table 1-1 summarizes the history of liquid agent detector (LAD) and chemical agent detector kit development

By 1950 US scientists had developed a detector tube test for G-series nerve agents The test was based on the Schoenemann reaction of G-agents with an alkaline indole, sodium pyrophosphate solution, to produce the insoluble dye, indigo The test consisted of adsorbing the G-agent on a plain silica gel detector tube and adding a drop of the solution indole-peroxide in water to the silica gel As little as 2 μg of G-agents were readily detectable by the formation of a green-blue band on the silica gel (Refs 12 and 13)

In 1953 the M6A1 paper replaced the M6 paper and the M7A1 crayon replaced the M7 crayon Both were improved items capable of detecting liquid G-agents

British development of the persistent VX nerve agent in 1960 also had a major impact on the technical characteristics required of detection devices for detection of chemical agents The M5 paint, M6A1 paper, and M7A1 crayon were unable to detect the VX agent and therefore were reclassified as obsolete in 1964 (Ref 10) In 1964 the Canadian-developed ABC-M8 VGH chemical agent detector paper replaced the M6A1 paper The M8 paper consists of a book of 25 DB3 dye-impregnated papers The paper changes to characteristic colors when exposed to a liquid V-agent (dark green spots), G-agent (yellow spots), or H-agent (red spots) Adding M8 VGH paper to the chemical agent detector kits provided a liquid VGH detection capability (Refs 12 and 14)

In 1960 enzyme detector tickets based on the substrate-hydrolyzing activity of cholinesterase enzymes were developed to detect V-agent vapors When enzyme detector tickets are exposed to V-agent vapors and a chromogenic substrate solution is added from a squeeze bottle, the active enzyme hydrolyzes the chromogenic substrate and changes the color to orange The detector ticket is flat polyvinyl plastic and can be used for vapor, aerosol, and surface sampling Forty tickets are sealed in a foil-polyethylene laminate to reduce deterioration in storage Dichloroindophenyl acetate (DIA) substrate was selected as the most stable compound with the best rate of hydrolysis when reacting with the enzyme The enzyme detector tickets were added to the various detector kits (Ref 12)

The M18A2 chemical agent detector kit, adopted by the Army as a standard item in 1977, is currently authorized for use by nuclear, biological, and chemical (NBC) specialists to identify a broad range of chemical agents and to send samples to technical intelligence teams or fixed laboratories for analysis The M18A2 kit can detect blister agents, nerve agents (G and V), choking agents, arsenicals, and blood agents in the air A book of ABC-M8 paper provides the VGH liquid agent detection capability for the kit (Ref 14)

The M256 chemical agent detector kit was type classified and replaced the M15 series kits The M256 kit consists of a plastic carrying case, 12 sampler-detector cards, instruction cards, and a book of ABC-M8 VGH chemical agent detector paper The sampler-detector cards contain reagent ampoules When the ampoules are crushed between the fingers, channels in the plastic sheets, of which the cards are made, direct the flow of the liquid reagents to wet the test spots The test spots change color when exposed to chemical agents in the air The M256 kit detects CX, H, HD, and L blister agents, V and G nerve agents, and AC and CK blood agents (Ref 14) The technology leading to the design of the M256 is described in more detail in Chapter 4

TABLE 1-1. SUMMARY OF CHEMICAL DETECTOR KITS AND LIQUID AGENT DETECTORS (Refs. 10 and 11)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS*	COMMENTS
	Liquid Agent Detectors			
1	M5 Paint	pH color change for H and L	Obsolete	No nerve agent capability
2	M6 Paper	pH color change for H and L	Obsolete	No nerve agent capability
3	M6A1 Paper	pH color change for H, L, and G	Expendable**	No V-agent capability
4	M7/M7A1 Crayon	pH color change for H and L	Obsolete	No nerve agent capability
5	ABC-M8 Paper	pH color change for persistent nerve agent family (V), nonpersistent nerve agent family (G), H, L, and CX	Expendable** (1973)	Has V, G, and H capability and reacts to lubricants and decontaminants
6	M9 Paper	Dye-impregnated paper, pH color change for V, G, H, and L	Expendable** (1980)	Has camouflage and adhesive backing, scuffing causes false indication, reacts to lubricants, decontaminants, and exposure to extremely high temperatures
	Chemical Agent Detector Kits			
7	M4 HS Kit (Detector Tubes)	Schoenemann reaction for H, HN, and L	Obsolete	No nerve agent capability and heater required
8	M9/M9A1/M9A2 Kit (Detector Tubes)	Schoenemann reaction for H, distilled mustard (HD), HN, L, CX, phenyldichloroarsine (PD), ED, DM, DA, DC, CG, AC, CK, GA, GB, and GD	Obsolete	G-agent detector added in 1950 and no V-agent capability
9	a M15 (E27R4) Kit (Detector Tubes)	Schoenemann reaction for G, CK, H, HD, mustard mixture (HT), HN, and CX	Obsolete	No V-agent capability
	b M15A1 (E27R5) Kit (Detector Tubes and Tickets)	Schoenemann reaction for G and H, Enzyme ticket—dichloroindophenyl acetate (DIA) substrate reaction for V-agents added	Obsolete	
	c M15A2 (E27R6) Kit (Detector Tubes and Tickets)		Obsolete	
10	a M18 (E28) Kit (Detector Tubes)	Schoenemann reaction for G, H, HD, HT, HN, CX, L, ED, DM, CG, AC, and CK	Obsolete	No V-agent capability
	b M18A1 (E28R1) Kit (Detector Tubes)		Obsolete	No V-agent capability
	c M18A2 (E28R2) Kit (Detector Tubes and Tickets)	Enzyme ticket—DIA substrate reaction added for V-agents	Standard (LCC-B)† (1977)	V-agent capability added

(cont'd on next page)

TABLE 1-1. (Cont'd)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS*	COMMENTS
11	M256 Kit (Sampler-Detector Cards)	Schoenemann reaction for CX, H, HD, L, V, G, AC, and CK	Standard (LCC-A)† (1977)	Cards replace detector tubes, tickets and reagents, takes 15 min to complete test
	Food and Water Testing Kits			
12	ABC-M3 Food Testing and Screening Kit	Go-no-go qualitative indicator color change for G-agent	Obsolete	No V-agent capability
13	M4 Poison Water Testing Kit	Quantitative—color changes—untreated water	Obsolete	No V-agent capability and reacts to treated water
14	AN-M2 Water Testing Kit	Go-no-go qualitative indicator change in untreated water, detects arsenicals, G-agents, mustards	Standard (LCC-B)† (1958)	Can be used with M30A1 kit to detect V, no V-agent capability, reacts to treated water, faint HN reaction
15	ABC-M30A2 Refill Kit	Used with AN-M2 water testing kit for V-agents	Expendable** (1972)	
16	M272 Water Testing Kit	Detects in treated and untreated water, tickets and tubes change color	Expendable** (1983)	Detects agents in treated and untreated water
	Sampling and Analyzing Kits			
17	M19 Sampling and Analyzing Kit	Qualitative and quantitative analysis for all known chemical agents, sampling for unknown agents	Standard (LCC-A)† (1964)	Portable laboratory in aluminum suitcase, contains all supplies and equipment for field analysis, requires specialized chemist training and skills to operate
18	M33 Analyzing Components Refill Kit	Contains consumables for resupplying M19 Kit	Expendable** (1964)	

* Type classification data is indicated for standard and expendable items
** The term "expendable" is used to denote those items that are no longer functional after use
† LCC signifies a logistic control code. Both LCC-A and B items are issued for use and receive full logistic support, but an LCC-B item is used in lieu of an LCC-A item or it is an item that can no longer be procured

The M9 chemical agent detector paper for detecting liquid chemical agents was adopted for Army use in 1980. The M9 paper is a roll of gray-green paper with an adhesive backing for attachment to uniforms or equipment. The dye-impregnated paper turns pink, red, red-brown, or red-purple when it contacts liquid nerve or blister agents (Ref. 14). The B-1 dye used in the original paper was mutagenic, but the Army decided to field the M9 paper until a suitable replacement dye was found. In 1982 Solvent Red 119 (SR119) was tested and found to be a satisfactory nonmutagenic replacement dye (Ref. 12).

In the early 1960s three kits were available to test for chemical agents in food and water. These were the ABC-M3 chemical agents food testing and screening kit, the AN-M2 chemical agents water testing kit, and the M4A1 poison water testing kit. These kits were capable of detecting most chemical agents except V-agents or incapacitating agents (Ref. 12). The ABC-M3 and M4A1 kits did not meet new user requirements, therefore, they were reclassified as obsolete in October 1970 (Ref. 10).

The AN-M2 chemical agents water testing kit was adopted for Army use as an expendable item in 1958. This kit is used to detect contamination of unchlorinated water by chemical agents. The AN-M2 kit contains qualitative and quantitative tests of water samples for arsenicals, mustard, nerve agents (G only), acidity or alkalinity, and chlorine demand. The kit does, however, give false readings when testing water treated with chlorine or iodine (Ref. 14).

The M272 chemical agents water testing kit was adopted as an expendable item in January 1983. This kit

is used by medical and engineering teams to detect hazardous levels of nerve, mustard, lewisite, and blood (cyanide-based) agents in raw and treated water. The kit functions in the presence of background material and chemicals used in the treatment of water The M272 kit was developed to improve upon and replace the AN-M2 water testing and screening kit and the ABC-M30A1 refill kit (Refs 10, 12, 15, and 16)

The M19 CBR agent sampling and analyzing kit was type classified as standard in 1964 The M19 kit is a portable laboratory used by technical intelligence teams to detect and identify unknown chemical agents and to perform preliminary processing of unidentified chemical and/or biological agent samples Consumable items in the M19 kit are resupplied from the M33 analyzing components refill kit and the M34 sampling kit (Ref 14) These two kits replaced the M10A1 and M12 kits, which were reclassified as obsolete in 1964

The introduction of toxins by Soviet-supported forces in Southeast Asia and Afghanistan during the past decade generated an urgent US Army requirement for an effective toxins detection and monitoring capability. Product improvement programs have been initiated to attain this capability as soon as possible with the M256 and M272 kits (Ref 12) There are, however, no current plans to improve the M19 kit

Since the 1950s the Army has investigated a variety of automatic chemical agent alarm technologies Table 1-2 lists the characteristics and principles of operation of some of the point sampling automatic chemical agent alarms that have been developed or are being developed. Of interest are some of the early E-series nerve agent alarms, which have evolved into the current standard chemical agent detection and monitoring systems

TABLE 1-2. SUMMARY OF POINT SAMPLING AUTOMATIC CHEMICAL AGENT ALARMS (Refs. 10, 11, and 12)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS	COMMENTS
		Early Alarms		
1	M5 (E17) Fixed Installation Automatic G-Agent Alarm	Aqueous Schoenemann reaction for G-agents	Obsolete (1969)	Large size (2 0 × 0 61 × 0 66 m) and weight (329 kg), not adaptable for field use
2	M6/M6A1 (E21) Field Automatic G-Agent Alarm	Colorimetric paper tape (*o*-dianisidine) for G-agents	Obsolete (1969)	First field G-agent alarm, no V-agent capability replaced by M8 alarm
3	M7 (E43R3) Field Automatic VG-Agent Alarm	Colorimetric paper tape	Obsolete (1969)	First field VG-agent alarm, replaced by M8 alarm
4	E22R1 GB Aircraft Alarm	Fluorescence quenching on paper tape	Cancelled	Did not meet user requirements
5	E25 Automatic G-Agent Alarm	Aqueous Schoenemann reaction for G-agents	Cancelled	Not portable (113 kg)
6	E38 Automatic G-Agent Alarm	Aqueous Schoenemann reaction for G-agents	Cancelled	Not portable (127 kg)
		Current Alarms		
7	M43 Chemical Agent Detector Unit (M8 Alarm)	Electrochemical reaction of agent in electrolyte solution Electronic detector cell senses change in voltage	Standard (LCC-A)* (1969)	First fully fielded portable chemical agent alarm (1969), rugged and portable, continuous resupply of electrolyte solution required from M299 refill kits

*LCC signifies logistic control code

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TABLE 1-2. (Cont'd)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS	COMMENTS
8	M43A1 Chemical Agent Detector Unit (M8A1 Alarm)	Ionization-type detector Alpha radiation source causes chemical agent ions in contaminated air to cluster Electronic module monitors electrical voltage output changes	Standard (LCC-A)* (1981)	Dry system, no resupply solutions required, rugged and portable, detects VG-agent only
		Developmental Alarms		
9	XM22 Automatic Chemical Agent Detector Alarm (ACADA)	Ion mobility spectrometry (IMS) used to detect nerve (G, V) agents, mustard, lewisite	—	Lightweight (9 kg)
10	Chemical Agent Monitor (CAM)	Ion mobility spectrometry detects chemical agent vapors (nerve and mustard) by sensing their molecular ions of specific mobilities (time of flight), uses timing and microprocessor techniques to reject interferents	International Materiel Evaluation (IME) Program	Hand-held, lightweight (2 kg) device, detects agent vapors, availability through IME
11	German Mass Spectrometer (GEMS)—MM-1 Mobile Mass Spectrometer	Quadrupole-based mass spectrometer detects chemical agents based on relative abundance of four unique ions of specific threat agent, can be programmed for up to 128 sets of 4 ions, for surface contamination monitoring uses inherent gas chromatography-like function of sample probe to obtain additional interferent-agent separation	International Materiel Evaluation (IME) Program	High specificity and detects, discriminates, identifies up to 128 different chemical agents or unknowns, availability through IME, extremely complex system, requires highly trained specialists for operation and maintenance, large size, servicing difficult
12	XM86 Detector Unit Chemical Agent Automatic Alarm Liquid (ALAD) XM85 Central Alarm Unit (CAU) Agent Automatic Alarm Liquid	ALAD detects single droplets (200 μm or larger) of liquid thickened GD (TGD), VX H, and L by physical-chemical reaction of agent with silver flake bearing paint resin agent causes swelling and separation of conductive silver flakes and change in electrical resistance of detector grid activating alarm, CAU continuously monitors ALAD to determine location, aerosol cloud course, velocity, and dimensions	Terminated	Unattended automatic liquid agent detection, portable system
13	Individual Chemical Agent Detector (ICAD™)	Consists of disposable sensor module containing electrodes, electrolytes and membranes for developing a signal proportional to the G- V- H-, or L-agent concentration in the air and activates audio alarm	Nondevelopmental Item (NDI)	Small, badge-size, battery-powered alarm for detecting chemical agent vapors in air that immediately warns individuals of hazard poor specificity

*LCC signifies logistic control code

Specifically, the E21 and E43R3 automatic field alarms are examples of early attempts to field a universal nerve agent point sampling alarm for Army use The sensors on these alarms operated on the principle of colorimetric paper tape (*o*-dianisidine), which changes color when wetted with a reagent and exposed to nerve agents in the air The E21 alarm was adopted as the M6 and M6A1 field automatic G-agent alarms, and procurement was limited because the E21 did not fully meet the required technical characteristics The E43R3 alarm was adopted as the M7 field automatic VG-agent alarm and designated for limited procurement pending development of a more effective system for field use Both the M6/M6A1 and M7 alarms were reclassified as obsolete in 1969 (Refs 10 and 12)

The M8 automatic chemical agent alarm (ACAA) was type classified as standard in 1969 The M8 alarm consists of a portable, battery-operated, electrochemical point sampling M43 detector unit and a battery-operated M42 alarm unit The M8 alarm was authorized to company-size units throughout the Army Various accessories, such as the M229 refill components kit, M10 power supply, M253 winterization kit, BA3517/U battery, and M182 and M228 mounting kits are needed to support the M8 alarm system in the field To reduce the initial fielding cost to the overseas commands, 10 different configurations based on various combinations of these accessories were type classified and authorized This decision eventually led to many problems in managing this high-density system, therefore, the 10 initial configurations were reduced to one.

The M43 detector unit uses electrolyte wetting solution from the M229 kit passing through an electrochemical cell to detect AC, CG, CK, CX, GA, GB, GD, and VX chemical agents in the air An M74 test set is used to test the electronics The M8 alarm and the M10 power supply were reclassified as LCC-B in 1981 upon adoption of the M8A1 alarm and M10A1 power supply (Ref 14)

The M8A1 automatic chemical agent alarm was type classified in 1981 The M8A1 alarm consists of the M43A1 detector unit, a portable, ionization-type electronic point sampling sensor, and the M42 alarm unit The M43A1 detector unit uses an alpha radiation (dry) source for detection of nerve agents The main advantage of the M8A1 alarm is the elimination of the costly M229 refill kit and time-consuming servicing that the M8 alarm requires The M10A1 power supply is a product improvement providing a smaller, more compatible (form and fit) power supply for converting from ac to dc power to operate the M8 and M8A1 alarms at fixed installations The remaining M8 alarm accessories are compatible with the M8A1 alarm configuration (Ref 12) Unlike the M43 detector unit, the M43A1 detector unit cannot detect choking, blister, or blood agents Planned product improvement for the M43A1 unit includes developing the capability to detect these agents and toxins used as agents (Refs 12 and 13).

Other improved automatic chemical agent detection and monitoring systems are in varying stages of development These include remote detectors or sensors, which will provide a greatly enhanced capability for CB detection and monitoring. Table 1-3 outlines some of the remote detection technologies being pursued in CB defense research and development (R&D) programs. Chapter 4 describes these technologies in more detail

The XM21 remote sensing chemical agent alarm is a first-generation automatic scanning sensor system that employs passive infrared (IR) technology for remote detection of chemical agent vapors The remote sensor system evolved from the long path infrared (LOPAIR) technology, which was investigated in 1956 The XM21 sensor detects the absorption or emission of IR energy by chemical agent vapors within its field of view (FOV) at a range of up to about 5 km (Ref 16). The XM21 alarm consists of a detector, tripod, and power source The XM21 alarm technology is based on a concept that uses Fourier transform spectroscopy and discrimination algorithms to compare the agent cloud IR pattern with the IR illumination naturally occurring in the background scene The XM21 alarm entered full-scale development in 1986 (Refs 17 and 18)

Of particular interest to the designer of CB detection and monitoring systems is the rapid development of active IR technology during the past decade CRDEC is pursuing differential scattered (DISC)/differential absorption light detection and ranging (LIDAR) (DIAL) (DISC/DIAL) remote sensing technology for a remote detection (of agent vapor or aerosol) and ranging (cloud distance) capability for chemical agents Testing from 1984 through 1987 employed a ground-mobile breadboard unit (GMBU) and has demonstrated that DISC/DIAL technology detects threshold concentrations of chemical vapors and aerosols at ranges of up to 3-5 km and chemical surface contamination at a range of 150-600 m The GMBU also demonstrated that active IR technology will achieve many other unique reconnaissance, detection, and identification capabilities not achievable through passive IR technology alone

Based on these findings and Air Force requirements, CRDEC is developing a second-generation remote detection system This system will be a computer-controlled automatic scanning device that combines active and passive IR sensor technologies for remote detection, discrimination mapping, warning, and transmission of ranging information (distance, location, content, and concentration) regarding chemical agent vapor, aerosol, and limited surface contamination This model is being developed to meet fixed site installation (FSI) requirements As this development effort matures, the Army will adapt the Air Force system to meet its Fixed Site

TABLE 1-3. SUMMARY OF CHEMICAL AGENT STANDOFF (REMOTE) DETECTION SYSTEMS (Refs. 12 and 13)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS	COMMENTS
1	E33R1 and E49 Scanning G-Agent Alarm (LOPAIR)	Long path infrared (LOPAIR) remote sensor (nerve agents)	R&D terminated (1966)	Remote detection of chemical agents demonstrated, forerunner of infrared remote detection system, required retro reflector setup 370 m away, positioning retroreflector in battlefield situations for effective operation is difficult
2	XM21 Remote Sensing Chemical Agent Alarm (RSCAA)	Portable, remote sensing alarm, uses passive infrared Fourier transform spectroscopy of vapor clouds, automatic scanning sensor detects absorption or emission of IR energy by chemical agent vapor clouds within its field of view (FOV) by comparison with IR illumination naturally occurring in the background scene	R&D	Remote detection of nerve and blister agent vapors in FOV up to 5 km, portability marginal
3	Advanced Warning 360 CW Scanning Alarm (CWSA)	Remote passive infrared sensor, has 36 filters set to sense 10 increments of airspace surrounding ship or facility	Navy standard	Response time 30 s, nerve agent vapors only, manual operation required
4	Light Detection and Ranging (LIDAR) Remote Detection System	Vehicle-transported remote sensor, combines active differential scatter (DISC) and differential absorption LIDAR (DIAL) infrared techniques to identify and measure chemical agents at a range of 3-5 km, DISC measures wavelength-dependent characteristics of scattering particles, recognizes pattern, identifies particulate composition by measuring backscatter at several wavelengths and range resolves this information, DIAL uses column content technique to measure absorption of IR energy in the 9- to 11-μm region by chemical agent aerosols laser pulses are transmitted, backscattered from naturally occurring atmospheric aerosols, and received by the sensor for processing using microcomputer and algorithms for discrimination and identification	R&D	Remote detection of nerve and mustard agent vapors, aerosols, droplets, and surface contamination, does not need a topographical target, range-resolving, mapping, identification, and column content capability, high-resolution measurements, weight, size and power requirements very high, short laser life, not portable

Detection and Warning System (FSDWS) and nuclear, biological and chemical reconnaissance system (NBCRS) requirements Parallel programs will pursue additional detection capabilities for biological and toxin agents and operation from helicopters, remotely piloted vehicles (RPV), and satellites (Ref 17)

Table 1-4 summarizes the development status of the biological agent detection kits and technologies that have been applied to the biological agent detection problem Table 1-5 summarizes the status of biological agent point sampling detectors and technologies For example, the point sampling biological detector and warning system (BDWS) development program was initiated in the 1960s entered demonstration and validation in 1971 entered full-scale development in 1975, but was terminated in 1983 before type classification

The BDWS consisted of the XM19 chemiluminescence automatic biological agent alarm and the XM2 biological agent sampler The XM19 alarm signaled the presence of biological agent aerosols by monitoring chemiluminescence reactions with specific reaction characteristics The XM2 sampler collected samples of the suspect aerosols and maintained their viability so that the organisms contained could be identified at designated medical laboratories A BDWS station consisted of the XM19 alarm, the XM2 sampler, consumable supply refill kits, and the M42 alarm units The M42 alarm unit provided the audio and visual alarm when biological agents were detected in the environment Each BDWS station required 110 V ac and 60 Hz power from electrical generators BDWS stations were to be assigned to command and control centers down to brigade level with a station density of about five per division and two per separate brigade (Refs 14 and 15)

The BDWS failed to meet user requirements for the following reasons

1 Harmless background interferents caused too many false alarms

2 The system was too heavy and bulky The large volume of air to be sampled required larger equipment than desired by the user community The XM19 alarm weighs 66 kg, and the XM2 sampler weighs 64 kg Both items measured about 0.56 m long, 0 41 m wide, and 0 79 m high (Ref 14)

3 Power requirements were high and required a dedicated generator system

Various technologies for remote detection of biological agents are being investigated through the Army's CB defense research program Table 1-6 summarizes the status of these programs

TABLE 1-4. SUMMARY OF BIOLOGICAL AGENT DETECTION KITS (Ref. 17)

	DETECTOR NAME OR ACRONYM	BASIC FUNCTIONS	STATUS
1	Sampling Kit, Biological Agent, E25	Collect aerosol samples	Sampling function was eliminated, and the other components were included in the E34 kit
2	Sampling Kit, CB Agent, M34	Collect soil and water samples, subject samples to microfiltration, preserve samples for identification by medical personnel	In supply system, only current capability for obtaining information on presence of BW agents, component of Sampling and Analyzing Kit, CB Agent, ABC-M19
3	Biological Agent Test Kit (BATEK)	Provide preliminary information to the commander relative to the necessity for protective action, confirm or negate the alarm, establish "all clear" conditions, detect presence of low concentrations of secondary aerosols, provide generic test for bacteria and viruses and a specific test for T-2 toxin	Exploratory development was to be completed by December 1984, performed poorly in the mission performance analysis and was not moved forward into demonstration and validation

TABLE 1-5. SUMMARY OF BIOLOGICAL AGENT POINT SAMPLING DETECTORS (Ref. 17 and 19)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS	COMMENTS
1	Circular Intensity Differential Scattering (CIDS)	Determination of the intensity of the light scattered when the incident beam is left circularly polarized minus that scattered when the incident beam is right circularly polarized, divided by the sum of the two, believed to discriminate among microorganisms based on differences in packing of DNA or RNA*	Under investigation	Nonliquid, rapid response, extreme single biological or toxic particle sensitivity
2	Single Particle Aerodynamic Relaxation Time (SPART) Analyzer	Laser-based instrument that can determine the aerodynamic size, shape, electrical charge, and fluorescence spectrum of the protein content of the particles suspended in air in real time or on an individual particle basis	Under investigation	Nonliquid, rapid response, extreme single biological or toxin particle sensitivity
3	Esterase Detector	Flow system used to collect, develop, and read out soluble or extractable products of enzyme activity from the intact organism	Breadboarded, under investigation	
4	Laser-Induced Fluorescence (LIF)	Uses a nonfluorescent dye that when enzymatically acted upon by an organism such as a bacterium produces a fluorescent metabolite	Under investigation	Provides qualitative and quantitative microorganism data within a relatively short time span (20-60 min)
5	Particle Size Analyzer (PSA)	Uses the detection of forward-scattered light (45 deg off axial) to count particles on an individual basis and classify them according to size	Did not possess adequate sensitivity, therefore the PSA approach was abandoned	Simple, inexpensive, rugged sensitivities to about 10% of background required
6	Partichrome Analyzer (PACT)	Particles are impacted upon a sticky tape, treated, stained with a dye, and then destained, protein particles accept and retain the stain, whereas others reject or lose the stain, tape is illuminated and viewed through colored filters, biological and nonbiological particles are counted	Little effort was expended on this detection system while the XM19 alarm was in development, PACT has reached the breadboard stage, new investigations are being initiated	Reduces effects of background by discriminating against nonprotein particles, critical focus and light source requirements, complex optics, liquid reagents create a logistic burden

*deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)

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TABLE 1-5. (Cont'd)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS	COMMENTS
7	Pyrolyzer	Cleanses air of particulate content, particulate matter is treated to produce ammonia from the protein matter present, the ammonia is reacted with hydrochloric acid to form particles, these particles are then detected in an ion-counting chamber	Original breadboard had a low sampling rate which led to poor sensitivity, higher current collection capability indicates enhanced sensitivity, this technique is currently being reexamined	Rapid response time, no complex optics, ruggedness, no critical liquid reagents, original low sampling rate led to poor sensitivity
8	LIDAR Point Detector	This technique is a short-range version of LIDAR, a biological fluorescence detection technique that depends on the existence of tryptophan which is present in all biological materials	Recently completed the research stage, in-house work at CRDEC is being performed on this technique, and the feasibility still looks good	Simplicity, low power requirement does not require any liquids, easily stored, requirement for extreme concentration of the biological aerosol
9	Mass Spectrometry (MS)	Single-particle laser ionization mass spectrometry is used to measure the mass spectra of individual particles	Now under study by the Jet Propulsion Laboratory, spectra were generated in March 1983 by ionizing biological particles on a continuous basis	If mass spectra of individual particles can be accurately measured, ability to separate out background materials will be enhanced
10	Single Particle Light Scattering	Light scatter from single particles is detected by a photomultiplier tube	Poor sensitivity, therefore approach was abandoned	Low power requirements; very simple, rapid response time, no liquid requirements, lack of specificity led to high false alarm rate
11	Fluorescence Antibody Staining Technique (FAST)	FAST uses a fluorochrome indicator to detect the presence of antibodies following reaction with the collected antigen, uses UV excitation to detect fluorescent tag	Both FAST and RAST devices have been breadboarded and tested extensively with both simulant and pathogen aerosols and on outside air, these techniques are still being investigated, with promising developments cited	Both FAST and RAST techniques help eliminate response due to background because of their specificity Both FAST and RAST require a different antibody preparation for each bacteria and use liquids that are difficult to store and very expensive RAST uses radioactive materials that present a waste disposal problem in the field
12	Radioactive-Labeled Antibody Staining Technique (RAST)	RAST uses a radioisotope to detect the presence of antibodies following reaction with the collected antigen uses scintillation counting to detect the radioisotope		

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TABLE 1-5. (Cont'd)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS	COMMENTS
13	Biological Detection and Warning System (BDWS)	The two components of the BDWS are the XM19 alarm and XM2 sampler The XM19 is designed to detect rapidly the presence of dilute biological aerosols in an ambient atmosphere The detection principle is based on the chemiluminescent reaction between alkaline luminol, sodium perborate, and the microorganism The XM2 collects a sample of the suspected biological aerosol upon command from the XM19 when an alarm is declared	BDWS reached engineering development stage, however, the developed system did not meet the Army's field needs By reducing the air sampling rate from 1000 to 200 L/min, significant reductions could be made in size, cost, and power	Requires no optics, modified version of the XM19 alarm achieves a very rapid response time (less than 30 s) Size, mechanical complexity, insufficient background discrimination, high power requirements, and need for liquid reagents could pose a logistical problem

TABLE 1-6. SUMMARY OF BIOLOGICAL AGENT STANDOFF (REMOTE) DETECTION (Refs. 17 and 19)

	DETECTOR NAME OR ACRONYM	BASIC DETECTION PRINCIPLE	STATUS	COMMENTS
1	Light Detection and Ranging (LIDAR)	A remote sensor receiver and signal processor monitors the intensity of the fluorescence of trypotophan	Under investigation	No liquid required, short response time, high power requirements, large size
2	Differential Scatter (DISC)	Pulsed laser technique for determining the presence and spatial location of aerosol clouds, DISC makes measurements of the wavelength-dependent scattering characteristics, which identify the composition of scattering particles, pattern recognition identifies the particulate composition made possible by measurement of backscatter at several wavelengths	Under investigation	Standoff capability possible, high power requirements, large size
3	Differential Absorption LIDAR (DIAL)	Combines long path absorption measurements with LIDAR instrumentation	Under investigation	Standoff capability possible
4	Raman Scatter	Uses a form of fluorescence to detect biological aerosols	Under investigation, may be able to identify biologicals as opposed to nonbiologicals	More specific than conventional fluorescence, very small interaction cross section of 10 or 10 orders of magnitude less than the signals produced using direct ultraviolet (UV) excitation of the tryptophan
5	Infrared	Uses infrared absorption of obscurant cross sections to detect biological aerosols	Although 1981-82 laboratory tests showed promise, actual field tests found large concentration requirement for a detection response, therefore, approach was dropped	Large concentration requirement

1-3.2 CHEMICAL AND BIOLOGICAL DEFENSE

The Army's current fighting doctrine is embodied in the AirLand Battle concept, which divides the battle into three operations rear, close, and deep The AirLand Battle doctrine describes the Army's approach to operating and applying combat power at the operational and tactical levels

The AirLand battlefield is not only an extended battlefield but also an integrated one It is extended because the battle is fought from the forward line of own troops (FLOT) both forward and rearward The range, accuracy, and general sophistication of modern weapon systems are such that both combatants can expect their rear areas as well as their forward areas to be attacked The AirLand Battle is integrated because the opposing forces have the capability to integrate electronic warfare and NBC weapons with the use of conventional weapons

Threat forces have the capability to produce and employ NBC weapons that can be delivered to any part of the battlefield In addition to causing damage and casualties when initially employed, NBC weapons cause surface contamination and downwind hazards over large

areas to personnel, supplies, equipment, vehicles, and terrain CB defense encompasses all three areas and operational and tactical levels of the AirLand battlefield

Threat forces possess the capability to contaminate equipment, terrain, and personnel with lethal persistent and nonpersistent agents primarily nerve, blister, and blood agents Agent-filled artillery and mortar shells, tube-launched rockets, aerial bombs, mines, and tactical missiles provide specific agent and munitions combinations that give a nearly all-weather capability to contaminate designated targets Stockpiled nerve agents include GA, GB, GD, and V-series agents Blister agents may include various types of mustard (H, HD, HT), HN, L, mustard-lewisite mixtures (HL), and CX Blood agents include AC and CK Chapter 2 describes the effects and characteristics of these chemical agents in detail Threat chemical agents are primarily used to accomplish the following tasks

1 To kill or incapacitate enemy personnel The main idea of this threat doctrine is to destroy the enemy and use his facilities, equipment, and terrain with the least resistance and damage possible Evacuation and treatment of chemical casualties will impose a heavy logistic burden on the enemy's transportation and medical support units

2 To force the enemy to wear chemical protective clothing and masks Wearing chemical protective clothing and masks reduces performance effectiveness in mission tasks by 30-50% exclusive of the fatigue and heat effects suffered from sustained wear

3 To restrict the enemy's capability to maneuver and concentrate forces

4 To contaminate the enemy's combat and combat support (CS), combat service support (CSS), and FSI When critical equipment, facilities, food supplies, petroleum resupply lines, ammunition supply points (ASP) air bases, and similar key areas or materiel are contaminated by persistent agents extensive protection and decontamination measures must be taken

Threat forces are able to synthesize toxins and to purify natural toxins Recent advances in biotechnology have made possible the manufacture of toxins in the laboratory in large quantities The United States, however, confines its military programs for toxins, whether natural or synthetic, to research for only defensive purposes Biotechnology methods applied to production of materials such as toxins represent the most serious potential threat that could achieve technological surprise over the United States The Soviet Bloc nations classify toxins as chemical warfare agents to be employed in all areas of the battlefield (Ref 20)

Prolific enemy use of CB agents on the battlefield would force our troops to assume various levels of the mission-oriented protective posture (MOPP) and to take time-consuming measures for contamination avoidance and decontamination Protection from CB agents requires wearing protective clothing and/or masks. A significant characteristic of the protective gear is the physical burden associated with prolonged wear, especially in warm temperatures The equipment is bulky and uncomfortable, and soldiers wearing this equipment in hot weather soon become fatigued, lose combat efficiency, and may suffer heat prostration Also they must be able to monitor CB agents so that they can remove their masks and unfasten the protective clothing with reasonable confidence when the all clear signal is given

Although collective protection equipment (CPE) systems give troops some respite from from the CB environment, such facilities or equipment will not be available to most soldiers on the battlefield Even those troops assigned to missions during which CPE is available must have some means of monitoring, detecting, and warning to insure that hazardous levels of CB agents are not present inside or outside shelters

Immediate treatment must be given to any troops exposed to CB agents Besides the loss of personnel through casualties from CB agents, considerable medical treatment facilities and personnel resources must be devoted to the treatment, evacuation, and care of casualties Warning and monitoring for these facilities and personnel are essential

The employment of CB warfare also requires the capability to decontaminate personnel, equipment, and key facilities needed to carry out the Army's missions on the battlefield Decontamination is a tedious task requiring a broad range of supplies, equipment, and personnel to do even a minimal job of reducing this hazard To reduce this hazard, it is essential to know not only when contamination is present but also when there is reasonable assurance that personnel, equipment, facilities, and terrain are free of contamination

CB detection and monitoring begins with the soldier, who may be located anywhere on the battlefield—from the FLOT to the rearmost boundary of the theater of operations Although the current individual detection equipment available to the soldier is limited to the M9 chemical agent detector paper for detecting liquid blister and nerve agents, research is being conducted to provide the soldier with methods to monitor for CB vapor contamination in the air

Squads use the M256A1 detector kit to detect and monitor chemical agents in the air Platoon- and company-size units use the M8A1 portable manpack automatic chemical agent alarm to detect and warn of nerve agent vapors and toxic chemical agents on the battlefield Due to rapidly improving technology, units will be using a variety of detection monitoring, identification, sampling and warning devices when performing CB

reconnaissance and other related CB detection and monitoring functions on the battlefield FSI require a variety of CB detection and monitoring systems to provide adequate warning and CB defense in the rear areas

Various studies of the Army's reconnaissance, detection, and identification (RDI) system have categorized the functions for performing the CB detection and monitoring mission on the battlefield (Refs 19 and 21) These studies and functions are discussed in the later chapters of this handbook Table 1-7 lists and defines these functions

1-4 OVERVIEW

Chapter 2 describes the various types of CB agents and their characteristics and dissemination techniques Chemical agents are discussed in terms of their general chemical composition, dose in terms of concentration and time, physiological response, sensitivity, and response time Candidate biological agents are discussed in terms of types, incapacitating dose or lethal dose, response time, physiological response, and physical forms Dissemination is discussed as it relates to the physical form of the agent, i e , liquid, aerosol, or vapor, and its distribution from a munition source

Chapter 3 describes the various combat scenarios that dictate detector system requirements, namely, combat and CS, CSS, reconnaissance, and FSI The chapter addresses the CB threat of agents employed, the method of employment in each of these battlefield situations, and the detector and monitor requirements

Chapter 4 describes the various CB detection technologies and the characteristics of CB agents that permit detection by particular chemical, physical, and biotechnological methods For each method of detection, the chapter addresses chemical, biological, and toxin detection requirements and capabilities necessary

Chapter 5 introduces the concept that detection technologies must be incorporated when developing equipment for the detection processes of sample acquisition, sample analysis, and response or alarm Sample acquisition for CB agents is addressed in relation to collection and line-of-sight concentration Sample analysis covers signal processing, i.e., visual and electronic methods, such as signal-to-noise ratio, pattern recognition, and discriminatory functions Response or alarm includes visual indication, audio warning, and electrical signals

Chapter 6 explains detector performance criteria in terms of (1) sensitivity and its relation to human response, combat concentrations, and background interferents, (2) response time and its relation to human response and masking time, (3) specificity and discrimination of agents versus battlefield contaminants, and (4) other design considerations, which are addressed in relation to how various required technical characteristics affect the design of CB detection and monitoring systems

Chapter 7 addresses criteria for design of chemical point sampling detectors, chemical standoff detectors (remote sensors), and biological agent detectors. For each type of detector, the design is addressed in relation to the threat scenario, detection requirements (criteria), and component design Component design is discussed in terms of the detection functions of sample acquisition, sample analysis, and response or alarm

REFERENCES

1 A Prentiss, *Chemicals in War*, McGraw-Hill Book Co , Inc , New York, NY, 1937

2 PAM 14-50, *Chemical Corps Training Information Pamphlet*, US Army Chemical Center and School, Fort McClellan, AL, June 1972

3 *A Handbook of Chemical Warfare Agents*, US Army Chemical Warfare School, Edgewood Arsenal, MD, 1931

4 *Report of Activities of the Technical Division During World War II*, Office of the Chief, Chemical

TABLE 1-7. DEFINITION OF RECONNAISSANCE, DETECTION, AND IDENTIFICATION (RDI) RELATED TERMS (Ref. 19)

Detect	Determine the presence of CB agent
Alarm	Signal or message that provides warning of CB attack
Track	Follow path of incoming munition or movement of CB hazard (agent), may provide data for mapping
Search	Seek CB agent by systematic movement of CB detection methods through preset sectors on the battlefield
Classify	Discern among CB agent classes
Identify	Discern among specific CB agents, or further define agent class and/or specific agent
Quantify	Measure concentration and/or amount of agent present
Map	Plot agent as cloud, aerosol, rain, or ground contamination as a function of area and time
Process	Manipulate data or information inputs with preestablished procedures and software to generate specific information for designated users for planning and operational purposes
Display	Present information in a form readily understandable by the user

Warfare Service, Army Service Forces, Washington, DC, 1 January 1946

5 TM 3-216/AFM 355-6, *Technical Aspects of Biological Defense*, Departments of the Army and Air Force, 12 January 1971

6 *Report of the Chemical Warfare Review Commission*, Chemical Warfare Review Commission, Washington, DC, 11 June 1985

7 E Hoshall, "Odor Identification of Chemical Warfare Agents", Chemical Warfare Service Bulletin 27, No 3, Washington, DC, July 1941.

8 *The History of Captured Enemy Toxic Munitions in the American Zone, European Theater/Command May 1945 to August 1948*, Office of the Chief Chemical Officer, Headquarters, European Command, August 1948

9 *German Chemical Warfare Materiel*, Intelligence Division, Office of the Chief Chemical Officer, Headquarters, European Theater of Operations, United States Army, 1945

10 *Data Book on Type-Classified/Standard Chemical Agents, Weapons, and Defense Materiel*, Report No CRDC-SP-85009, US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, September 1985

11 AR 70-1, *System Acquisition Policy and Procedures*, 10 October 1988

12 G G Outterson, R J Norstrom, and R E. Wyant, *Summary Study of Detection and Warning*, Draft Contractor Report, Battelle Columbus Laboratories, US Army Chemical Research and Development Center Aberdeen Proving Ground, MD, April 1981

13 R Shaw, J Hoffland, and J Carrico, *Remote Sensing for Chemical Defense*, US Army Research Office, Research Triangle Park, NC, 26 November 1985

14 TM 43-0001-26-1, *Army Equipment Data Sheets—Chemical Defense Equipment*, Department of the Army, 12 May 1982

15 P Cummings, *New Developments in Chemical-Biological Defense Materiel*, ARCSL-SR-81002, US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, April 1981

16 J Rice, Jr *Data Book on Developmental and Product-Improved Items/Systems of Chemical Materiel*, EO-SR-77004, US Army Edgewood Arsenal, Chemical Systems Laboratory, Aberdeen Proving Ground, MD, March 1977

17 *Assessment of Chemical and Biological Sensor Technologies*, Board on Army Science and Technology, National Research Council, National Academy Press, Washington, DC, 1984

18 TM 3-6665-319-10, *Operator's Manual—Water Testing Kit, Chemical Agents M272*, Department of the Army, 30 November 1983

19 *Functional Analysis of Integrated Reconnaissance, Detection and Identification (RDI) Systems on the Battlefield* (U), Report No CRDEC-CR-87091, US Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, 30 June 1987 (THIS DOCUMENT IS CLASSIFIED SECRET)

20 FM 3-100, *NBC Operations*, Department of the Army, 17 September 1985

21 *Reconnaissance, Detection and Identification (RDI) Master Plan (MP)*(U), Report No CRDC-CR-85032, US Army Chemical Research and Development Center and the US Army Chemical School, Aberdeen Proving Ground, MD, August 1985 (THIS DOCUMENT IS CLASSIFIED SECRET)

BIBLIOGRAPHY

FM 3-87, *Nuclear, Biological, and Chemical (NBC) Reconnaissance and Decontamination Operations*, Department of the Army, 22 February 1980

P Casell, "Establishing Violations of International Law Yellow Rain and the Treaties Regulating Chemical and Biological Warfare" Stanford Law Review 35, 259 (January 1983)

Alexander M Haig, Jr., *Chemical Warfare in Southeast Asia and Afghanistan*, Special Report No 98, United States Department of State, Washington, DC, 22 March 1982

Soviet Chemical Weapons Threat, DST-1620F-051-85, US Defense Intelligence Agency, Directorate for Scientific and Technical Intelligence, Washington, DC, 1985

CHAPTER 2
CB AGENTS: CHARACTERISTICS AND DISSEMINATION TECHNIQUES

Chemical and biological (CB) agent dissemination as it relates to the physical form of the agent and its distribution over target area and agent characteristics are discussed in this chapter The general classifications of chemical agents and biological agents and some of the basic dissemination techniques are addressed The composition, dose response, and physical forms of agents are provided Agent dissemination and the consequent placement of detectors are discussed

2-0 LIST OF SYMBOLS

C = concentration of a chemical or biological agent in the atmosphere, mg/m^3
$C_B(x,y,z,t)$ = biological agent concentration function in space and time, org/m^3*
$C_C(x,y,z,t)$ = chemical agent concentration function in space and time, mg/m^3
Ct = dosage (vapor concentration of the agent multiplied by the time agent is present), mg·min/m^3
Ct_B = biological dosage, org·min/m^3**
$D(x,y,z)$ = total dosage field from a point source, mg·min/m^3
$D(x,y,z,t)$ = partial dosage function from a point source, mg·min/m^3
D_B = biological dosage that is the integration of Ct over time, org·min/m^3**
D_C = chemical dosage that is the integration of Ct over time, mg·min/m^3
D_{INF} = infective dose, org
D_{INH} = inhaled dose, mg
ICT_{50} = inhalation median incapacitating dosage, mg·min/m^3
ID_{50} = liquid median incapacitating dose, mg/kg
LCT_{50} = inhalation median lethal dosage, mg·min/m^3
LD_{50} = liquid median lethal dose, mg/kg
LD^B_{50} = biological median lethal dose, org
Q = initial amount of gas to be disseminated, mg
TCt_5 = minimum effective dosage, mg·min/m^3 or mg
t = time concentration is present, min
t_1 = beginning of time interval of exposure, min
t_2 = end of time interval of exposure, min
$\bar{u}$ = mean transport wind speed, m/min
$X(x,y,z,t)$ = mean concentration of gas function in the atmosphere at time t, mg/m^3
x = downwind coordinate, m
y = across wind coordinate, m
z = upward coordinate, m
α = decay rate factor, dimensionless
β = breathing rate, m^3/min
σ_x = standard deviation of the longitudinal (downwind) concentration distribution, m
σ_y = standard deviation of the lateral (across wind) concentration distribution, m
σ_z = standard deviation of the vertical (upward) concentration distribution, m

* organisms per cubic meter
** organisms·minutes per cubic meter

2-1 INTRODUCTION

The diversity of highly toxic materials available for use as CB agents affects the requirements for detection and monitoring systems Many toxic chemical compounds, biological organisms, and toxins—chemical compounds that are the natural by-products of biological organism production and growth—have become a part of the offensive weapons arsenal of various nations Considerable research has been devoted to investigating highly toxic chemical compounds, extremely virulent strains of biological organisms, and toxins

Development of the methods and munitions necessary to employ the more promising of these agents effectively on the battlefield has been concurrent with the search for these new materials

Some of the materials that have been investigated are so toxic and fast acting that defensive measures have also required special attention, particularly in the areas of detection and warning The presence and location of the agents must be detected, and the threatened troops must be informed in time for them to take protective action

The forms in which these materials are encountered, the physiological effects they produce, and the variability in the time required to affect exposed personnel all contribute to the difficulty of detection and warning The diversity of chemical composition is also a significant part of the problem It has led to the investigation and use of approaches that exploit properties of the materials that will effectively differentiate each material and also identify

each material by a unique signature This discrimination problem is compounded by the frequent practice of mixing several agents in one munition

The remaining paragraphs of this chapter describe chemical agents and biological material by

1 Describing the chemical and physical characteristics and toxicology of agents

2 Discussing characteristics and physiological effects of biological agents

3 Describing how agent dissemination affects the physical characteristics of the dispersed agent, which in turn affect the employment of detectors and detection systems

2-2 AGENT CHARACTERISTICS

The term "agent" applies to threat warfare material and refers to a toxic chemical, a toxic biological organism, or a toxin Although this paragraph mainly addresses the classes of chemical agents, the characteristics of biological agents and toxins are similar to those of chemical agents Chemical agents are classified according to their chemical composition, physical state (liquid, solid, or gas), toxicity (toxic or incapacitating), and physiological response (nerve, blister, blood, choking, or vomiting) Agents are described as persistent and nonpersistent Persistency is a function of agent volatility, weather, terrain, and the munition used Highly volatile agents are generally nonpersistent and their effectiveness lasts for a few hours, whereas agents that have low volatility are more persistent and can last for a few days Even agents within a given class vary considerably in these characteristics, and a combination of these characteristics provides the basis for the various detection methods Physiological response is most commonly used to classify chemical agents for detection and monitoring purposes (Ref 1)

The chemical composition of a chemical agent is an essential characteristic for detection, identification, and monitoring Most detection techniques rely on some chemical characteristic signature given by the agent vapors The unique spectral properties of chemical compounds provide a means of detection and identification by their characteristic wavelengths Spectral characteristics usually are evaluated at a single wavelength This property provides a means by which such advancements in technologies as infrared (IR) and ultraviolet (UV) sensors can be applied to the detection of CB agents

Most military chemical agents are liquids with varying degrees of volatility, which is a measure of the tendency of a chemical substance to go from the liquid or solid state directly to the vapor state Volatility is expressed as milligrams of vapor per cubic meter at a specific temperature and pressure It depends on vapor pressure and varies with temperature Liquid agents also produce vapor through evaporation All liquid agents evaporate at a rate that directly corresponds to their volatility Solids, on the other hand, produce hardly any vapor since their volatility is low Consequently, solid or liquid agents of low volatility and vapor pressure must be disseminated as microscopic airborne particles, i.e., aerosols, by mechanical or thermal means. All type-classified chemical agents are stored in liquid form and disseminated in an aerosol or particle form The detection of agents is dependent on the forms most likely to be encountered on the battlefield The forms of agents are based on their physical state after dissemination, i e , vapor, aerosol, or liquid (Ref 1)

A vapor is the gaseous form of a solid or liquid agent An aerosol is a suspension of fine liquid or solid agent particles in a gaseous medium Once disseminated, a liquid agent is restricted by the type of surfaces on which it is deposited and its viscosity

Agent properties have been modified in some dissemination systems to increase persistence and to obtain improved target coverage Materials such as polymethyl methacrylate and cellulose gums have been employed to thicken the agents A colloidal or true solution of the agent-thickener combination is obtained, which results in a liquid of significantly higher viscosity In dissemination systems in which aerodynamic breakup is used, the droplet size produced by thickened agents is much larger than the droplet size produced by unthickened, or neat, agents The larger droplets greatly improve control of agent deposition

The duration of the effectiveness of a chemical agent is dependent on its physical and chemical properties, meteorological conditions, methods of dissemination, and terrain Chemical agents are often described as either persistent or nonpersistent (Persistency is not considered a class) A persistent agent is an agent that remains in the environment for extended periods of time and retains its potency on the battlefield from days to weeks. A nonpersistent agent dissipates relatively quickly and retains its potency on the battlefield from a few minutes to about an hour (Ref 1)

Factors that determine the duration of a hazard are the physical properties of the agent, weather conditions, method of dissemination, terrain and target conditions, and agent toxicity Temperature, atmospheric stability, wind speed, and precipitation are the most important meteorological factors in determining the duration of a hazard Vegetation, soil, and buildings also play an important part in the duration of effectiveness of a chemical agent at its point of release Persistency also affects the requirements for contamination avoidance and decontamination For example, decontamination personnel are required to don impermeable protective clothing as well as protective masks in order to perform decontamination in the safest possible manner.

Persistency is a function of agent vapor pressure and volatility, i e , highly volatile agents with high vapor pressure evaporate more rapidly and the hazard persists

for short periods. Liquid agent evaporation and hazard duration are functions of meteorological conditions and agent particle size. Viscosity is another important physical factor that affects persistency and agent effectiveness

The size of the droplets or particles disseminated by a munition greatly influences the effectiveness of agents that are normally liquid or solid In explosive munitions the droplet sizes are dependent upon the amount and type of burster charge and upon the fuzing of the munition (air or ground burst) Nonexploding munitions, such as aerosol generators and spray tanks, are devices used to vary the degree of dispersion and thus influence the duration of the effectiveness of chemical agents

Toxicity is defined as the property possessed by a material that enables it to injure the physiological mechanism of an organism by chemical means, and the maximum effect of this injury is death Chemical agents that produce death are classified as lethal agents, whereas chemical agents that produce temporary physical disability, mental confusion, amnesia, or stupor are classed as incapacitating agents A chemical or biological agent casualty is a person who has been sufficiently affected by a lethal or incapacitating agent to make him or her incapable of performing duties or continuing the mission The United States (U S) no longer produces or stockpiles incapacitating agents

The main threat agents are classed as toxic chemical agents Used in effective concentrations in the field, toxic chemicals, regardless of their physical state, can produce injury or death Toxic chemical agents are also classified according to their use as casualty agents The toxicity of agents at specific concentration levels affects the requirements for the sensitivity and response time of detection equipment The threshold effect level of the agent, i e , the amount of agent dosage that causes the first appearance of symptoms in exposed personnel, must be ascertained in order to establish meaningful sensitivity parameters for the design of detectors that will meet the user requirements on the toxic battlefield

The toxicities of the agents, particularly the effective dose and time to affect personnel, are important design considerations They help to establish priorities for the operating characteristics of detectors such as sensitivity and response time

Sensitivity is the concentration of agent the detector system will detect within its characteristic response time Concentration is the quantity of a chemical or biological agent present in a unit volume of air The concentration of airborne chemical agents is usually expressed in milligrams per cubic meter

Response time is the amount of time needed for the detector or sensor system to detect an agent, to process the information gathered on the agent encountered, and to respond by displaying in some form the required information (such as detection, identification, or quantification) to be used for operational decision-making purposes The ideal detector detects the presence of a hazardous concentration of an agent (sensitivity) and responds immediately (real time) so that threatened troops can take protective measures before casualties occur

Exposure to CB agents is usually stated in terms of levels of dosage, therefore, an understanding of these levels is essential for the designer of CB detection and monitoring systems Inhalation dosage Ct is the concentration of a chemical agent in the atmosphere C multiplied by the time t the concentration remains Dosage is usually expressed as milligram·minutes per cubic meter

Other terms commonly used to express the effects of chemical agents are

1 *Liquid Dose* The amount of liquid agent received by a person on his skin is usually expressed as median lethal dose LD_{50} in milligrams of contaminant per kilogram of body mass (Ref 1)

2 *Threshold Effect Level* The amount of agent that causes the first appearance of symptoms in exposed and unprotected personnel (Ref 2)

3 *Detoxification Level* The concentration or level of agent that can be counteracted or destroyed by the human body within a short period of time without harmful effects (Ref 2)

4. *Detoxification Rate* The rate at which the body is able to counteract the effects of a chemical agent It is an important factor in determining the hazard of repeated exposure to low concentrations of chemical agents Some chemical agents are not detoxified at any detectable rate by the human body Sarin (GB) has a cumulative toxic effect (Ref. 1)

5 *Median Incapacitating Dosage or Dose* The incapacitating dosage or dose of an agent is generally expressed as the median incapacitating dosage or dose, i.e , the amount of inhaled vapor or liquid agent on the skin that is sufficient to disable 50% of a large group of unprotected, exposed personnel For inhalation effect the median incapacitating dosage is expressed as ICt_{50} and for liquid effect as the median incapacitating dose ID_{50} They vary in accordance with the protection furnished by the masks and clothing worn by personnel (Ref 1)

6 *Median Lethal Dosage or Dose* The median lethal dosage or dose is the amount of agent that is sufficient to cause death to 50% of a large group of unprotected, exposed troops if they do not receive medical treatment in time This dosage or dose is generally expressed as the dosage LCt_{50} in milligram·minutes per cubic meter for a chemical agent to be inhaled as a vapor or aerosol For a chemical agent employed for absorption through the skin, the dosage or dose is generally expressed as a dose LD_{50} in milligrams per kilogram of body mass (Ref 1).*

*Lethal dosage may also be expressed in amounts other than median dosage, e g , LCt_{25} is the dosage required to kill 25% of unprotected, exposed troops

7. *Incapacitation 5%* The agent concentration or level that prevents, through disablement or serious degradation of abilities, 5% of all unprotected, exposed troops from performing their mission (Ref.2)

8 *Infectious 5%* Concentration of biological agent that will infect 5% of all unprotected, exposed troops (Ref 2)

After exposure to a chemical agent, an individual may show signs and symptoms that are more or less than expected for a given dosage, depending on

1 How long the breath was held during short exposure

2 Speed with which mask was donned

3 Ability to fit mask and any mask leakage factors present

4 Whether the chemical agent was also absorbed through the skin

5 Whether the chemical agent stimulated the breathing rate

6 Rate and depth of breathing of the individual at time of exposure

7 Amount of physical exertion by the individual at time of exposure

8 Rate of detoxification, especially if exposure was long

The physiological effectiveness of skin and respiratory aerosol dosages is influenced by particle size as well as by time and concentration because retention by the lungs and impingement upon the skin are functions of particle size These dosages are usually expressed in milligram·minutes per cubic meter for a particle size

Until the 1950s the previously listed variables were generally ignored, and the Ct values were assumed to measure the amount of chemical agent received by an individual breathing at a normal rate in a temperate climate with average humidity These values provided a basis for comparison of the chemical agents More exacting techniques and test equipment, however, have been developed and arrive at a more scientific approach for computing dosage, as illustrated by D_c, that results from an exposure to an agent over a time interval (Ref 3)

$$D_c = \int_{t_1}^{t_2} C_c(x,y,z,t)\,dt, \quad \text{mg·min/m}^3 \qquad (2\text{-}1)$$

where

$C_c(x,y,z,t)$ = chemical agent concentration function in space and time mg/m^3

t_1 = beginning of time interval of exposure, min

t_2 = end of time interval of exposure, min

The coordinates x, y, and z relate the point of concentration measurement (or exposure) to the location of the source e g an exploding munition The "bubbler", one of the commonly used field testing samplers, provides results in terms of dosage, i e., the integration indicated in Eq. 2-1

Most agents also produce toxic effects when the skin is exposed to the vapor or liquid Although nerve agents are the most serious threat, blister agents can cause debilitating and disabling injuries Percutaneous (whole body or skin) exposure is not as easy to define as inhalation exposure For vapor exposure the levels are stated in terms of dosage and measured in milligram·minutes per cubic meter, whereas for liquid exposure the levels are stated in terms of dose and measured in milligrams Dosage alone does not indicate the toxicity of a chemical agent

The actual toxicity of an agent is determined by the dose a soldier receives For inhalation, the soldier's breathing rate must also be considered The inhaled dose D_{INH} is

$$D_{INH} = Ct \cdot \beta, \text{ mg} \qquad (2\text{-}2)$$

where

Ct = dosage, mg·min/m^3

β = breathing rate, m^3/min

Although the term "breathing rate" is commonly used in this context, the correct terminology is "minute volume", i.e , the quantity of air inhaled in one minute "Breathing rate" is more accurately the term for the number of respirations per unit of time

The body surface is not uniformly vulnerable to agent effects The eyes and the skin surfaces of the head and neck are especially vulnerable Table 2-1 presents an

TABLE 2-1. ESTIMATED PENETRATION RATE OF PERCUTANEOUS SINGLE-DROP APPLICATIONS OF VX NERVE AGENT (Ref. 4)

BODY AREA*	PENETRATION RATE, μg·min/cm^2
Ear	0 498
Forehead	0.318
Top of head	0 203
Cheek	0 183
Back of neck	0 070
Forearm (volar)	0 037
Armpits (axilla)	0 032
Abdomen	0 027
Back of knee (popliteal)	0 017
Buttocks	0 012
Back	0 008

*Usually specified for a 70-kg man

example of this variation in sensitivity, based on the percent of subjects with symptoms, as exhibited by the agent penetration rate for nerve agent VX The time required to obtain a physiological response is also dependent on the type of exposure Systemic effects from inhalation are the most rapid, therefore, exposed troops must hold their breath and don a protective mask immediately The eyes are affected rapidly also The visible symptoms of exposure of skin surfaces usually are delayed but the actual injury occurs well in advance of visible symptoms Therefore, immediate donning of protective clothing is required

2-2.1 CHEMICAL AGENTS

2-2.1.1 Nerve Agents

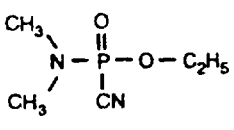
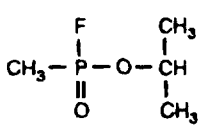
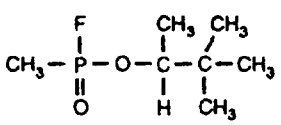
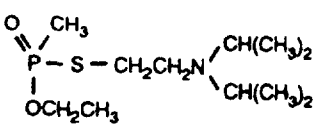
Nerve agents are chemical agents that directly affect the human nervous system and are highly toxic in both the liquid and vapor forms These agents can be absorbed through the skin or inhaled and quickly act to cause incapacitation and death Essentially, nerve agents cause an increase of the amount of acetylcholine in the body by their interference with the enzyme acetylcholinesterase Thus they affect the transmission of nerve impulses Nerve agents belong to the class of organophosphorus compounds that, though different in structure elicit a common physiological response

Nerve agents are the most toxic class of chemical agents Minute doses of nerve agents can produce incapacitation and fatalities in less than a minute Nerve agents are subdivided into G- and V-series agents

The G-series of nerve agents can range from low- to high-volatility compounds that are disseminated as gases, aerosols, and liquids and by the use of thickeners, can be disseminated as toxic rain (large droplets) The G-agents are toxic by both inhalation as the primary route and by percutaneous absorption as a secondary route Dosage for chemical agents is expressed in terms of Ct A Ct of 100 for GB will cause lethality in 50% of the unprotected, exposed population The onset of symptoms is rapid, and death occurs in minutes

The V-series agents are low-volatility compounds that are disseminated as aerosols and liquids (including toxic rain) and are persistent and toxic primarily by percutaneous absorption The percutaneous toxicity of V-agents is approximately 50 to 100 times greater than that of G-agents; however, symptoms occur more slowly with V-agents when they are absorbed through the skin V-agents are colorless, odorless, and difficult to detect on the battlefield The known compounds have a range of physical properties and toxicities that influence their employment, the form in which they are encountered, and the problems of detection Table 2-2 summarizes selected nerve agent properties Table 2-3 shows the effects of those agents for eye, inhalation, and skin toxicity

TABLE 2-2. NERVE AGENT PROPERTIES (Ref. 1)

SYMBOL	STRUCTURE	NAME	MOLECULAR WEIGHT	LIQUID DENSITY AT 25°C g/cm³	VAPOR PRESSURE AT 25°C mm Hg	VOLATILITY AT 25°C mg/m³
GA*		Ethyl N N-dimethyl phosphoramidocyanidate	162 3	1 073	0 070	610
GB		Isopropyl methyl phosphonofluoridate	140 10	1 0887	2 9	22 000
GD**		Pinacolyl methyl phosphonofluoridate	182 178	1 0222	0 40	3900
VX		O-ethyl S-[2-(diisopropylamino) ethyl] methyl phosphonothioate	267 38	1 0083	0 0007	10 5

*GA = tabun
**GD = soman

TABLE 2-3. NERVE AGENT TOXICITY (Ref. 2)

AGENT	EYE, mg·min/m³	SKIN		INHALATION (ASSUME MILD ACTIVITY), mg·min/m³	
		VAPOR, mg·min/m³		LIQUID, g/person	
	TCt_5*	ICt_{50}	LCt_{50}	LD_{50}	ICt_{50}	LCt_{50}
GA	3 2**	No data	20,000-40,000	1-1 5	300	400
GB	4 0	8000-8850	15,000	1 7	35	70
GD	2 0	1900	2900	4 0	75	100
VX	4 0	25	50	5 0	18	35

*TCt_5 is the amount of agent dosage that causes 5% of exposed, unprotected personnel to exhibit threshold effects
**Median concentration detectable by eye effects (mg/m³)

2-2.1.2 Blister Agents

Blister agents are chemical agents that affect the eyes, lungs, and skin In liquid or vapor form these agents can burn or blister any part of the body they may contact, either internally or externally They are effective in small quantities and produce delayed casualties

Mustard (H, HD, or HT) is the most likely blister agent to be encountered on the battlefield Liquid mustard is classified as a persistent agent Agent persistency depends upon the munition used and the weather Heavily splashed liquid persists from one to two days in concentrations that provide casualties of military significance under average weather conditions and from a week to months under very cold conditions Once dissolved in water, the hydrolysis of mustard is very rapid Its solubility, however is so low that hydrolysis is not an effective decomposition factor (Ref 1) Therefore, mustard can present a serious hazard to troops forced to wade or swim in waters contaminated with liquid mustard Mustard vapor or liquid is not nearly as toxic as the nerve agents but causes severe burning of the lungs upon contact Exposure of the skin to mustard is not accompanied by symptoms nor do any local manifestations occur until redness develops Depending upon the type of mustard encountered, this redness develops from 30 s to 6 h after exposure Mustard is especially damaging to the eyes as a vapor or liquid H is Levinstein mustard, HD is distilled mustard, and HT is a mixture of 60% HD and 40% T, a sulfur and chlorine compound similar in structure to HD

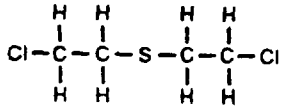
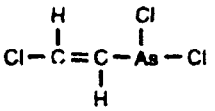
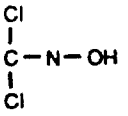
Intelligence analyses indicate that lewisite (L) and combinations of mustard and lewisite are threat agents (Ref 5) A mustard-lewisite mixture (HL) is a variable of HD and L that provides a low-freezing mixture (−25° C) for use in cold weather operations or as a high-altitude spray Lewisite produces effects similar to those produced by mustard but in addition acts as a systemic poison and causes pulmonary edema (fluid in the lungs), diarrhea, restlessness, weakness, subnormal temperature, and low blood pressure Unlike mustard, however, lewisite produces immediate pain upon exposure Because L and HL are arsenicals, hydrolyze rapidly, and are less toxic than other agents of military interest, the U S classifies them as obsolete agents

Phosgene oxime (CX) is a blister agent that can be used as a harassing agent CX causes painful wheals that appear as welts, like bee stings, when it contacts the skin

Nitrogen mustards (HN) are persistent blister agents in which nitrogen is the central atom These related chemical compounds are considered derivatives of ammonia (NH_3) because the hydrogen atoms are replaced by various organic radicals

Table 2-4 summarizes the selected properties of blister agents, and Table 2-5 shows toxicity levels for common blister agents

TABLE 2-4. BLISTER AGENT PROPERTIES (Ref. 1)

SYMBOL	STRUCTURE	NAME	MOLECULAR WEIGHT	LIQUID DENSITY AT 20°C g/cm³	VAPOR PRESSURE AT 20°C mm Hg	VOLATILITY AT 20°C mg/m³
HD		Bis-(2-chloroethyl) sulfide	159 08	1 268*	0 072	610
L		Dichloro (2-chloro-vinyl) arsine	207 35	1 89	0 394	4480
HL**	Mixture (63% L 37% HD)	Mustard-lewisite mixture	186 4	1 66	0 248	2730
CX		Dichloroformoxime	113 94	No data	11 2*	1800

*at 25°C

**Eutectic Mixture 63% L 38% HD by weight

TABLE 2-5. BLISTER AGENT TOXICITY (Ref. 2)

AGENT	EYE mg·min/m³		SKIN				INHALATION, mg·min/m³
			LIQUID, mg		VAPOR, mg·min/m³		
	TCt_5*	ICt_{50}	TCt_5	ID_{50}	TCt_5	ICt_{50}	LCt_{50}
HD	50	200	—	—	50	—	1500
L	—	<300	—	1500	—	—	1200-1500
HL	—	200	—	1200-1500	—	—	1500
CX	—	—	200	—	200-500	—	3200

*The data shown under TCt_5 may have been reported as "minimum effects" level or "no effects" level or as some other characterization of minimal exposure

2-2.1.3 Blood Agents

Blood agents have such high volatilities that they evaporate almost immediately after dissemination and are taken into the body by inhalation They affect the circulatory and respiratory systems by blocking the use of cytochrome oxidase by cells that carry oxygen in the blood These agents can act very quickly and cause symptoms ranging from cyanosis (bluish discoloration of the skin) to convulsions, coma, and death

Typical blood agents are cyanogen chloride (CK) and hydrogen cyanide (AC) Arsine (SA), or arsenic trihydride, is also included in this classification They are primarily inhalation threats that attack the enzyme cytochrome oxidase and prevent absorption of oxygen by the blood The U S has reclassified these blood agents as obsolete

Although blood agents are much more volatile and less toxic than nerve agents, military interest in these compounds has persisted because they are not readily adsorbed on activated charcoal A special treatment, whetlerization, during which the activated charcoal is impregnated with a mixture of metal salts, is required The current standard, designated ASC Whetlerite, is somewhat vulnerable because exposure to hot, humid environments degrades its effectiveness against CK

Table 2-6 summarizes selected properties of blood agent compounds, and Table 2-7 shows inhalation toxicity for common blood agents

TABLE 2-6. BLOOD AGENT PROPERTIES (Ref. 1)

SYMBOL	STRUCTURE	NAME	MOLECULAR WEIGHT	DENSITY		VAPOR PRESSURE AT 25°C mm Hg	VOLATILITY AT 25°C, mg/m^3
				VAPOR, air = 1	LIQUID g/cm^3		
AC	$HC \equiv N$	Hydrogen cyanide	27 0	0 93	0 68*	742	$1\ 1 \times 10^6$
CK	$Cl-C \equiv N$	Cyanogen chloride	61 48	2 1	1 18**	1000	$2\ 6 \times 10^6$
SA	$As(H)_3$	Arsenic trihydride arsine	77 93	2 96	1 34**	11,000†	$30\ 9 \times 10^6$††

*at 10°C
**at 25°C
†at 20°C
††at 0°C

TABLE 2-7. BLOOD AGENT TOXICITY (Ref. 1)

AGENT	INHALATION, mg min/m^3	
	ICt_{50}	LCt_{50}
AC	Varies with concentration	2000*
CK**	7000	11,000
SA	2500	5000

*Exposure time of 0 5 min effectiveness is concentration dependent
**Eye irritant detectable at 12 mg·min/m^3

2-2.1.4 Choking Agents

Choking agents are nonpersistent chemical agents that vaporize very rapidly after dissemination and are taken into the body by inhalation

They are characterized by high vapor pressure and high volatility, and their toxicity is much lower than that of nerve agents These materials affect the respiratory system by damaging the nose, throat, and lungs In extreme cases, membranes swell, lungs become filled with liquid, and death results from lack of oxygen

Phosgene (CG) is a typical choking agent The U S reclassified CG as obsolete many years ago, however, phosgene is still used as an industrial chemical (gas) Other countries may still stockpile phosgene or such derivatives as diphosgene (DP) for chemical warfare purposes

Table 2-8 lists the principal physical and chemical properties of various choking agents, and Table 2-9 summarizes toxicological data on some of these agents

2-2.1.5 Vomiting Agents

Vomiting agents are compounds that cause nausea and vomiting and may also cause coughing, sneezing, pain in

TABLE 2-9. CHOKING AGENT TOXICITY (Ref. 1)

AGENT	INHALATION, mg·min/m^3	
	ICt_{50}	LCt_{50}
CG	1600	3200
DP	1600	3200

*For resting personnel

TABLE 2-8. CHOKING AGENTS (Ref. 1)

SYMBOL	MOLECULAR FORMULA	NAME	MOLECULAR WEIGHT	LIQUID DENSITY * g cm^3	VAPOR PRESSURE,* mm Hg	VOLATILITY, mg/m^3
CG**	$COCl_2$	Carbonyl chloride (phosgene)	98 92	1 373	1 173	4 300 000†
DP	$ClCOOCCl_3$	Trichloromethyl chloroformate (diphosgene)	197 85	1 653	4 2	45,000*

*at 20°C
**Phosgene was the principal member of the class Diphosgene was ineffective due to lower vapor pressure
†at 7 6°C

the nose and throat, nasal discharge, and/or tears Headaches often accompany these symptoms In confined areas sustained exposure to vomiting agents can lead to death of exposed individuals These compounds do not present a detection requirement Chloropicrin (PS) and adamsite (DM or DM1), former training and riot control agents, were in this category before they were declared obsolete by the U S Other nations may have PS stocks in their inventory

Chloropicrin is a nonpersistent liquid that vaporizes rapidly when disseminated Adamsite and its derivatives, diphenylchloroarsine (DA) and diphenylcyanoarsine (DC), are solids that when disseminated in the air, condense to form aerosols

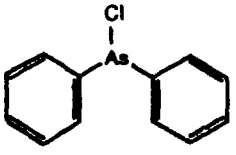
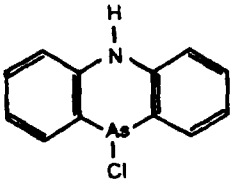
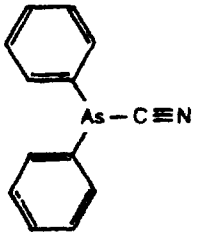
Table 2-10 summarizes the physical and chemical properties of vomiting agents DM, DA, and DC, and Table 2-11 summarizes their toxicities

TABLE 2-11. VOMITING AGENT TOXICITY (Ref. 1)

AGENT	INHALATION, mg·min/m^3	
	ICt_{50}	LCt_{50}
DA	12*	15,000
DM	22**	15,000
DC	30†	10,000

* 10-min exposure
** One-min exposure
† 30-s exposure

TABLE 2-10. VOMITING AGENTS (Ref. 1)

SYMBOL	STRUCTURE	NAME	MOLECULAR WEIGHT	DENSITY g/cm^3	VAPOR PRESSURE mm Hg	VOLATILITY mg/m^3
DA		Diphenylcloroarsine	264 5	1 387 (liquid density at 50°C)	0 0036*	48*
DM		Diphenylamino-chloroarsine (also phenarazine chloride)	277 57	1 65 (solid density) at 20°C)	Negligible	Negligible
DC		Diphenylcyanoarsine	255 0	1 3338 (liquid density at 35°C)	0 0002**	2 8**

*at 45°C
**at 20°C

2-2.2 BIOLOGICAL AGENTS

Biological agents include bacteria, viruses, rickettsia, fungi, and toxins National policy states that biological materials, such as bacteria and viruses, as well as chemical materials derived from biological sources, such as toxins, be considered similarly Unlike chemical agents, which generally cause casualties relatively quickly, biological agents (including some toxins) do not cause immediate casualties The longer term effects of biological agents and toxins can be deadly if their use is not detected before symptoms appear The spread of disease by live microorganisms through arthropod vectors and person-to-person contact increases the range and area threatened by enemy use of biological agents

Microorganisms that constitute antipersonnel biological warfare (BW) threats can be divided according to their taxonomy into viruses, rickettsia, fungi, and bacteria Fungi is a class of pathogens capable of producing serious diseases in humans In general, however, fungal diseases are basically less acute than diseases produced by the other three classes of pathogens Viruses and rickettsia share the characteristic that they can grow only within living cells, but they differ in size—rickettsia are larger Bacteria are the largest of the three and do not require living cells to grow Protozoa and fungi are possible, but very unlikely, BW agents Table 2-12 summarizes the characteristics of some biological agents

Toxins produced by biological organisms or synthesis constitute some of the most toxic substances known, e g , botulinum, staph enterotoxin, and shellfish toxin Mycotoxins, such as tricothecene, are of particular concern because of their use in Afghanistan and Laos in the 1980s

The onset of the diseases produced by biological agents may vary from a few days to two weeks Some of the toxins produce symptoms in a matter of minutes These factors influence use of the agents and design of the detection and warning equipment

Biological organisms and toxins are usually fragile materials that gradually are rendered harmless upon exposure to the environment Living organisms are particularly sensitive to ultraviolet light and low relative humidities whereas toxins undergo chemical decomposition The rate at which organisms die is the decay rate

Organisms are microscopic bodies occurring in many shapes and forms When produced for BW applications, these organisms are in a slurry (suspension in a liquid medium) or powder form

Exposure to biological agents is described in dosage units similar to those for chemical agents The dosage equations are equivalent except concentration is expressed in units of organisms per unit volume (Ref 3)

The actual biological dosage D_B can be expressed as

$$D_B = \alpha \int_{t}^{t_1} C_B(x,y,z,t)dt, \text{ org·min/m}^3\text{*} \quad (2\text{-}3)$$

where

$C_B(x,y,z,t)$ = biological agent concentration function in space and time, org/m^3

α = decay rate factor, dimensionless

As with chemical agents, toxicities are less ambiguously defined in other terms, i e , the number of organisms required for infection This infective dose D_{INF} is obtained by

$$D_{INF} = Ct_B \cdot \beta, \text{ org} \quad (2\text{-}4)$$

where

Ct_B = biological dosage, org·min/m^3

An average value is generally used to represent breathing rate, however, a more detailed analysis may use a probability distribution for this variable, which reflects the differences in individuals and the variety of activities in which they are involved The dose is the number of organisms ingested D_B and β are based on a probability distribution For example, the LD_{50}^{β} represents the dose required to infect 50% of the unprotected population exposed to a lethal level

Response time and sensitivity are critical factors in biological agent detection False alarm rate and agent identification are closely linked with detector response time and sensitivity Detectors designed with high sensitivities may detect nonagent material present on the battlefield, such as fertilizer, petroleum, oil, and lubricants (POL), organic pesticides, and smoke Even at low levels, these nonagent materials, commonly referred to as interferents, can cause alarms to function Therefore, there must be tradeoffs between detecting pathogenic organisms and preventing personnel from being exposed to casualty-producing concentrations Pathogens must be detected in a sufficiently low concentration, and false alarms must be minimized

*org·min m^{-3} = organisms minutes per cubic meter

TABLE 2-12. SELECTED BIOLOGICAL MICROORGANISMS (Ref. 5)

TYPE	MORTALITY, %	INCUBATION PERIOD, day	SYMPTOMS
Anthrax (pulmonary) (*Bacillus anthracis*)	100	1-5	For inhalation, onset is mild and resembles an upper respiratory infection For skin, a painless pustule forms on exposed surface and causes mild fever, headache, and malaise followed by cyanosis, dyspnea, mediastinitis, and hemoptysis
Brucellosis (*Brucella*)	2-5	5-21	Low-grade fever, chills, headache, weakness, insomnia, sweating, anorexia, pain over the spine, and malaise Other complications include orchitis, subacute bacterial endocarditis, and ocular disorders
Cholera (*Vibrio cholerae*)	10-80	1-5	Sudden onset of diarrhea, vomiting, muscular cramps, and collapse Dehydration leads to cyanosis, pinched facies, loss of skin turgor, and thready peripheral pulses
Glanders (*Actinobacillus mallei*)	100	1-5	Acute localized supportive infection, acute pulmonary infection, acute septicemia, and mucous membrane discharge
Plague (pneumonic) (*Yersinia pestis* or *Pasteurella pestis*)	100	2-5	Severe lymph node infection with very tender and sometimes necrotic lymph nodes, also prostration, cough, dyspnea, and cyanosis
Tularemia (*Pasteurella tularensis* or *Francisella tularensis*)	Usually low	1-10	Sudden onset with high fever, chills, and prostration Enlarged lymph nodes
Dystentary or shingellosis (*Shigella species*)	<10	1-4	Fever, crampy lower abdominal pain, and diarrhea that may be bloody
Q-fever (*Coxiella burnetti*)	<1	4-26	Headache, chills, fever, malaise, myalgia and anorexia
Rocky mountain spotted fever (*Rickettsia rickettsii*)	20	2-14	Severe headache, shaking, rigor, prostration, myalgia (especially in back and legs), nausea, vomiting, and fever
Typhus (epidemic) (*Rickettsia prowazeki*)	10-40	5-15	Headache, chills, and fever followed by spasticity, agitation, stupor, and coma

(cont'd on next page)

TABLE 2-12. (cont'd)

TYPE	MORTALITY, %	INCUBATION PERIOD, day	SYMPTOMS
Chikungunya fever	<1	3-12	Abrupt onset of fever, rigor, headache, pain in the large joints, skin rash on trunk, myalgia, and pharyngitis
Dengue fever	<1	5-8	Abrupt onset of headache, retro-orbital pain, backache, leg and joint pain, and pain with eye movement
Yellow fever	30-40	2-6	Sudden onset of headache, dizziness, fever, slowing of pulse followed by neck, leg, and back pain, nausea, and vomiting In severe cases there are hemorrhages, loss of urine output, and delirium
Smallpox	25-40	6-22	Fever, headache, myalgia (especially of the back), abdominal pain followed by pustule formation In severe forms there is severe prostration, bone marrow suppression, hemorrhagic skin lesions, and bleeding Death occurs in 3 to 4 days from onset of symptoms
Coccidiodomycosis (*Coccidiodes immitis*)	<10	7-21	Half of victims are asymptomatic, others have fever, chills, fatigue, headache, severe arthralgia, skin rash, and symptoms of respiratory infection

2-2.2.1 Bacteria

There are thousands of different species of bacteria Each is characterized by its size, shape, structure, and arrangement Individual organisms have one of three general forms spherical or ellipsoidal, cylindrical or rodlike, and spiral or helicoidal Spherical forms, such as staphylococci and streptococci, have diameters of 0 75 to 1 25 μm (Ref 6) Rod forms, such as typhoid and dysentery, have widths between 0 5 and 1 00 μm and lengths of 2 0 to 3 0 μm Refinements in electron microscopy and developments in microbial cytology and bacterial anatomy have made cell structure an important element in bacterial characterization Fig 2-1 is an example of how arrangement plays a role in the characterization process

Some bacteria have the capability to convert to highly resistant forms called spores This form is an essentially dormant one that can be reactivated when the proper nutritional environment is provided Bacterial organisms that have been considered biological warfare agents are

1 *Bacillus anthracis* (anthrax)
2 *Yersinia pestis* (plague)
3 *Francisella tularensis* (tularemia)

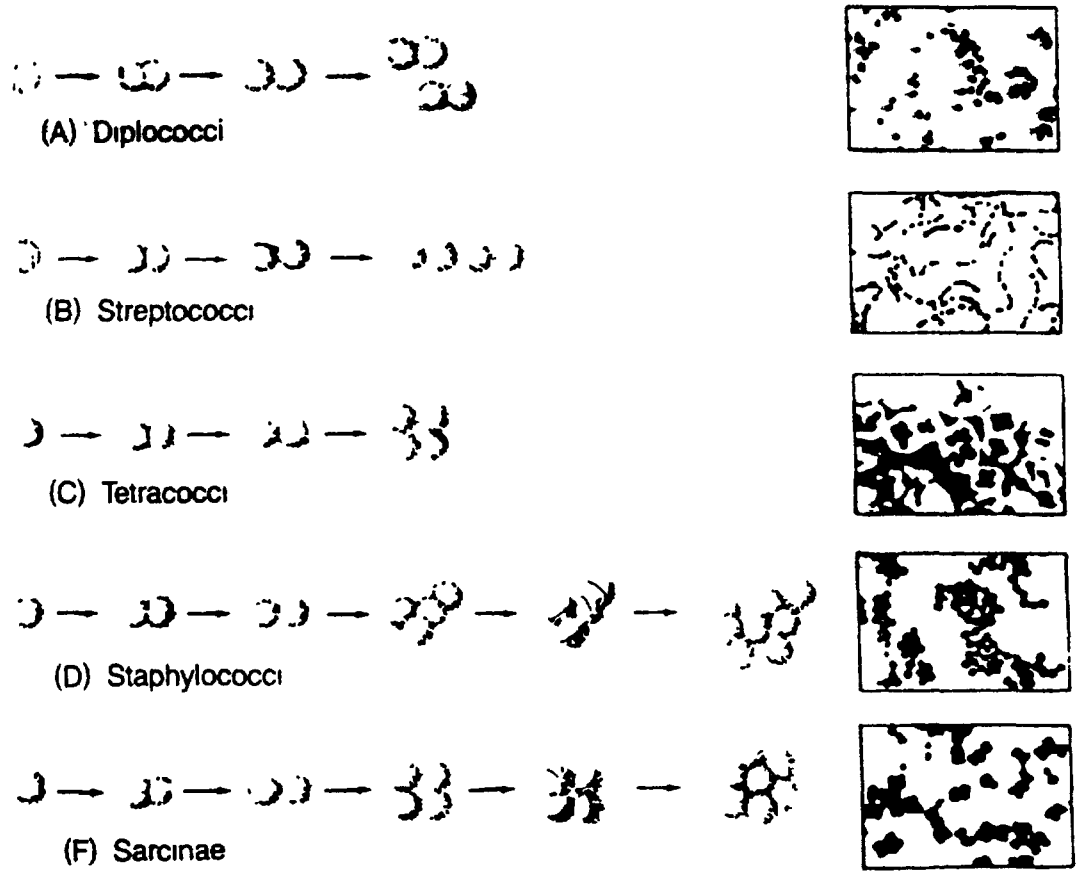


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Figure 2-1. Anatomy of Bacteria (Ref. 6)

2-2.2.2 Viruses

Viruses constitute a large group of infectious organisms Unlike bacteria, viruses depend on the enzymatic components of the infected cell for their existence They are parasitic Although early investigators concluded that viruses were not living matter, later they were found to contain ribonucleic acid, which is considered living matter Some larger viruses also contain the material of genes They appear to function by taking over the chemistry of the host cell in their own interests The average virus is only about 1/1000 the size of the average bacterium

Viruses that have been considered biological warfare agents are

1 Group A Arboviruses, e g , Chikungunya fever, dengue fever

2 Group B Arboviruses, e g , yellow fever

2-2.2.3 Rickettsia

Rickettsia, like the viruses, are in a class called sorbacteria Their size is between that of bacteria and viruses and, like the latter, they are parasitic The rickettsia, however, are parasitic to animals such as ticks and lice These insects are carriers and spread the disease

Pathogenic organisms that produce well-known diseases and are also potential biological warfare agents are

1 *Rickettsia rickettsii* (Rocky Mountain spotted fever)

2 *Rickettsia prowazeki* (typhus)

3 *Coxiella burnetii* (Q-fever)

Rocky Mountain spotted fever is spread by ticks and typhus is spread by lice

2-2.2.4 Toxins

US Army FM 27-10, *The Law of Land Warfare*, dated 18 July 1956, specifically states, that " United States considers bacteriological warfare (BW) to include not only biological weapons but also toxins all toxins, however, regardless of the manner of production, are regarded by the United States as bacteriological methods of warfare "(Ref 7) This statement places broad limits on the definition of toxins and includes synthetically produced materials

Toxins are produced by a large number of living organisms from bacteria and fungi to algae, frogs, and other animals Chemically, toxins are proteins and alkaloids Known toxins are either cytotoxins or neurotoxins Cytotoxins cause cell destruction both internally and

percutaneously Like nerve agents, the neurotoxins interfere with the function of the nervous system

Table 2-13 summarizes information on toxins whose properties have been investigated. Developments in biotechnology methods, however, could change the character of toxins Considerable efforts have been devoted to producing botulinum toxin, staphylococcal enterotoxin, and saxitoxin (derived from algae concentrated in shellfish)

2-3 AGENT DISSEMINATION

Agent dissemination methods are mainly dependent on the normal physical form (liquid, aerosol, or vapor) of the agent under varying atmospheric conditions The goal is to distribute the material effectively over the chosen target to achieve a 50% probability of severe incapacitation to troops over 50% of the target area before protective action can be taken These requirements generally define the dissemination technique A less vigorous technique than a high-explosive system may be appropriate to avoid destruction of the agent For example, if the agent is a vapor, under normal conditions the dissemination method should create an instantaneous concentration and have a high probability of achieving the desired physiological response

During approximately the first 30 s after dissemination, the size and travel of an agent are determined primarily by the functioning characteristics of the munition or delivery system When dispersed as chemical agent vapor or an aerosol, the agent forms an agent cloud Thereafter, the travel and diffusion of the agent cloud are determined primarily by weather and terrain (Ref 8)

Terrain contours influence the flow of chemical clouds as they influence airflow Chemical clouds tend to flow over low rolling terrain and down valleys and to settle in hollows and depressions and on low ground Local winds coming down valleys at night or up valleys during the day may deflect the cloud or reverse its flow On the other hand, the terrain may produce conditions favorable for chemical cloud travel when general area forecasts predict calm conditions

A chemical cloud released in a narrow valley and

TABLE 2-13. INVESTIGATED TOXINS (Ref. 5)

TYPE	MORTALITY, %	ONSET PERIOD, h	SYMPTOMS
Botulinus toxin formed from *Clostridium botulinum*	75	12-36	Most common symptoms are ocular diplopia, blurred vision, and photophobia Other symptoms include constipation, urine retention, and reduced salivation and lacrimation
Mycotoxins (tricothecene type)	ND*	ND*	Effects vary considerably In general, trichothecenses act as hepatotoxins, nephrotoxins, dermatoxins, alimentary toxins, and neurotoxins
Saxitoxin (shellfish toxin)	ND*	0 25-4	Tingling numbness in the facial area with muscular weakness and prickly feelings in the fingertips followed by increasing lack of muscular coordination, paralysis, and respiratory failure
Tetrodotoxin	ND*	0 25-0 75	Nausea, vomiting, diarrhea, and epigastric pains, tingling and prickling in the extremities, dizziness, pallor, and malaise followed by muscular paralysis, tremor, and coma
Ricin (castor bean)	ND*	6-10	Nausea, vomiting, bloody diarrhea, abdominal cramps, tenesmus, drowsiness, stupor, cyanosis, and dehydration followed by anuria that can provoke death by uremia

*ND = No data

subjected to a mountain breeze retains a high concentration of agent as it flows down the valley because of the minimal lateral spread. Hence high dosages are obtained in narrow valleys or depressions High dosages are difficult to obtain, however, on crests or on the sides of ridges or hills Also, after a heavy rain, the formation of local mountain or valley winds is sharply reduced In areas of adjacent land and water, daytime breezes from the water and nighttime breezes from the land control chemical cloud travel

Agent clouds tend to go around obstacles such as trees and buildings Rough ground, including ground covered with tall grass or brush, retards the movement of clouds, whereas flat country promotes an even, steady movement

Transport, or the travel, of chemical agents depends on the physical form that results from the dissemination process Vapors and aerosols less than 10 μm in diameter behave in similar manners under the control of atmospheric forces (primarily wind speed and atmospheric stability) The transport of intermediate-sized droplets, 10 to 100 μm, is controlled by gravitational forces as well as by atmospheric forces Gravitational forces have a more dominant role for larger particles (>100 μm) Atmospheric stability influences droplet transport indirectly, i e , the wind field structure is related to the atmospheric stability

Liquid agent transport is complicated by the fact that liquid agents are volatile and go through a phase change from liquid to vapor during transport. Therefore, predicting the transport of disseminated agent requires consideration of all three potential forms, vapor and aerosol within the smaller droplet size range, intermediate-sized droplets, and large droplets

To be effective, solid agents must be disseminated as aerosols with particle sizes of predominantly less than 10 μm This size requirement arises from two factors (1) The particles must be in this size range to be inhaled and produce casualty effects, and (2) they must also be in this size range to maximize the area covered by the agent

A major factor that influences agent dissemination is the weapon system used to employ the agent and the mode of agent release Almost all conventional weapon systems, from mortars to long-range tactical missiles, can have compatible chemical ammunition or warheads and are available to land, air, and naval forces Military forces have specific fire-planning requirements for chemical weapons that calculate the rate and density of fire depending on target size and location Typical delivery and dissemination systems are

1 Missiles
2 Artillery
3 Mines
4 Multiple rail- and tube-launched rockets
5 Fighter-bombers and attack helicopters with aerial bombs, rockets, and spray tanks

In general, threat doctrine calls for delivering nonpersistent agents, such as GB, by artillery shells or rockets against frontline combat and combat support troops for immediate casualty effects The doctrine requires delivering a persistent V-agent or low-volatility G-agent, such as thickened GD, against rear area targets, such as fixed site or terrain denial situations, by missile warheads, bombs, or rockets Typical targets for chemical weapons are

1 Nuclear delivery systems
2 Airfields
3 Naval bases and seaports
4 Command, control, and communications facilities
5 Storage depots
6 Supply routes
7 Troop concentrations
8 Artillery and armor
9 Amphibious and helicopter landing zones

Data on the field behavior of chemical agents are critical inputs to the development process for detection, warning, and identification equipment Until 1967 an extensive testing effort existed in which the use of weapon systems filled with a chemical agent supported the development efforts Since then, however, outdoor functional tests have been conducted with agent simulants. These simulants have been selected to match the actual agents in both physical and chemical properties.

Mathematical modeling of agent transport in the environment assists system development and testing The modeling efforts are highly dependent on the data derived from testing This testing forms the basis for the development of empirically derived models to validate those based on theoretical considerations Modeling plays an increasingly important role in the development process The physical processes that govern the behavior of agents in the environment, however, are complex Existing models incorporate scientific assumptions to deal with these complexities

The theoretically based models usually depict the distribution of the agent in air in terms of a three-dimensional Gaussian function This assumption is not verified by test data, however, the data do indicate that the total dosage prediction (integration of Eq 2-1 over the full duration of cloud passage) gives acceptable agreement The partial dosage case of the first 15 to 30 s after cloud formation or arrival is covered by the models, but the confidence that can be placed in these results has been questioned (Ref 9) Recent developments in test technology are expected to provide the capability for real-time monitoring of agent concentration using light detection and ranging (LIDAR) systems These systems should help to fill two requirements (1) to provide an assessment of current models and (2) to provide the data necessary to develop new and improved models

2-3.1 CHEMICAL AGENTS

2-3.1.1 Liquid

Systems for disseminating liquid agent are designed to provide maximum coverage of the target to the desired contamination density (usually expressed in units of milligrams per square meter) To obtain the best coverage the munition should function over the target Three concepts of munition function are

1 Explosive burster
2 Spray tank
3 Aerodynamic breakup of bulk quantities

Conventional munitions, which usually incorporate a central explosive burster, use somewhat lower agent-to-burster ratios than those used for agents for which the goal is vaporization Aerial spray tanks are effective when used at low altitudes These systems use the forward motion of the aircraft (ram air) and compressed gases to eject the agent through nozzles

Coverage of large areas is achieved by a simple dissemination technique using aerodynamic breakup to disperse large masses of agent suddenly exposed by stripping a thin metal shell from a missile warhead Unless the viscosity of the agent (resistance to shear) is changed, however, the resulting particle size is too small and inadequate contamination densities are obtained Usually the wind carries the small particles off the selected target area The large droplet sizes needed for effective dissemination and transport require a viscosity change, which is achieved by thickening the agent with appropriate polymers Agents of both low and moderate volatility can be disseminated using this concept Particle sizes with mass median diameters in the range of 2500 μm are typical for these systems

Table 2-14 summarizes particle size data for a variety of dissemination systems There is a wide range of sizes produced by each system, but the mass median diameter (MMD) is smaller in each case for neat (unthickened) agents Tables 2-15 and 2-16 show the relationship between droplet size and contamination density that results from dissemination and transport of thickened and unthickened agent-filled munitions Liquid agents change from liquid to vapor after dissemination During the dissemination process, both liquid and vapor hazards are present in the contaminated area Persistence is a term used to define the period of time during which all hazards exist after dissemination Vapors are transported and subsequently dissipate to nonhazardous levels in relatively short times (usually less than 30 min), thus persistence is normally associated with the liquid phase

TABLE 2-14. DROP SIZE DISTRIBUTIONS FOR LIQUID CHEMICAL AGENTS (Ref. 2)

DROP SIZE	EXPLOSIVE BOMBLETS	EXPLOSIVE ARTILLERY		EXPLOSIVE BOMBS		BULK RELEASE MISSILES	SPRAY TANKS
	NEAT AGENT	NEAT AGENT	THICKENED AGENT	NEAT AGENT	THICKENED AGENT	THICKENED AGENT	NEAT AGENT
Diameter range μm	20-500	40-1000	500-5000	60-1500	500-5000	500-5000	60-1500
Mass median diameter μm	100	200	2500	300-500	2500	2500	200

TABLE 2-15. DISTRIBUTION OF DROP SIZE AND CONTAMINATION DENSITY COMBINATIONS FOR THICKENED AGENTS (Ref. 2)

AGENT	DROP SIZE, mm	CONTAMINATION DENSITY, mg/m^2			
		1-100	100-1000	1000-5000	5000-10,000
		FRACTION OF COVERAGE AREA			
TGD (thickened GD)	0 1-0 5	0 21	0	0	0
	0 5-1 0	0 35	0 10	0	0
	1 0-5 0	0 10	0 15	0 03	0
	>5 0	0 03	0 02	0 01	0
THD (thickened HD)	0 1-0 5	0 22	0 08	0	0
	0 5-1 0	0 06	0 22	0 12	0 01
	1 0-5 0	0 03	0 06	0 13	0 02
	>5 0	0 01	0 02	0 02	0

TABLE 2-16. DISTRIBUTION OF DROP SIZE AND CONTAMINATION DENSITY COMBINATIONS FOR UNTHICKENED AGENTS (Ref. 2)

DROP SIZE, mm	CONTAMINATION DENSITY, mg/m^2					
	1-10	10-100	100-500	500-1000	1000-5000	5000-10,000
	FRACTION OF COVERAGE AREA					
0 04-0 06	0 23	0 20	0	0	0	0
0 06-0 11	0 13	0 16	0 04	0 01	0	0
0 11-0 20	0 03	0 04	0 04	0 03	0.02	0
0 20-0 37	0.01	0 01	0 01	0 01	0 01	0 02

Thickened agents are more persistent because of their increased particle size The contaminated area produced presents an active source of vapor both on target and downwind for extended periods Table 2-17 summarizes the effects of thickening materials on the physical properties of agents Thickened agents and the more persistent liquid agents create areas that are a source of potential transfer of contamination to individuals crossing or occupying the areas and a source of vapor downwind of the contaminated terrain The characterization of the concentration dosage field from an evaporating source is complex This complexity is primarily due to the importance of time and the requirement to monitor the vapors over periods extending from many hours to days Conversely, nonpersistent agent clouds that pass a point in a few minutes (normally not more than 20 min) require only a minimal consideration of time to determine their hazard

Table 2-18, generated by use of Ref 9, summarizes the evaporation process for a large area contaminated with thickened GD (TGD) These data were developed by computer simulation using

TABLE 2-17. EFFECT OF THICKENING ON AGENT PROPERTIES* (Ref. 9)

	NEGLIGIBLE	SIGNIFICANT
Density	X	
Boiling point	X	
Freezing point	X	
Vapor pressure	X	
Volatility	X	
Surface tension	No data	
Viscosity		X**
Evaporation		X**

*Most agent properties are virtually unchanged by thickening because only a small percentage of thickening agent is required to achieve the desired result As evaporation proceeds and the fraction of thickener increases, however, this characterization changes

**Increased viscosity influences the aerodynamic breakup properties of the agent and results in a substantial increase in mass median diameter (MMD) For a given mass of agent, the deposited area for the larger drops presents a proportionally smaller surface for evaporation

TABLE 2-18. THICKENED GD DOWNWIND DOSAGE AS A FUNCTION OF TIME

DOWNWIND DISTANCE, km	DOSAGE, mg·min/m³															
	Time, h	0 28	0 56	1 12	1 39	1 67	1 94	2 24	2 50	2 78	3 33	4 17	4 86	5 56	6 25	6 94	MAX*
0 00		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
0 10		13 0	20 0	39 0	45 0	49 0	53 0	56 0	59 0	62 0	66 0	71 0	74 0	76 0	78 0	79 0	90 0
0 20		18 0	33 0	54 0	62 0	68 0	74 0	78 0	82 0	86 0	92 0	98 0	102 0	106 0	108 0	110 0	125 0
0 25		20 0	46 0	59 0	68 0	75 0	81 0	86 0	90 0	94 0	100 0	107 0	112 0	115 0	118 0	120 0	137 0
0 30		21 0	39 0	64 0	72 0	80 0	86 0	92 0	96 0	100 0	107 0	115 0	120 0	123 0	126 0	129 0	146 0
0 35		23 0	41 0	67 0	76 0	84 0	91 0	97 0	102 0	106 0	113 0	121 0	126 0	130 0	133 0	136 0	154 0
0 45		25 0	45 0	73 0	83 0	92 0	99 0	105 0	110 0	115 0	123 0	131 0	137 0	141 0	145 0	148 0	164 0
0 55		26 0	47 0	77 0	88 0	97 0	105 0	112 0	117 0	122 0	130 0	140 0	146 0	150 0	154 0	157 0	178 0
0 65		27 0	50 0	81 0	93 0	102 0	110 0	117 0	123 0	128 0	137 0	147 0	153 0	158 0	161 0	165 0	187 0
0 75		28 0	52 0	84 0	96 0	106 0	115 0	122 0	128 0	133 0	142 0	152 0	159 0	164 0	168 0	171 0	194 0
0 85		29 0	53 5	87 0	99 7	110 0	119 0	126 0	132 0	138 0	147 0	158 0	164 0	169 0	175 0	177 0	201 0
0 88		30 0	54 0	88 0	100 4	111 0	119 0	127 0	133 0	139 0	148 0	159 0	165 0	170 0	174 0	178 0	202 0
0 90		27 0	46 0	75 0	86 0	95 0	102 0	109 0	114 0	119 0	127 0	136 0	142 0	146 0	150 0	153 0	173 0
0 95		19 0	34 0	56 0	65 0	71 0	77 0	82 0	86 0	90 0	96 0	102 0	107 0	110 0	113 0	115 0	131 0
1 00		15 0	28 0	47 0	54 0	59 0	64 0	68 0	71 0	74 0	79 0	85 0	89 0	92 0	94 0	96 0	108 0
1 10		11 0	21 0	36 0	41 0	45 0	49 0	52 0	55 0	57 0	61 0	65 0	68 0	70 0	72 0	74 0	84 0
1 25		8 0	16 0	27 0	31 0	34 0	37 0	40 0	42 0	43 0	46 0	50 0	52 0	54 0	55 0	56 0	64 0
1 50		5 1	11 0	19 0	22 0	25 0	27 0	28 0	30 0	31 0	34 0	36 0	38 0	39 0	40 0	41 0	46 0
2 00		2 4	6 5	12 0	14 0	16 0	17 0	18 0	19 0	20 0	22 0	23 0	24 0	25 0	26 0	27 0	30 0
2 50		1 1	4 2	8 6	10 0	11 5	12 0	13 0	14 0	15 0	16 0	17 0	18 0	19 0	20 0	21 0	22 0
3 00		0 3	2 9	6 5	7 9	8 9	10 0	11 0	11 2	12 0	13 0	14 0	14 0	15 0	15 0	16 0	18 0
3 50		0 0	2 0	5 2	6 3	7 2	8 0	8 6	9 2	9 6	10 0	11 0	12 0	12 0	12 6	13 0	15.0
4 00		0 0	1 3	4 2	6 2	6 4	6 6	7 2	7 7	8 8	9 1	9 5	10 0	10 0	10 6	11 0	12 0
4 50		0 0	0 8	3 4	4 3	5 0	5 6	6 2	6 6	7 0	7 6	8 2	8 6	8 9	9 2	9 4	11.0
5 00		0 0	0 4	2 8	3 6	4 3	4 9	5 3	5 7	6 1	6 6	7 2	7 5	7 8	8 1	8 3	9 5
5 50		0 0	0 1	2 3	3 1	3 7	4 2	4 7	5 0	5 3	5 8	6 4	6 7	7 0	7 2	7 4	8 4
6 00		0 0	0 0	1 9	2 7	3 2	3 7	4 1	4 5	4 7	5 2	5 7	6 0	6 2	6 4	6 6	7 6
6 50		0 0	0 0	0 0	0 0	2 8	3 3	3 5	4 0	4 2	4 6	5 1	5 4	5 6	5 8	6 0	6 9

*MAX = Time required for all liquid to evaporate and the resulting vapor to be transported a specific downwind distance

1 Target size 1000 × 875 m
2. Wind speed. 2.235 m/s
3. Temperatures 1.6, 8.3, and 22 7°C
4 Contamination density. 1 g/m^2
5 Mass median diameter 2500 μm

The simulation, generated by the Surface Evaporation (SUREVAP) Model, provides a history of the vertical profile of the axial dosage and concentration at selected times and downwind points The lateral "picture" of the cloud is not shown For large areas, this lateral variation may not be too severe since the crosswind change in concentration and dosage may not differ too greatly from the axial values until the edges of the cloud are approached The concentration and dosage predictions are computed at a height of 1 5 m and at a distance of 1500 m from the downwind edge of the contaminated area Table 2-18 shows that the total evaporation time at lower temperatures is long and the bulk of the contamination has evaporated in a small fraction of the total evaporation time

2-3.1.2 Gases

Chemical warfare agent compounds that can be classified as or behave as gases are

1 Liquids with high vapor pressure that are gases under usual temperature conditions

2 Liquids with moderate vapor pressure that become predominantly vapor when disseminated.

The first of these categories includes compounds such as AC and CG The boiling points of these compounds (25 7°C for AC and 7 6°C for CG) are below or close to normal atmospheric temperature (Ref 1) Consequently, when exposed to the environment, they spontaneously vaporize This process is expedited by the standard dissemination systems used for these agents

The second category contains compounds that remain liquid at normal atmospheric temperatures These compounds have boiling points well above the boiling point of water For example, the nerve agent, GB, has a boiling point of 158°C The dissemination technique is designed to maximize vaporization These compounds are classed as nonpersistent agents The categories "persistent" and "nonpersistent" are clearly not exclusive and do not infer restrictive modes of behavior. Current modeling goals are to incorporate sufficient flexibility to accommodate all compounds and thereby also accommodate the problems that arise in classifying compounds that change from one physical state to another at normal atmospheric temperatures Transitional compounds include nearly all important agents Nonpersistent agents are generally disseminated by high-explosive means including artillery systems, multiple launch rocket systems (MLRS), bombs, and missiles with multiple bomblet warheads

The atmospheric transport theory and modeling is more completely developed for nonpersistent agents than it is for persistent liquid agents Major testing programs, which continued until 1970, provided important support to theory and model development The test data on this class of agents were largely responsible for the development of a segment of the atmospheric transport model used today

The applicable mathematical models are based on the atmospheric diffusion theory originated by Sutton and furthered by Calder (Ref 10) This theoretical structure extends to cover chemical agent gases and considers such factors as size, location of the dissemination source, and those specific aspects relative to exposure The model considers an amount of gas Q instantaneously released into the atmosphere at a time, $t = 0$, by a point source at the origin of a fixed coordinate system The x,y,z coordinates are downwind, across wind, and upward, respectively Two *a priori* assumptions are involved (1) that the same mean concentration in the cloud is distributed normally, i e , Gaussian, in each of the three directions and (2) that the standard deviation* of the distribution of mass in each of these directions is defined by a simple power law function of the distance traveled A statement of the model is

$$X(x,y,z,t) = \frac{Q}{\sqrt{2\pi}\sigma_x(t)} \exp\left[-\frac{(x-\bar{u}t)^2}{2\sigma_x^2(t)}\right] \times \frac{1}{\sqrt{2\pi}\sigma_y(t)} \exp\left[-\frac{y^2}{2\sigma_y^2(t)}\right] \times \frac{1}{\sqrt{2\pi}\sigma_z(t)} \exp\left[-\frac{z^2}{2\sigma_z^2(t)}\right], \quad \text{mg/m}^3 \qquad (2\text{-}5)$$

where

x = downwind coordinate, m
y = across wind coordinate, m
z = upward coordinate, m
$\bar{u}$ = mean transport wind speed, m/min
t = time, min
X = mean concentration of gas function in the atmosphere at time t, mg/m^3
Q = the initial amount of gas to be disseminated, mg
σ_x = standard deviation of the longitudinal (downwind) concentration distribution, m
σ_y = standard deviation of the lateral (across wind) concentration distribution, m
σ_z = standard deviation of the vertical (upward) concentration distribution, m

*The use of the term "standard deviation" is analogous to its use in statistics and characterizes the variation, i e , distribution of mass, of agent in the cloud

The concentration expression can be integrated to give the following equation for dosage

$$D(x,y,z) = \int_0^{\infty} \frac{Q}{\sqrt{2}\pi^{3/2}\sigma_x(t)\sigma_y(t)\sigma_z(t)} \times \exp\left\{-\frac{1}{2}\left[\frac{(x-\bar{u}t)^2}{\sigma_x^2(t)} + \frac{y^2}{\sigma_y^2(t)} + \frac{z^2}{\sigma_z^2(t)}\right]\right\} dt, \text{ mg·min/m}^3 \quad (2\text{-}6)$$

where

$D(x,y,z)$ = total dosage field from a point source, mg·min/m^3

The σ's are assumed to be constants at any distance x in the downwind progress of the cloud Eq 2-6 shows the integration over limits that encompass the time for complete cloud passage This relationship is defined as "total dosage" Of more significance to the problems of detection and warning is the dosage at times intermediate to total dosage, i e , the concept of "partial dosage" Partial dosage ensures that the detector senses the presence of an agent cloud promptly and prevents harmful exposure Thus the capability to compute dosages (exposures) for these intermediate times is necessary The partial dosage expression is

$$D(x,y,z,t) = \frac{Q}{2\pi\sigma_y(x)\sigma_z(x)\bar{u}} \times \exp\left\{-\left[\frac{y^2}{2\sigma_y^2(x)} + \frac{z^2}{2\sigma_z^2(x)}\right]\right\} \times \left\{1 - \text{erf}\left[\frac{x-\bar{u}t}{\sqrt{2}\sigma_x(x)}\right]\right\}, \text{ mg·min/m}^3 \quad (2\text{-}7)$$

where

$D(x,y,z,t)$ = partial dosage function from a point source mg min/m^3

As noted earlier, the σ's are defined by simple power law functions The term "erf" designates error functions, which are tabulated in standard compilations of mathematical functions Because inhalation is the primary route of entry for agents in this form and time of action is most rapid for this mode of action, it is particularly critical to be able to characterize the process reliably The results of the application of the models characterize exposure in terms of time and level (Ref 10)

2-3.1.3 Aerosols

Aerosols are defined as finely divided liquid or solid particles suspended in a gaseous medium The particle size is not rigidly defined, but it is considered to be where the atmospheric transport behavior of an aerosol cloud is dominated by turbulent forces and consequently approaches that of a gas or vapor Only a small fraction of the agent disseminated from standard explosive munitions is in the aerosol size range Consequently, agent aerosols cannot be effectively disseminated using the same munitions that disseminate agents in liquid form Munitions for solid agent dissemination include spray tanks and aerosol generators incorporated into other munitions such as bombs

In past years efforts have been made to exploit methods that produce small particles (10 to 100 μm) of chemical agents because the combination of vapor and aerosol produced an enhanced toxicity effect This effect was later found to be unsupportable and munitions development in this area was terminated Biological agent dissemination, however, is designed to maximize the yield of small particles The goal is to achieve a high level of inhalation capability

Data to describe the sampling process that occurs as a result of both nasal and mouth breathing have been derived from experiments in which a head form or a complete mannequin was exposed to aerosols in a wind tunnel Breathing was simulated by sinusoidal flow, and isokinetic sampling was employed to determine the quantity of the test aerosol inhaled

The data derived from these investigations are shown in Figs 2-2 and 2-3 The sampling efficiency of mouth and nasal breathing is similar, although a somewhat smoother decline in sampling efficiency versus aerodynamic diameter for mouth breathing seems to be apparent

The fate of aerosol particles that enter the respiratory tract is shown in Fig 2-4 These results are derived from theoretical considerations of the behavior of particles in an airstream as it passes through tubes sized to simulate the respiratory system The processes of impaction, sedimentation, and diffusion were considered in these computations

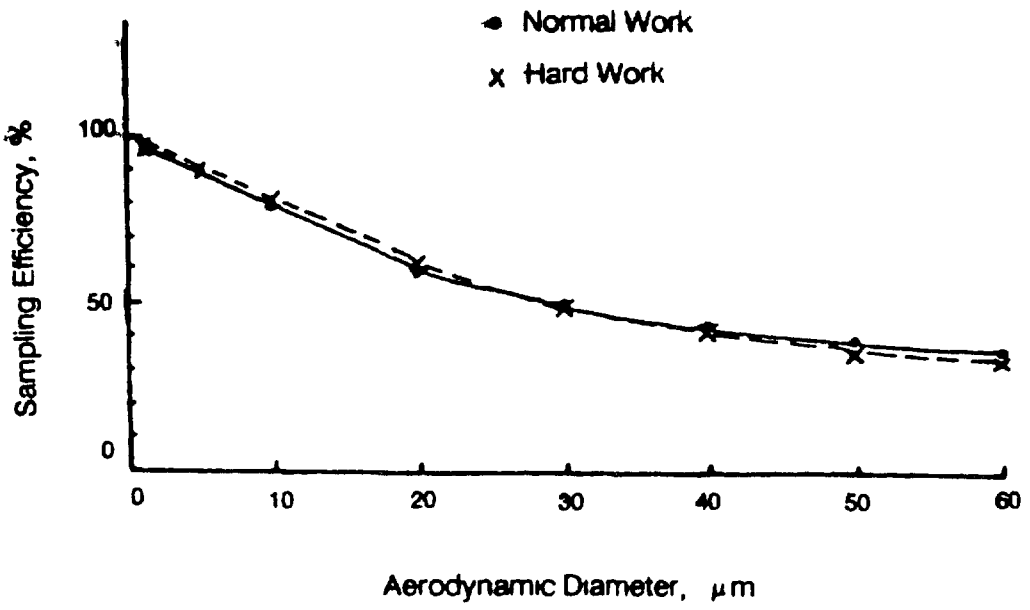


Figure 2-2. Average Sampling Efficiency for Mouth Breathing (Ref. 11)

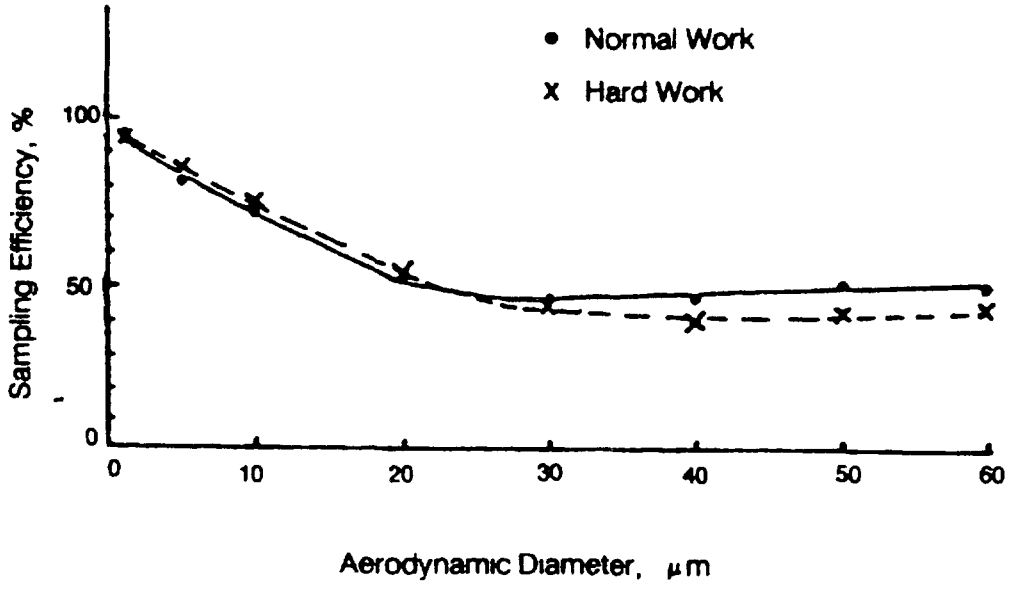
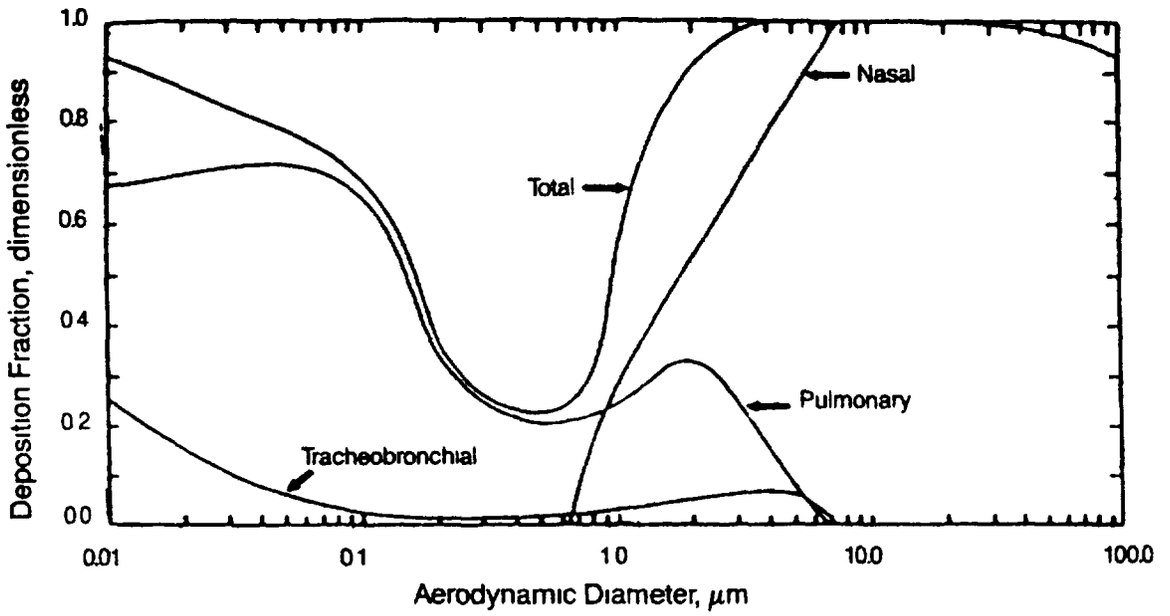


Figure 2-3. Average Sampling Efficiency for Nasal Breathing (Ref. 11)



Note This figure assumes a respiratory rate of 15 L/min, with a tidal volume (TV) of 1450 cm^3 and 15 respirations per minute

Figure 2-4. Deposition Fraction for Inhaled Aerosols of Various Particle Sizes (Ref. 11)

2-3.2 BIOLOGICAL AGENT DISSEMINATION

There are no verified instances of the use of biological agents in recent history Biological agents, however, could be produced, stockpiled, and disseminated without being immediately detected Poor sanitary conditions during wartime compound biological warfare (BW) detection problems (Ref 12)

Threat dissemination of biological agents could be accomplished by aircraft spray, aerosol bombs and generators missiles infected animals, vials, capsules, or hand dispensers The selection of a biological agent depends on the target nature of the operation climate, and weather Biological agents may be released on theater reserve forces marshalling areas supply depots and deep rear area installations to impede the support of frontline troops

There is no conclusive evidence of nations maintaining an in-being capability to employ BW weapons either in a strategic or theater role Many potential U.S adversaries have conducted research and development (R&D) programs in this field in the past, and there is some indication that such R&D is continuing despite treaties to the contrary The United States has forsworn the use of biological weapons, and national policy is to maintain only defensive capabilities (Ref 13)

Despite these considerations that suggest a low likelihood of employment of biological weapons, the known past research and existing development base and our national policy to maintain defenses mean that the possibility of biological warfare must be taken seriously Consequently and because of a relative lack of BW experience, the biological threat must be approached as a description of possibilities, largely based on consideration of past R&D efforts Furthermore, the distinction made by the former Soviet Union that toxins are "chemical agents" increases the threat of their use in tactical situations (Ref 13)

Biological agents disseminated in aerosol, liquid, or solid form can enter the body through inhalation, lesions on the skin, and by ingestion Ingestion threats can be accomplished by saboteurs' contaminating food or water supplies Inhalation threats are produced by generating fine aerosols, which can be inhaled These aerosols can be produced either with dry powder forms of the agent or slurries of the agent in some liquid Regardless of their form agent particles or drops with diameters in the 1- to 5-μm size are considered the most effective for dissemination of biological agents for inhalation effect

Biological agents that are living organisms do not survive well in the natural, open environment Exposure to the ultraviolet rays of the sun and low relative humidity rapidly kills these microorganisms after dissemination If, however, live, infectious microorganisms enter the body and the agent victim is not properly treated, the microorganism will multiply and incapacitate the victim The disease may spread to the entire population in a large area and cause an epidemic if countermeasures, such as isolation, immunization, personal hygiene, and area sanitation, are not enforced (Ref 13)

Some biological agents can be disseminated by arthropod vectors, such as fleas mosquitoes, and ticks Some agents can be used to contaminate food and water

supplies The main threat from biological agents, however, is the direct application of aerosols on rear area targets Aerosols can be applied to contaminate surfaces either as a primary threat or as a by-product of direct antipersonnel action (Ref 12)

Bacterial and fungal spores are very persistent in virtually all environments, they may survive for years in a harsh environment without nutrients and water When conditions become favorable, spores can transform into vegetative cells to produce casualties in the area long after the original contamination (Ref 12)

Toxins are generally solids Although some toxins are percutaneously active, inhalation and ingestion are the principal routes of entry for many toxins The methods of dissemination depend upon the route of entry being attacked The percutaneously active toxins could be disseminated in a way manner similar to that used for persistent chemical agents To obtain an inhalation effect, the toxins could be disseminated similarly to solid chemical agents and microorganisms Toxicity data on toxins are scarce, and little or no data exist on inhalation or percutaneous toxicity (Ref 2) Some toxins are known to be highly toxic, rapid acting, and difficult to detect, therefore, they may be used for tactical operations similar to those for which toxic chemical munitions are used to take advantage of these agent characteristics Data on toxins are changing rapidly due to ongoing research programs

Because of their delayed effects, most threat microorganisms in a theater or strategic role have generally been used for targets deep in the theater or along the borders of the country being attacked Thus the most likely delivery systems are large rockets, missiles, bombs, manned and remotely piloted aircraft with spray tanks, submarines, and surface vessels

Spraying-, bursting-, and dispensing-type munitions can be used to disseminate BW agent aerosols Spraying from a low-flying, fast-moving aircraft will generate an initially quasi-linear aerosol cloud, whereas a bursting munition will produce a more localized cloud Dispensers can also create either linear or point sources of contamination In all cases drift and diffusion spread the aerosol cloud over a large area Local micrometeorology, however, can easily affect drift and diffusion processes Wind speed and direction, air stability, and temperature gradient also affect agent dispersion and area coverage The actual distribution and density of agent material can vary greatly from place to place, therefore, any CB detector and alarm system must be built to recognize and take into account this probability

Because of the wide area over which microorganisms can be dispersed, biological agent detectors should be scattered throughout the rear areas of the battlefield to warn the most likely targeted personnel of the presence of disease-producing organisms The number of these detectors per troop unit will probably be low Toxins present a hazard similar to that presented by chemical agents to troops in the forward areas of the battlefield The placement and number of toxin detectors should be similar to those of chemical agent detectors

REFERENCES

1 FM 3-9, *Military Chemistry and Chemical Compounds*, Department of the Army, 30 October 1975

2 *Reconnaissance, Detection, and Identification (RDI) Master Plan (MP)*(U), CRDC-CR-85032, US Army Chemical School and US Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, 19 April 1985, (THIS DOCUMENT IS CLASSIFIED SECRET)

3 *PARACOMPT, Parametric Analysis of Respiratory Agents Considering Operations, Motivation, Protection and Time*, US Army Chemical Research and Development Laboratories and US Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, January 1963

4 D Vanderbilt, *Development of an Improved Liquid Agent Detector*, CRDC-CR-84033, US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, March 1985

5 G G Outterson, R J Norstrom, and R E Wyant, *Summary Study of Detection and Warning*, by Battelle Columbus Laboratories for US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, April 1981

6. M J Pelczar and R D Reid, *Microbiology*, McGraw-Hill Book Co., Inc., New York, NY, 1972

7 FM 27-10, *The Law of Land Warfare*, Department of the Army, 18 July 1956

8 FM 3-6, *Field Behavior of NBC Agents*, Department of the Army, 3 November 1986

9 R Saucier, *NUSSE3 Model Description* CRDEC-TR-87046, US Army Chemical Research Development and Engineering Center, Aberdeen Proving Ground, MD, May 1987

10 G H Milly, *Atmospheric Diffusion and Generalized Munitions Expenditures*, ORG Study NR 17, US Army Chemical Corps, Operations Research Group, US Army Chemical Center, MD, May 1958

11 K S K Chinn, *Toxic Chemicals in the Soil Environment Vol 3 Evaluation of Potential Inhalation Hazards From Suspension of CW-Agent-Contaminated Soil During Dust Storms*, DPG/TA-85/02C, Dugway Proving Ground, UT, March 1986

12 TM 3-216, *Technical Aspects of Biological Defense* Department of the Army, 12 January 1971

13 Defense Intelligence Agency, *Soviet Chemical Weapons Threat*, DST-1620F-051-85, Directorate for Scientific and Technical Intelligence, Washington, DC, 1985

CHAPTER 3
OPERATIONAL SITUATIONS AND DETECTOR REQUIREMENTS

This chapter describes the operational situations the Army will face on the battlefield, how these situations will influence the enemy's selection and use of chemical and biological (CB) agents, and how the situations and environment will affect requirements for CB detection and monitoring systems. Par 3-1 explains how target mobility, location, operational mission, response, and CB defense posture will influence enemy use of CB warfare and how these potential threats and operational situations will influence the design of CB detection and monitoring systems Par. 3-2 describes four functional groupings of battlefield units, their operational missions and capability to operate in a CB environment, as well as the rationale for this approach in the context of detector design requirements and performance criteria.

3-1 INTRODUCTION

Enemy use of CB agents and their associated delivery systems depends on numerous operational factors These factors include the mobility of the target, target location operational mission, probable protection level required for personnel, and urgency of target response, i e , onset of symptoms and contamination All of these significantly impact agent and delivery system selection If enemy forces employ CB agents on the battlefield, the combination of various operational situations with known threat agents and delivery systems yields a vast variety of potential CB hazard situations Detectors must be developed that will meet the entire spectrum of challenges

The target characteristics of mobility, location, and operational mission are largely interdependent Targets located closest to the forward line of own troops (FLOT) tend to be very mobile and usually are fulfilling combat and combat support missions Farther behind the FLOT however, units are spread out and the targets tend to be less mobile and usually fulfill combat service support missions Due to the diversity of unit sizes and missions in this region, the enemy will employ a variety of longer range weapons depending on the objective and targeting success

In a CB environment the standard United States (US) combat uniform is the chemical overgarment with protective gloves, mask, hood, and overboots Based on the immediate CB threat, unit commanders determine what level of mission-oriented protective posture (MOPP) must be assumed by their troops (Ref 1) As shown in Fig 3-1 the five MOPP levels are

1 MOPP Zero The soldier carries a CB mask with hood Gloves protective overgarment and overboots are readily available

2 MOPP1 The soldier wears the overgarment open or closed and carries overboots, mask with hood and gloves

3 MOPP2 The soldier wears the overgarment open or closed, wears the overboots, and carries the mask with hood and the gloves

4 MOPP3 The soldier wears the overgarment the overboots, mask with hood, and carries the gloves The overgarment may be left open, and the protective mask hood may be rolled up in warm weather

5 MOPP4 The soldier wears the overgarment closed and wears the overboots, mask with hood, and gloves (Ref 1)

In all operational situations the probable protection level (or MOPP) of the target personnel influences the enemy's use of chemical agents Based on intelligence reports and estimates of the situation, the enemy may choose to use fast-acting, nonpersistent nerve agents against target personnel perceived to be unprotected or unmasked The enemy may also choose to use persistent blister agents against personnel assumed to be wearing protective clothing and masks These troops will sustain casualties from percutaneous liquid contamination when they are masked only The persistent hazards of these agents also force fully protected personnel to remain in protective gear for extended periods Extended periods in MOPP4 greatly reduce the effectiveness of soldiers (Ref 2)

The wide variety of CB agents and delivery systems the enemy can use across the battlefield poses many threats Each combination of agent and delivery system poses a unique challenge to detectors Therefore, detectors must be developed that are capable of detecting each of the hazards and agent challenges that may be present across the battlefield

3-2 SITUATIONS

The problems faced by the field user of detection and monitoring equipment must be understood by the designer of such equipment if it is to be responsive to field needs Critical needs for battlefield information about CB agents shape the characteristics required of detectors

MOPP 1

Overgarment	Worn*
Overboots	Carried
Mask and Hood	Carried
Gloves	Carried

MOPP 2

Overgarment	Worn*
Overboots	Worn
Mask and Hood	Carried
Gloves	Carried

MOPP 3

Overgarment	Worn*
Overboots	Worn
Mask and Hood	Worn*
Gloves	Carried

*In hot weather the coat or hood can be left open for ventilation

MOPP 4

Overgarment	Worn
Overboots	Worn
Mask and Hood	Worn
Gloves	Worn

MOPP Zero

Mask and Hood	Carried
Overgarment	Readily Available
Overboots	Readily Available
Gloves	Readily Available

Figure 3-1. Standardized MOPP Levels (Ref. 1)

Because such needs vary across the battlefield, four different situations or functional groupings of units based on their unique and common operational or mission requirements are addressed: combat and combat support, combat service support (CSS), reconnaissance (RECON), and fixed site installations (FSI) These functional groupings include the majority of units involved in the AirLand Battlefield and envisioned under the Army 21 Concept structure (Ref 3)

Each situation has common and unique requirements that are critical in the context of detector performance criteria Performance criteria are statements of the levels of performance established for a system within each of its required operational characteristics Current detector performance criteria were generated by the Reconnaissance, Detection, and Identification Master Plan (RDIMP), a joint US Army Training and Doctrine Command (TRADOC) and US Army Materiel Command (AMC) master plan, which was prepared by the US Army Chemical School (CMLS) and US Army Chemical Research, Development, and Engineering Center (CRDEC) in 1985

The master plan encompasses a definition of battlefield user and detection system developer requirements It also contains an analysis of current and future detection technologies as an aid to determining technology approaches that meet user needs in the near-, mid-, and far-term The RDIMP defines detector characteristics and subcharacteristics in terms of specific performance criteria for each of the four battlefield situations Multiple levels of performance are given for many of these characteristics Level 1 is the ultimate or desired need in terms of performance perceived by the user Other levels indicate less than desirable but acceptable levels of performance, the lowest level is the minimal acceptable performance (Ref 3) Detector design requirements and performance criteria for each situation or functional group are discussed in the paragraphs that follow

3-2.1 COMBAT AND COMBAT SUPPORT

Combat and combat support units will be engaged in all types of combat operations with varying missions and environmental conditions on the modern, integrated battlefield Combat and combat support operations include infantry and armor combined arms teams, light infantry, fire support, air defense, close air support, combat engineers, Army aviation, and electronic warfare

Successful offensive operations will depend upon close, organized cooperation of the joint services to achieve concentration of effort, surprise, speed, and flexibility When on the defensive, combat units and their allocated combat support units will attempt to block, disrupt, and disorganize an enemy attack In both offensive and defensive operations, combat and combat support units will be subjected to a wide variety of enemy chemical and biological threats.

The enemy will most likely employ nonpersistent agents against combat and combat support units to inflict the maximum possible number of immediate casualties, degrade mission performance, and slow friendly attack momentum along avenues of approach More persistent chemical agents may be used for terrain denial or may be delivered in flank areas away from the main enemy breakthrough area to contain and channelize units Conventional biological agents (pathogenic organisms) are not considered to be a likely threat to combat and combat support units because the onset of symptoms is delayed, the targets are too close to the enemy's own troops, and the area coverage is uncertain and uncontrollable

Given the close proximity of our troops to enemy combat units and probable precise enemy target acquisition, enemy delivery systems may include cannon artillery, missiles, rockets, and multiple rocket launcher systems Rapid-fire rocket systems are capable of delivering large quantities of agent and thus can cover large areas with lethal concentrations with almost no warning Artillery systems also are capable of covering large areas with lethal concentrations, but the time required to do so is greater than with rocket systems

Immediate challenges to detectors from nonpersistent or semipersistent agents delivered by these systems will be primarily in vapor form with droplet mass median diameters (MMD) of less than 200 μm. Due to the mobility of combat and combat support units, there is also a high probability that they will encounter areas previously contaminated with more persistent agents, for example, flank areas Thus detectors must be capable of detecting ground contamination Secondary vapor emissions from these areas are likely to have very low concentrations, so detectors must have high sensitivities

Due to the nature of combat operations, detectors must be very versatile Technology advances in types of agents, agent toxicities, and modes of dissemination will create ever-changing challenges to detector technologies Critical to the success of these units is the capability of detectors to detect all known and unknown agents with a real-time or close to real-time response (warning) in order to minimize casualties

Other operational factors will significantly impact detector development criteria The mobile nature of combat and combat support operations will require detectors capable of operating on the move To be successful, combat and combat support units must fight in the most efficient manner possible When he is in protective gear, i e , MOPP gear, a soldier's efficiency is greatly diminished For this reason, false alarms that

put the soldiers in unnecessary MOPP must be minimized In the monitoring role, it is important to know when the concentration of a toxic substance has been reduced to the level at which it is safe to remove protective clothing

Detector sensitivities must be geared to human response The components must be small and lightweight and must require minimal setup, operator input, and maintenance Detectors must be rugged in order to survive all the environmental, meteorological, and operational situations that will be encountered on the battlefield Finally, detectors must be highly reliable, available, and maintainable

Because detection without timely warning to troops is of minimal value, detectors must be capable of responding with both audible and visible alarms to personnel in the immediate area Also the alarm must be transmitted via radio or other means to higher, adjacent, or lower units

Detectors must also be capable of obtaining, processing, and sending other types of data to support battlefield actions Detectors must determine agent class e g , nerve, blister, blood, and exact identification, e g , sarin (GB), soman (GD), persistent nerve (VX), distilled mustard (HD), phosgene oxime (CX), hydrogen cyanide (AC), cyanogen chloride (CK), or phosgene (CG), as well as the amount of agent present These data, when transmitted to higher headquarters, will support commanders making operational decisions These decisions include whether the contaminated unit should move and decontaminate or remain and decontaminate The data will also enable commanders to warn units that may be approaching a hazard or units that are threatened from the downwind drift of the agent cloud

Table 3-1 shows detector characteristics and performance criteria specified for combat and combat support units

3-2.2 COMBAT SERVICE SUPPORT (CSS)

Typical combat service support units are located from 15 to 50 km rearward of the FLOT, throughout the corps support area, and in the communications zone The mission of these units is to develop and maintain maximum combat power by sustaining combat and combat support forces Future conflicts will be intense and will consume all resources very rapidly Combat service support units must supply and resupply depleted resources such as ammunition, equipment, repair parts, and petroleum, oils, and lubricants (POL), and repair damaged equipment Combat service support units include maintenance, medical, supply, transportation, personnel, and ordnance

Survival and efficient operation of combat service support units must be emphasized to ensure their capability to support combat operations Commanders must plan tactics and logistics concurrently to ensure that the tactical scheme of maneuver and fire support is logically supportable and can be accomplished in a timely manner

Combat service support units operate from widely dispersed positions Commanders must consistently receive information concerning the status of supply stocks and transportation systems The effectiveness of the combat service support system is heavily dependent on command decisions based on timely information in order to meet changing situations, environments, and requirements

Combat service support units on the battlefield vary in size and mission Smaller, more mobile combat service support units, such as units closer to the FLOT, encounter threats similar to combat and combat support units Large service support units, such as supply and maintenance units, are usually located toward the rear of the battlefield and operate as semifixed or fixed sites These units may encounter persistent agent threats

Chemical attacks on combat service support units have a significant effect on logistic operations Contaminated supplies, such as ammunition, equipment, and repair parts, may require decontamination before issue to combat units Maintenance and repair work often done at CSS units would be significantly hampered by contaminated equipment

Because of the many threat agents and delivery systems available to the enemy, chemical attacks represent a serious threat to combat service support units Due to the wide variety of combat service support unit sizes and missions and depending on the objective and targeting success, the enemy will be more selective in weapons employment Smaller service support units closer to the FLOT may be within enemy artillery and rocket range, whereas larger CSS units located farther from the FLOT are more likely to be targets for aerial bombs and missiles

TABLE 3-1. DETECTOR CHARACTERISTICS AND PERFORMANCE CRITERIA FOR COMBAT AND COMBAT SUPPORT (Ref. 3)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
1 Agent Detection**	
a Chemicals b Biologicals c Toxins	Level 1 All known and unknown agents in all physical states Level 2 All known agents, with capability to expand to all unknown agents
2 Response Time	
a Detection**	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Real time on demand (<5 s) for Level 3 sensitivity criteria Level 2. 2 min for Level 1 and 2 sensitivity criteria
b Identification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 1 min on demand Level 2 10 min
c Quantification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Instantaneous and continuous (5 s) Level 2 2 min
3 Sensitivity**	
a Chemicals**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3 Incapacitation 5% of affected population
b Biologicals**	5% of affected population infected
c Toxins**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3. Incapacitation. 5% of affected population
4 Detector Operation Parameters	
a Accuracy	Per 72-h mission False positive One False negative Very low probability of occurrence
b Size**	Per component Volume 0 028 m^3 Weight Level 1 4 536 kg Level 2 Man-portable
c Data transmission	Within unit Capability of interfacing with warning transmission system Night vision compatible Battalion· Automatic transmit Attack occurred Which agent present Location Date/time group
d Service/setup-takedown	Level 1 Instantaneously usable 1 min Level 2 30 min
e Consumables**	Within size constraints for 72-h mission
f Alarm	Emit trigger automatic (electronic and optical signal)
g Environmental extremes	Hot, basic, and cold (AR 70-38)†
h Power**	Internal supply within size constraints

(cont'd on next page)

TABLE 3-1. (Cont'd)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
5 **Survivability**	
a RAM	Reliability—500 h mean time between failure (MTBF) Availability—23 of 24 h Maintainability—90% of failures can be corrected by the unit within 1 h
b Conventional attack	High probability of survival
c NBC attack	AR 70-71 regarding NBC survivability must be met AR 70-60 regarding nuclear survivability must be met
6 **Agent Identification**	Identify all known, be adaptable to unknown
7 **Operator Requirements**	
a Input	None (turnkey operation)
b Qualifications	Common skills, nonspecific
8 **Ruggedness**	MIL-STD-810
9 **Range**	Immediate operational area of platoon (approximately 1 km^2 for reconnaissance, detection, and identification (RDI) system)
10 **Capability to Operate While Mobile**	
11 **Agent Quantification**	Quantify all known, be adaptable to unknown
12 **Reset Time** (Time between samples)	Level 1 Continuous <15 s Level 2 2 min
13 **Time for Prototype Production**	Not determined
14 **Sensor Cost**	Not determined
15 **Producibility**	Not determined

*Level 1 is the desired need in terms of performance as perceived by the user Other levels indicate less than desired but acceptable levels of performance The lowest level is the minimally acceptable performance

**Critical characteristics or subcharacteristics

†The basic climatic design types as defined in AR 70-38 ranges are

Constant high humidity	temperature 24°C	RH 95-100%
Variable high humidity	temperature 26° to 35°C	RH 74-100%
Basic hot	temperature 30° to 43°C	RH 14-44%
Basic cold	temperature −21° to −32°C	RH saturation

Persistent chemical agents may be used to disrupt and degrade support functions along mobility and supply routes Persistent chemical agents also will be the agents of choice against major supply, equipment, and ammunition depots and supply points Contamination with persistent agents results in a long-lasting hazard to personnel who must work with and handle the supplies, and thus it degrades unit sustainability and operations Nonpersistent chemical agents may be used on airdrop zones for enemy airborne or airmobile operations or on areas likely to be exploited in the near future Use of pathogenic biological agents against smaller CSS units closer to the FLOT is unlikely because of the delayed reaction time, large area of coverage, and the possibility of infectious disease being spread to the enemy forces The enemy may, however, use biological agents against larger CSS units toward the rear. The possibility exists of course that any type of agent or munition could be used in any situation if the appropriate level enemy commander deems it necessary to achieve his objectives

Because many CSS units must operate from widely dispersed positions and should remain highly mobile, the detector performance criteria for CSS units are similar to those for combat and combat support units Detectors must detect all known and unknown agents Detector sensitivity requirements and criteria for power, size, weight, and mobility usually are identical to those for combat and combat support units The efficiency of CSS units is also degraded significantly when missions are performed in MOPP gear Therefore, the requirement that minimal time be spent in MOPP gear is the same as for combat and combat support units

Table 3-2 shows detector characteristics and performance criteria for CSS units

TABLE 3-2. DETECTOR CHARACTERISTICS AND PERFORMANCE CRITERIA FOR COMBAT SERVICE SUPPORT (CSS) (Ref. 3)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
1 **Agent Detection****	
a Chemicals b Biologicals c Toxins	Level 1 All known and unknown agents in all physical states Level 2 All known agents, with capability to expand to all unknown agents
2 **Response Time**	
a Detection**	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Real time on demand (<5 s) for Level 3 sensitivity criteria Level 2 2 min for Level 1 and 2 sensitivity criteria
b Identification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 1 min on demand Level 2 10 min
c Quantification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Instantaneous and continuous (5 s) Level 2 2 min
3 **Sensitivity****	
a Chemicals**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3 Incapacitation 5% of affected population
b Biologicals**	5% of affected population infected
c Toxins**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3 Incapacitation 5% of affected population
4 **Detector Operation Parameters**	
a Accuracy	Per 72-h mission False positive One False negative Very low probability of occurrence
b Size**	Per component Volume 0 028 m^3 Weight Level 1 4 536 kg Level 2 Man-portable
c Data transmission	Within unit Capability of interfacing with warning transmission system Night vision compatible Battalion Automatic transmit Attack occurred Which agent present Location Date/time group
d Service/setup-takedown	Level 1 Instantaneously usable 1 min Level 2 30 min
e Consumables**	Within size constraints for 72-h mission
f Alarm	Emit trigger automatic (electronic and optical signal)
g Environmental extremes	Hot, basic, and cold (AR 70-38)†
h Power**	Internal supply within size constraints

(cont'd on next page)

TABLE 3-2. (Cont'd)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
5 **Survivability**	
a RAM	Reliability—500 h (MTBF) Availability—23 of 24 h Maintainability—90% of failures can be corrected by the unit within 1 h
b Conventional attack	High probability of survival
c NBC attack	AR 70-71 regarding NBC survivability must be met AR 70-60 regarding nuclear survivability must be met
6 **Agent Identification**	Identify all known, be adaptable to unknown
7 **Operator Requirements**	
a Input	None (turnkey operation)
b Qualifications	Common skills, nonspecific
8 **Ruggedness**	MIL-STD-810
9 **Range**	Approximately 3 km^2 desirable
10 **Capability to Operate While Mobile**	
11 **Agent Quantification**	Quantify all known, be adaptable to unknown
12 **Reset Time** (Time between samples)	Level 1 Continuous <15 s Level 2 2 min
13 **Time for Prototype Production**	Not determined
14 **Sensor Cost**	Not determined
15 **Producibility**	Not determined

*Level 1 is the desired need in terms of performance as perceived by the user Other levels indicate less than desired but acceptable levels of performance The lowest level is the minimally acceptable performance

**Critical characteristics or subcharacteristics

†The basic climatic design types as defined in AR 70-38 ranges are

Constant high humidity	temperature 24°C	RH 95-100%
Variable high humidity	temperature 26° to 35°C	RH 74-100%
Basic hot	temperature 30° to 43°C	RH 14-44%
Basic cold	temperature −21° to −32°C	RH saturation

3-2.3 RECONNAISSANCE (RECON)

The purpose of reconnaissance is to gather information upon which commanders and their staffs may form plans, make decisions, and issue operational orders Reconnaissance includes surveillance, the term given to systematic observation by any means Army units have an inherent reconnaissance mission that includes nuclear, biological, and chemical (NBC) reconnaissance NBC reconnaissance is needed to provide commanders with information to plan, make decisions, and/or issue orders during NBC operations

Aside from the inherent reconnaissance missions within all units, certain units have a dedicated reconnaissance mission and others a dedicated surveillance mission These units conduct reconnaissance on all aspects of the battlefield, such as terrain, the effects of weather, and the presence or absence of the enemy Reconnaissance is a continuous, integral part of the modern battlefield Much of the success of a reconnaissance unit depends on its stealth, speed, maneuverability, and strength It is not equipped to fight the enemy to gain information

Reconnaissance units are located throughout the battlefield and are subjected to all threats associated with combat and combat support and CSS units Reconnaissance units have specific NBC responsibilities that introduce unique additional NBC hazards and associated requirements

NBC reconnaissance units support the commander in locating and designating contaminated and uncontaminated terrain to facilitate troop, supply, and equipment movement Information from reconnaissance provides intelligence permitting maneuver units to avoid hazards or to take the required defensive measures for operations in contaminated areas NBC reconnaissance units

need to provide commanders with integrated, systemized, and timely NBC hazard information with high levels of accuracy

Reconnaissance units are subjected to the entire spectrum of enemy chemical agents and delivery systems They are subjected to CB threats with much greater frequency than any other type of unit Because direct targeting of these highly mobile units is difficult, the most significant hazard faced by these units is previously contaminated terrain, especially along reconnaissance routes or in surveillance areas These areas will most likely be contaminated with persistent nerve or blister agents and will present significant contact hazards as well as a secondary vapor hazard Reconnaissance units, especially in rear areas, could also encounter areas contaminated with biological agents

This situation presents unique challenges to detectors Reconnaissance units must be capable of detecting all known and unknown agents with close to real-time (immediate) response Detectors must be capable of detecting, identifying, and monitoring CB agent contamination while the RECON team is on the move Detector sensitivity is critical because the agent concentrations likely to be encountered from secondary evaporation will be minimal

Detection equipment and crews of chemical reconnaissance units are housed in a ground vehicle This situation requires detector power, weight, and size specifications similar to those of combat and combat support units, although not quite as constrained The equipment must be highly reliable, accurate, and rugged An additional requirement for many reconnaissance units will be the need for a remote detection capability to extend the range for detectors including a "look ahead" as well as a "look down" capability for aerial reconnaissance units Detectors must be capable of operating continuously, day and night, in all environments Effective reconnaissance must provide data to commanders and their staffs thus detectors are required to interface with communications equipment capable of transmitting required data

Table 3-3 lists detector characteristics and performance criteria specified for reconnaissance (RECON) units

3-2.4 FIXED SITE INSTALLATIONS (FSI)

Fixed site installations represent critical resources to the theater command. These installations include airbases, depot storage areas, ammunition supply points, maintenance facilities, signal sites, and some medical installations that are usually located far to the rear of the battlefield Combat and combat support and CSS units are dependent on fixed sites in many ways, consequently, enemy attacks against these sites can have serious long-term effects

Fixed sites are highly vulnerable to enemy air attacks, infiltration, and terrorist activities Therefore, these sites present lucrative targets to threat forces employing NBC weapons Although persistent agents are considered the primary threat to fixed sites, nonpersistent chemical attacks can be expected prior to an attempted assault or takeover of these sites Persistent chemical agents present a long-term hazard resulting in contaminated equipment and critical supply items Personnel will be forced to remain in MOPP gear for extended periods, thus their efficiency is reduced and their mission performance is significantly degraded Due to the long-range distance of FSI from the enemy, threat delivery systems for chemical agents will probably include bombs, aircraft equipped with spray tanks, and missiles Agents also may be delivered upwind of a fixed site so that the resulting cloud drifts over the site without warning or indication of its presence.

Enemy use of biological agents against fixed sites is more probable than for any other situation Delivery of biological agents may come from conventional delivery systems or through covert sources

Detectors must be capable of detecting all known and unknown agents with sufficient response to prevent or minimize the number of immediate casualties Following an attack, reconnaissance of ground surfaces and facility exteriors and surveillance of personnel and equipment must be undertaken High detector sensitivity levels will be required for detection of low-level concentrations in FSI operational areas Detection of the agent no longer provides sufficient chemical information, identification and quantification also are required for information or data processing to support the prediction of hazard persistency as well as downwind travel

TABLE 3-3. DETECTOR CHARACTERISTICS AND PERFORMANCE CRITERIA FOR RECONNAISSANCE (RECON) (Ref. 3)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
1 **Agent Detection****	
a Chemicals b Biologicals c Toxins	Level 1 All known and unknown agents in all physical states Level 2 All known agents, with capability to expand to all unknown agents
2 **Response Time**	
a Detection**	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Real time on demand (<5 s) for Level 3 sensitivity criteria Level 2 15 s for Level 2 sensitivity
b Identification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 1 min on demand Level 2 10 min
c Quantification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Instananeous and continuous (5 s) Level 2 2 min
3 **Sensitivity****	
a Chemicals**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3 Incapacitation 5% of affected population
b Biologicals**	5% of affected population infected
c Toxins**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3 Incapacitation 5% of affected population
4 **Detector Operation Parameters**	
a Accuracy	Per 72-h mission False positive One False negative Very low probability of occurrence
b Size	Per component Volume 0 028 m^3 Weight Level 1 4 536 kg Level 2 Components must fit in tactical vehicle
c Data transmission	Within unit Capability of interfacing with warning transmission system (Signal may or may not be electronic, may be optical) Night vision compatible Division/Corps Data must be capable of being transmitted over Division/Corps nets Attack occurred Which agent present Location Date/time group
d Service/setup-takedown	Level 1 Instantaneously usable 1 min Level 2 30 min
e Consumables**	Within size constraints for 24-h mission
f Alarm	Emit trigger automatic (electronic and optical signal)
g Environmental extremes	Hot, basic, and cold (AR 70-38)†
h Power**	Vehicle power within size constraints

(cont'd on next page)

TABLE 3-3. (Cont'd)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
5 **Survivability**	
a. RAM	Reliability—500 h (MTBF) Availability—23 of 24 h Maintainability—90% of failures can be corrected by the unit within 1 h
b Conventional attack	High probability of survival
c NBC attack	AR 70-71 regarding NBC survivability must be met AR 70-60 regarding nuclear survivability must be met
6 **Agent Identification**	Identify all known, be adaptable to unknown
7 **Operator Requirements**	
a Input	None (turnkey operation)
b Qualifications	Common skills, nonspecific Level 1 Common skills, nonspecific Level 2 MOS 54E, reconnaissance scout
8 **Ruggedness**	MIL-STD-810
9 **Range**	Minimally acceptable operational range 3-12 km required
10 **Capability to Operate While Mobile**	
a Ground	Capable of operating at 48 km/h required
b Air	Look ahead 3-5 km, 45 deg to either side of center lookdown scan capability
11 **Agent Quantification**	Quantify all known, be adaptable to unknown
12 **Reset Time** (Time between samples)	Level 1 Continuous < 15 s Level 2 2 min
13 **Time for Prototype Production**	Not determined
14 **Sensor Cost**	Not determined
15 **Producibility**	Not determined

*Level 1 is the desired need in terms of performance as perceived by the user Other levels indicate less than desired but acceptable levels of performance The lowest level is the minimally acceptable performance

**Critical characteristics or subcharacteristics

†The basic climatic design types as defined in AR 70-38 ranges are

Constant high humidity	temperature 24°C	RH 95-100%
Variable high humidity	temperature 26° to 35°C	RH 74-100%
Basic hot	temperature 30° to 43°C	RH 14-44%
Basic cold	temperature −21° to −32°C	RH saturation

Detectors must provide data to maintain the operating capability of personnel in a threat environment for a long time and must be sensitive enough to provide an indication that a threat to personnel no longer exists to minimize time spent in MOPP gear For this reason, detectors must have a low false alarm rate and must be highly reliable, available, and maintainable The nature of operations at a fixed site installation allows for increases in detector power, size, and weight requirements Detectors for FSIs can be less rugged and need not have the capability to operate while mobile

Table 3-4 shows detector characteristics and performance criteria specified for fixed site installations

TABLE 3-4. DETECTOR CHARACTERISTICS AND PERFORMANCE CRITERIA FOR FIXED SITE INSTALLATIONS (FSI) (Ref. 3)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
1 **Agent Detection****	
a Chemicals b Biologicals c Toxins	Level 1. All known and unknown agents in all physical states Level 2· All known agents, with capability to expand to all unknown agents
2 **Response Time**	
a Detection**	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Real time on demand (<5 s) for Level 3 sensitivity criteria Level 2 2 min for Level 1 and 2 sensitivity criteria
b Identification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 1 min on demand Level 2 10 min
c Quantification	
(1) Chemicals (2) Biologicals (3) Toxins	Level 1 Instantaneous and continuous (5 s) Level 2 2 min
3 **Sensitivity****	
a Chemicals**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3 Incapacitation 5% of affected population
b Biologicals**	5% of affected population infected
c Toxins**	Level 1 Detoxification level Level 2 Threshold response level, 5% of affected population Level 3 Incapacitation 5% of affected population
4 **Detector Operation Parameters**	
a Accuracy	Per 72-h mission False positive One False negative Very low probability of occurrence
b Size	Per component Volume Adjustable Weight Adjustable
c Data transmission	Within unit Capability of interfacing with warning transmission system Night vision compatible Corps or Organization (automatically transmit) Attack occurred Which agent present Location Date/time group

(cont'd on next page)

TABLE 3-4. (Cont'd)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA*
d Service/setup-takedown	Level 1 Instantaneously usable 1 min Level 2. 30 min
e Consumables	Within size constraints for 24-h mission
f Alarm	Emit trigger automatic (electronic and optical signal)
g Environmental extremes	Hot, basic, and cold (AR 70-38)†
h Power	Unrestricted
5 **Survivability**	
a RAM	Reliability—500 h (MTBF) Availability—23 of 24 h Maintainability—90% of failures can be corrected by the unit within 1 h
b Conventional attack	High probability of survival
c NBC attack	AR 70-71 regarding NBC survivability must be met AR 70-60 regarding nuclear survivability must be met
6 **Agent Identification**	Identify all known, be adaptable to unknown
7 **Operator Requirements**	
a Input	None (turnkey operation)
b Qualifications	Common skills, nonspecific
8 **Ruggedness**	MIL-STD-810
9 **Range**	Immediate operational area of fixed site and beyond (approximately 3 km^2 for RDI system)
10 **Capability to Operate While Mobile**	
11 **Agent Quantification**	Quantify all known, be adaptable to unknown
12 **Reset Time** (Time Between Samples)	Level 1 Continuous < 15 s Level 2 Minimally acceptable 2 min
13 **Time for Prototype Production**	Not determined
14 **Sensor Cost**	Not determined
15 **Producibility**	Not determined

*Level 1 is the desired need in terms of performance as perceived by the user Other levels indicate less than desired but acceptable levels of performance The lowest level is the minimally acceptable performance

**Critical characteristics or subcharacteristics

†The basic climatic design types as defined in AR 70-38 ranges are

Constant high humidity	temperature 24°C	RH 95-100%
Variable high humidity	temperature 26° to 35°C	RH 74-100%
Basic hot	temperature 30° to 43°C	RH 14-44%
Basic cold	temperature −21° to −32°C	RH saturation

REFERENCES

1 FM 3-87, *Nuclear, Biological, and Chemical (NBC) Reconnaissance and Decontamination Operations*, Department of the Army, 22 February 1980

2 FM 3-100, *NBC Operations*, Department of the Army, 17 September 1985

3 *Reconnaissance, Detection, and Identification Master Plan (RDIMP)* (U), CRDC-CR-85032 US Army Chemical School, Fort McClellan, AL, and US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, 19 April 1985 (THIS DOCUMENT IS CLASSIFIED SECRET)

BIBLIOGRAPHY

FM 3-4, *NBC Protection*, Department of the Army, 21 October 1985

FM 3-5, *NBC Decontamination*, Department of the Army, 24 June 1985

FC 3-19, *NBC Reconnaissance*, US Army Chemical School, Fort McClellan, AL, 1 August 1986

CHAPTER 4
CHEMICAL AND BIOLOGICAL (CB) DETECTION TECHNOLOGIES

This chapter describes chemical, physical, and biotechnological methods used to detect CB agents. It describes the scientific principles associated with each technology, application of these technologies to military environments, and potential detection capabilities The role of quantitative and qualitative analysis as the basis for detection equipment is discussed Chemical methods of detection are explained, and associated concepts and principles are described The concepts classified as biotechnology methods of detection and selected technologies associated with detection of biological agents are discussed

4-1 INTRODUCTION

Well-established methods of qualitative and quantitative analysis have been the starting point of development of detection systems Many of these methods have a long history of successful use in laboratories throughout the world, and a well-documented body of literature is available The principal challenge facing the developer of detection equipment is to adapt the basic features of these methods and concepts to the special demands of military applications Noteworthy among the military requirements are

1 Small volume and weight
2 Ruggedness
3 Operation over a wide range of climatic extremes

The laboratory is a controlled environment and personnel are trained in the requirements associated with laboratory handling and use of equipment, therefore, a major transformation in equipment is necessary to produce detection equipment for military use

Methods based on the chemistry of agents were the basis for the earliest detection attempts Many of the standard methods of qualitative analysis are based on color change These color change methods were the basis for early manual detection equipment or kits, which still provide a supplement to automatic devices Colorimetric techniques also provided the basis for some of the earlier automatic detectors In these devices detection was based on a change in light transmission through a liquid caused by color change or reflecting paper tape

Detection systems based on wet chemistry, such as colorimetric techniques, have never been very popular with soldiers Each system has its own particular problem that adds to the logistic burden associated with supporting the detection system

Detectors based on physical principles have largely replaced the wet chemical techniques in current systems and in the technologies being investigated for future systems The bases for physical methods are inherent in the agent molecule and its reaction to some form of energy The most prominent physical detection techniques rely on electromagnetic spectroscopy, mass spectrometry, and ionization-based concepts

4-2 CHEMICAL METHODS

Initially, all methods for detection of toxic chemical agents depended on the properties of certain dyes to exhibit a color change When contact with the agent is made, the solubility of these dyes depends on the acid-base properties of the agent The dyes are incorporated into papers or crayons, or they are coated on a plastic film base The color change occurs upon contact with a liquid agent

Manual vapor detection based on color change is accomplished through agent contact with suitable reactants on a small quantity of silica gel in a glass tube Air is drawn through the tube in a prescribed manner with either water or reactants introduced The tube is checked visually for the presence or absence of color change, which indicates the presence of agent vapor The reactions in Figs 4-1 through 4-5 are representative of the chemistry employed in these visual detection kits Most of these tests require about 1 5 min to perform for each agent

The most recent development in manual detection employs a device called a sampler-detector card (a disposable plastic sampler) This card provides a medium for tests for most toxic agents The basic configuration and layout of the sampler-detector card is shown in Fig 4-6

The sampler-detector card simplifies the problem of vapor detection It is self-contained, uses a series of simple steps to release the reagents, and requires only static exposure of the prepared sample surface to air

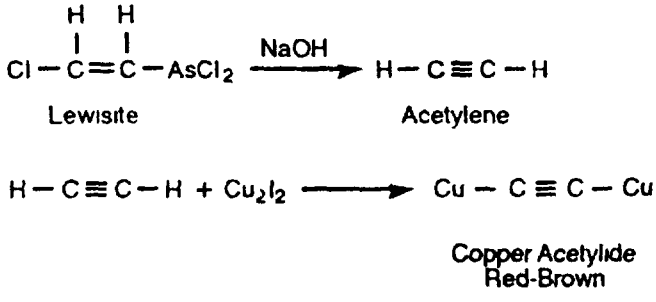


Figure 4-1. Reactions Employed in Visual Kits: Test for Lewisite (Ref. 1)

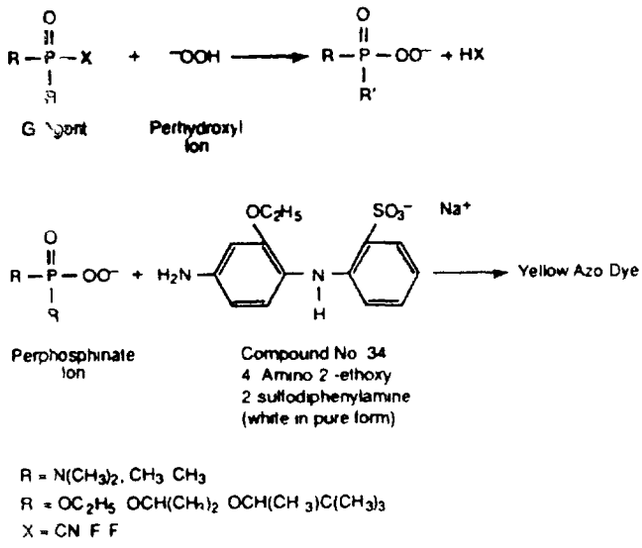


Figure 4-2. Reactions Employed in Visual Kits: Test for G-Type Agents (Schoenemann Reaction) (Ref. 1)

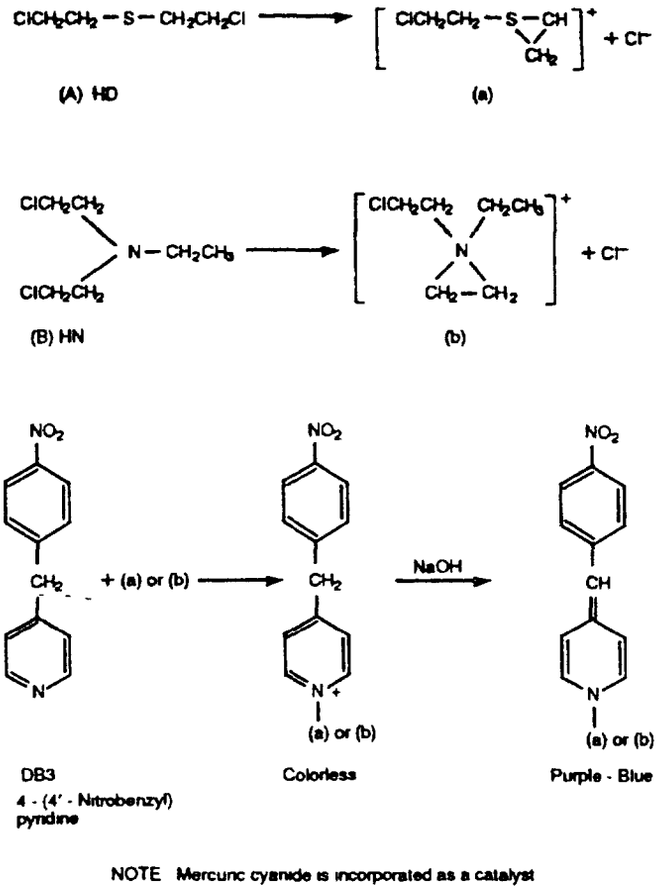


Figure 4-3. Reactions Employed in Visual Kits: DB3-NaOH Test for HD or HN (Ref. 1)

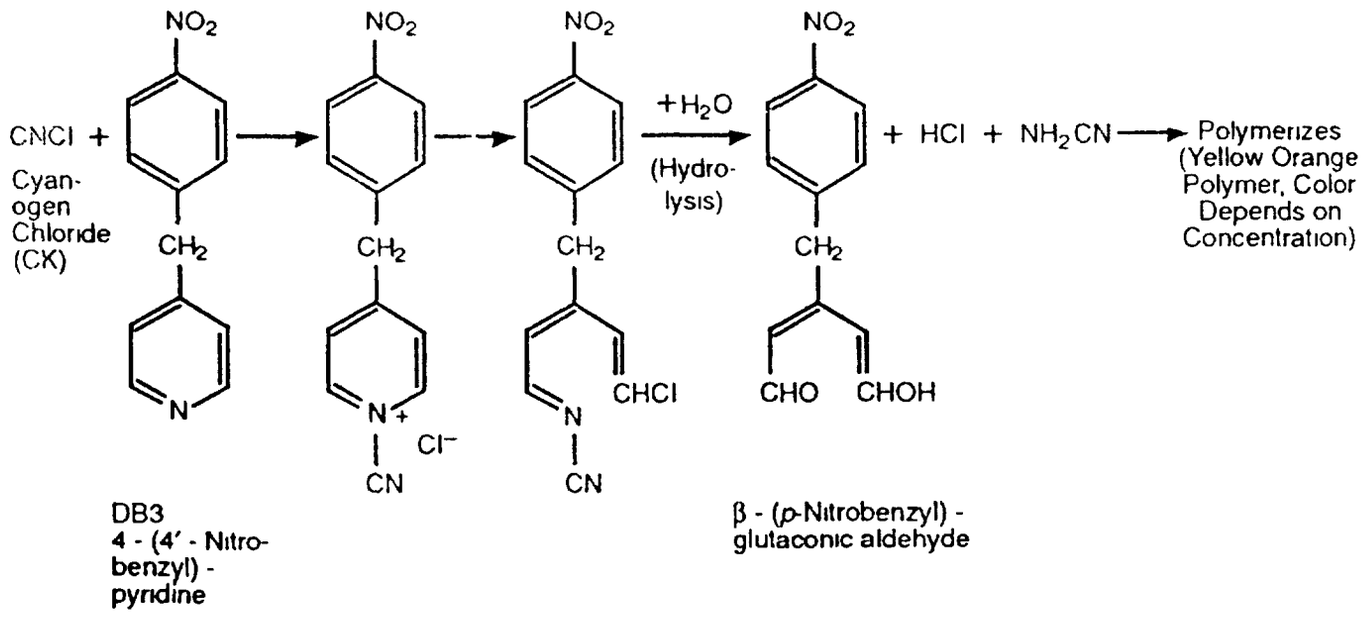
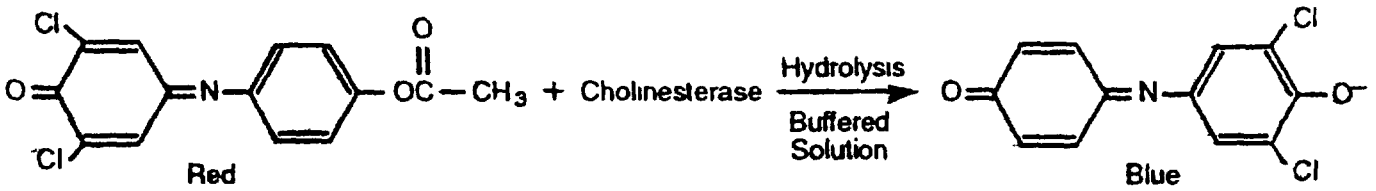


Figure 4-4. Reactions Employed in Visual Kits: Test for Cyanogen Chloride (Ref. 1)

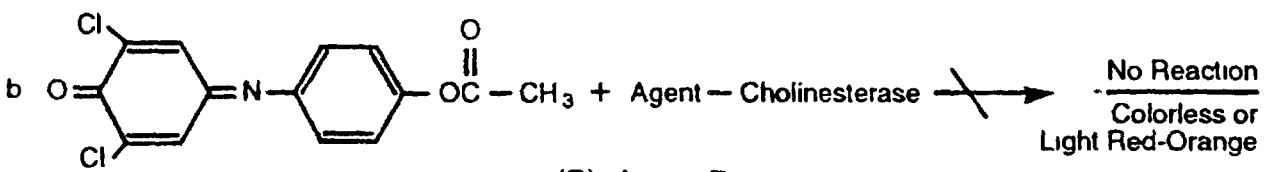


Red 2, 6-Dichloroindophenyl Acetate

2, 6-Dichloroindophenylate

(A) No Agent Present

a Agent + Cholinesterase ⟶ Agent — Cholinesterase



(B) Agent Present

Figure 4-5. Reactions Employed in Visual Kits: General Test for Anticholinesterase Material—Phosphoro, Phosphono, Quaternary Ammonium Salts, and Carbamates (Ref. 1)

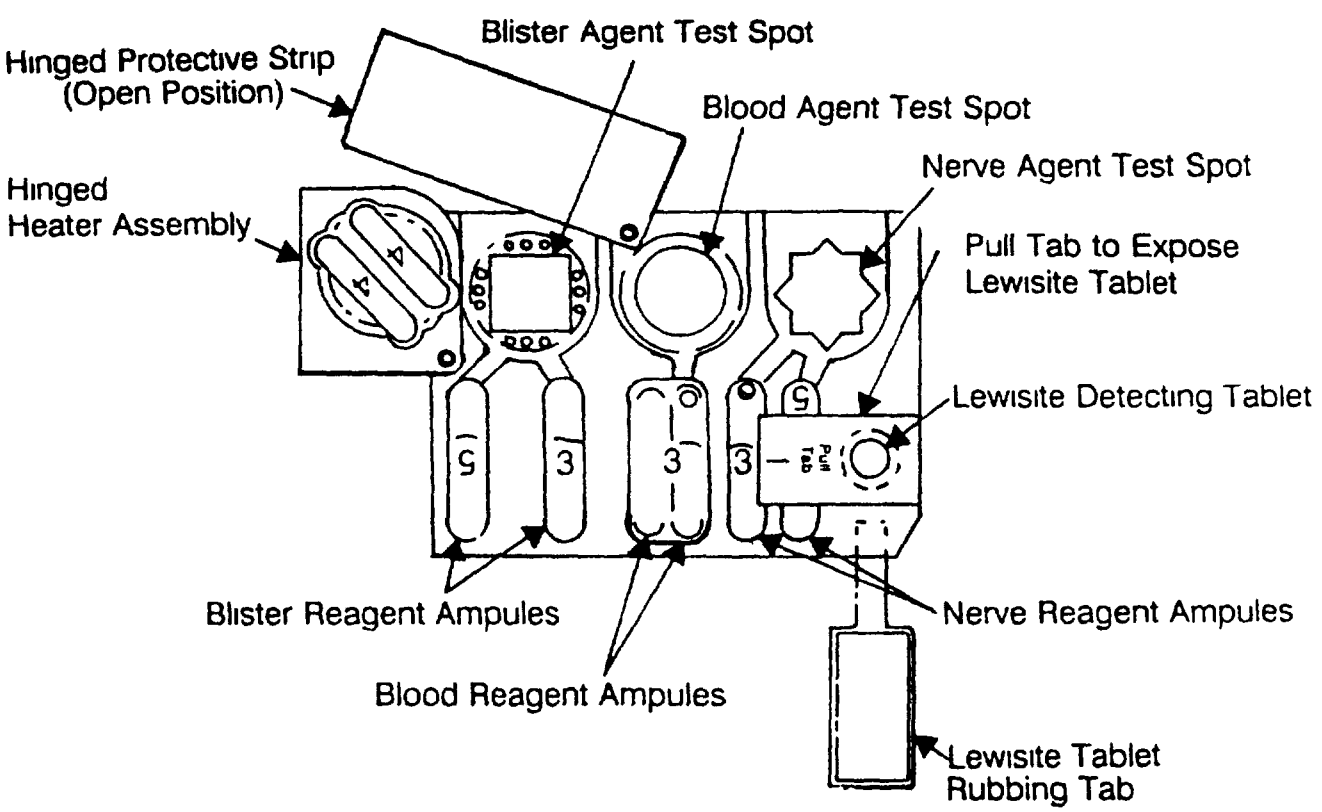


Figure 4-6. Disposable Plastic Sampler (Ref. 2)

4-2.1 COLORIMETRIC

When a molecule absorbs light, it undergoes a transition from a state of lower energy to a state of higher energy This concept is absorption spectroscopy and is used in most colorimetric analysis In most instances one or two chemical solutions are added to an unknown solution to produce a color that is analyzed spectroscopically This methodology is used in many kits and detection devices, as shown previously in Figs 4-1 to 4-5

Early attempts to provide high-sensitivity, rapid-response automatic detectors used colorimetric reactions In these systems color change was detected by a photocell that responded to the change in reflectance of a wetted spot on paper tape through which air was passed The reflectance of the wetted spot was compared with a dry spot on the tape, and when the change exceeded a preset level, a visual and/or audible alarm was triggered These detectors were based on the Schoenemann reaction, which is actually a family of reactions conducted in alkaline solution The sensitivity of the reaction is reported to be such that the reaction will detect 0 02 parts per million (ppm) of GB in 2 min and will respond to concentrations above 2 0 parts per billion (ppb) in 5 min (Ref 3)

4-2.2 FLUOROMETRIC

Fluorescence, the emission of radiation (light) by a substance that has absorbed radiation from another source, amplifies the amount of emitted radiation over that which would be achieved with reflected light alone Often the emitted radiation has a different wavelength from the incident radiation and is substance dependent This process was used in an early automatic alarm by selection of the reagent for the Schoenemann reaction so that a fluorescent product, indoxyl, would result

Photoluminescence is a process whereby a solution is radiated with a light source and the resultant solution fluoresces The distinction between photoluminescent and absorption processes is that in a photoluminescent process a fluorescent dye is produced in a chemical reaction, whereas in an absorption process a color is produced that is analyzed spectroscopically

Fluorometric analysis is a very sensitive method of analysis, but usually the solutions are not stable over a long time period One widely investigated and used fluorometric technique was the sodium pyrophosphate-peroxide and indole method When these two chemical solutions were mixed with a nerve agent solution, the resulting solution slowly increased in fluorescence to a peak value and then decreased

Fluorometric techniques have long been investigated for use in chemical detection devices, and numerous compounds have been tested Two compounds tested were indole and aluminum morin Indole was investigated for use in plant chemical agent alarms E-17 and E-59 Indole reacts with strong oxidizers to produce the highly fluorescent indoxyl The presence of nerve agent catalyzes the reaction Aluminum morin, a related compound, is fluorescent as a dry compound and is impregnated on a dry tape for use in one of the nerve agent alarms If a nerve agent containing the phosphorus—fluorine bond (P—F), such as sarin or soman, passes through this tape, the agent reacts with and strips off the aluminum morin and leaves a black nonfluorescing compound The absence of fluorescence indicates the presence of nerve agent

Because detection of biological agents requires a sensitive technique, fluorometric principles were investigated Fluorometric analysis is about 10 times more sensitive than colorimetric analysis Several concepts for biological detection also make use of fluorescence and are described in par 4-4

4-2.3 ELECTROCHEMICAL

Electrochemical and absorption spectroscopy are comparable in function because both use wet chemistry methods and both depend on a reaction of nerve agents with a substrate to produce a compound of detectable moiety The electrochemical process produces a compound that is detectable as a change in potential between two electrodes, whereas the absorption process produces color change, which is analyzed spectroscopically

Under appropriate conditions a number of chemical reactions may result in the development of a potential in a cell Such a reaction may also alter the conductivity of the solution in the cell and thus cause a change in potential The introduction of a G-agent with the P—F bond into a cell containing 0 04 mL of isonitrosobenzoyl acetone (IBA) results in the formation of a cyanide ion (CN^-) These reactions are shown in Fig 4-7

The reactions produce one mole of CN^- per mole of G-agent reacting at pH 9 3, the pH in the reaction cell The released cyanide ion is detected electrochemically and shows the existence of a concentration of organophosphorus agent in the air (Ref 4)

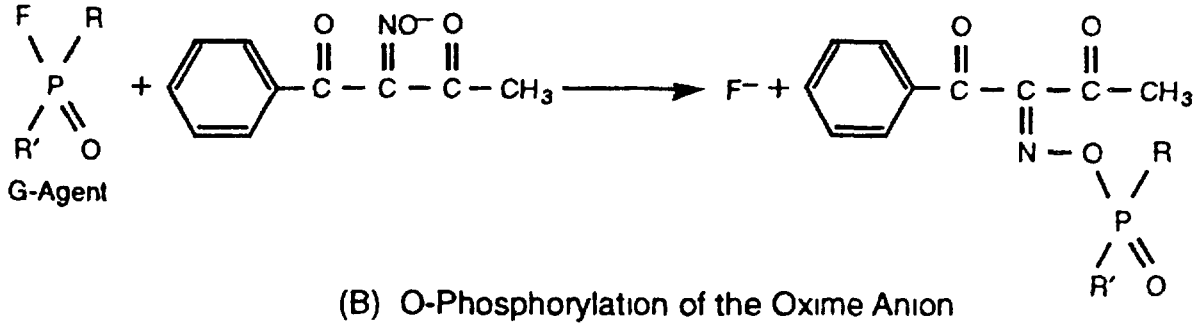
Reactions with G-agents are very rapid V-agents are converted to more chemically reactive compounds by passing the airstream through a conversion filter, which converts the V-agents to G-type compounds When sufficient CN^- has been produced to result in a cell voltage that exceeds a preset threshold of 15 mV, an alarm is activated

The biochemistry of enzymes has been investigated for automated application The resulting detectors have features similar to those of the early wetted tape system, however, the detector monitors electrical potential across a cell in which the wetted reaction medium is held The presence of an anticholinesterase agent inhibits the hydrolysis of the substrate by the enzyme and causes a change in potential across the cell

Prototype models of the electrochemical detector have good sensitivity, 0 1 mg/m^3 for GB and a response time

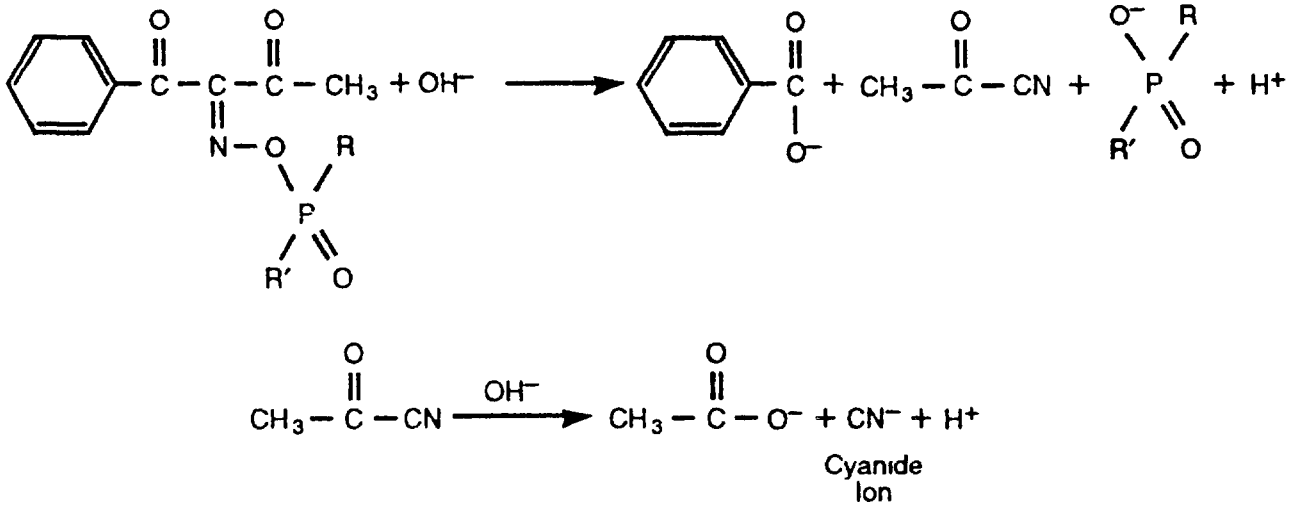
Isonitrosobenzoyl Acetone (IBA)

(A) Formation of the Oxime Anion



G-Agent

(B) O-Phosphorylation of the Oxime Anion



(C) Cleavage of Oxime Phosphonate (Rapid) and Formation of Cyanide Ion

R = CH_3

R′ = $OCH(CH_3)_2$, $OCH(CH_3)C(CH_3)_3$

Figure 4-7. Reaction of G-Agent With IBA

of 1 min These models are small—127 mm × 127 mm × 254 mm (5 in × 5 in × 10 in)—and weigh 3 6 kg (8 lb) Disadvantages include resupply and stability of required reagents, difficulty in automating the system, and difficulty of operation by soldiers of detectors using wet chemistry

The M8 chemical agent detector uses an electrochemical cell, which is constructed of plastic, as its source of detection The cell consists of silver and platinum electrodes, a silver bead scrubber, and a solution containing isonitrosobenzoyl acetone (IBA) The combination senses any change in potential when agent is present

4-3 PHYSICAL METHODS

Physical methods of CB agent detection and monitoring rely on the agent molecule and its structure, which determines its response to various forms of energy Several of the most promising technologies classified as physical methods are based on spectroscopic principles These systems rely on the fact that molecules exhibit a unique spectral signature when they are irradiated with energy in selected regions of the electromagnetic spectrum Fig 4-8 illustrates the electromagnetic spectrum with characteristic regions marked according to wavelength

Characteristic molecular spectra occur in a broad segment of the electromagnetic spectrum, i e , ranging from the microwave region to the ultraviolet (UV) region CB agents exhibit various spectral characteristics across the ranges of the electromagnetic spectrum, therefore, some ranges can be readily adapted to CB detection techniques Other ranges, however, cannot be easily applied to CB detection techniques

4-3.1 SPECTROSCOPIC PRINCIPLES AND TECHNOLOGIES

The spectroradiometric sensing and detection of CB agents in any form (liquid, aerosol, or vapor) generally require four distinct yet interrelated components and/or characteristic features, including (Ref 6)

1 A source of electromagnetic radiation

2 A physical phenomenon in which the interaction of the agent and electromagnetic radiation results in some modification of the radiation

3 A receiver or detector of the radiation signal

4 A signal process or computer-based algorithm that determines whether the modification to the incident radiation correlates to some predetermined or likely pattern

Sources of electromagnetic radiation in these spectroradiometric concepts can be classified as either passive or active Passive systems use the naturally occurring radiation from the background, the atmosphere, and/or the characteristic emission from the agent itself as a source, whereas active systems artificially stimulate the agent cloud by employing their own source of radiation The most common active radiation source for detection systems is the laser, which can produce coherent radiation in wavelengths ranging from the ultraviolet to the infrared (IR) regions In the microwave and millimeter wavelength region, active radiation sources include klystrons and magnetrons

Extensive research is being conducted in the development of frequency-agile, continuously tunable lasers that are capable of producing coherent radiation over wide spectral intervals Such lasers will give detection and monitoring systems much greater flexibility by providing spectral data in the most useful spectral wavelength regions Increasing the number of spectral wavelengths monitored provides a higher resolution image to perform interference discrimination schemes

Several relevant physical phenomena may occur when electromagnetic radiation is incident on a gas or aerosol sample (cloud) in the atmosphere The signal is "transmitted" if radiation passes through the sample unaltered Although this transmission phenomenon is of little interest to detection equipment designers, it does allow passage through the atmosphere of radiation that provides a reference for the detector system

The remaining physical phenomena of absorption and scattering provide the basis for the majority of spectroscopic sensing systems Absorption and scattering are dependent on the molecules in the path of the radiation, as well as on the wavelength of the radiation Thus it is possible to design and develop CB detection and moni-

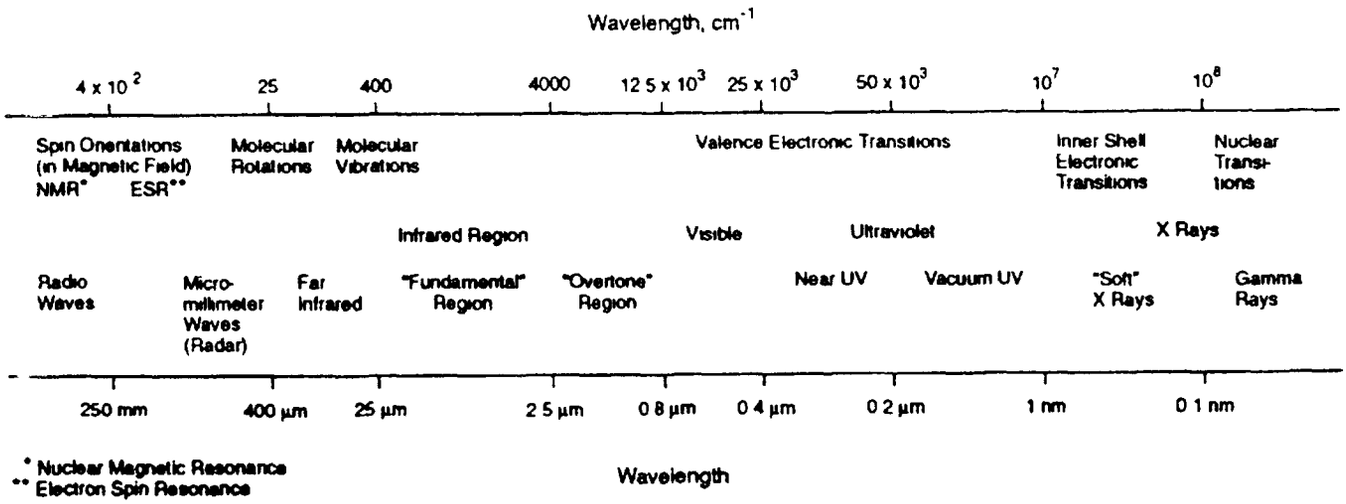


Figure 4-8. Schematic of Electromagnetic Spectrum (Ref. 5)

toring systems that spectroscopically monitor these phenomena and respond to the characteristic spectral responses of the agents of interest

Selection of the most appropriate spectral region for sensing of CB agents relies primarily on three considerations The first consideration is the ability of the particular radiation wavelength to propagate through naturally occurring and common atmospheric constituents For example, the far infrared region (25-500 μm) exhibits intense absorption by water vapor under rather common atmospheric conditions This intense absorption limits its utility for CB agent detection techniques

The second key parameter is the choice of wavelengths for which agents of interest exhibit characteristic and appropriate, strong spectral features, i e , strong absorption or scattering An extensive data base of agent and simulant spectral responses is a basis for determination of the most appropriate and effective spectral regions for CB detection technologies

The third critical consideration concerns the spectral responses of possible interferents and obscurants, either natural or induced Detection techniques on the battlefield are useful only if they can operate and perform with high reliability in the presence of a variety of obscurants and interferents Knowledge of the spectral features of possible interferents and obscurants is essential to development of discrimination algorithms used to distinguish possible interferents from CB agents

A brief overview of the spectral characteristics of agents of interest for wavelengths ranging from the microwave and millimeter wave region through the ultraviolet region is presented in the paragraphs that follow

The microwave and millimeter wave region includes radiation wavelengths of 500 μm or greater Spectral features of agent molecules in this region are caused by molecular rotational transitions Although durable sources of radiation are available in this region, absorption measurements must be performed at low pressures (<130 Pa), and these low pressures significantly limit the application of microwave spectroscopy to CB detection in the lower atmosphere

The infrared region of the electromagnetic radiation spectrum includes wavelengths ranging from 0 7 to 500 μm Infrared spectroscopy, as applied to CB detection, uses the unique molecular spectral characteristics of the various agents within the infrared region as a basis for detection Within the infrared region three subranges exist for which the feasibility and applicability of CB detection techniques vary significantly

In the far infrared region (25-500 μm) spectral characteristics are driven primarily by rotational transitions and vibration bands The use of infrared spectroscopy as a means of CB detection is extremely limited in this region due to the presence of intense water vapor absorption under common atmospheric conditions Water vapor absorption effectively overwhelms the absorption characteristics of other atmospheric matter, including CB agents

In the middle infrared region (2.5-25 μm) spectral features are due to fundamental and combination vibration rotation bands This particular region of the infrared spectrum is often referred to as the "electromagnetic window" for spectroscopic sensing of chemicals and gas. The most extensive research has been conducted in this region Spectroscopic analysis in this region is the most fully developed and is used quite widely for both military and civilian applications

Within this region, chemical agents (particularly the organophosphorus nerve agents) exhibit their strongest absorption bands in relation to other atmospheric constituents Fig 4-9 shows how several absorption peaks for GB occur in the 8-12 μm region, these peaks correspond to wavelengths at which the greatest energy absorption occurs High energy absorption is essential in order to obtain a high level of specificity. Many interferents, particularly dust and smoke, have strong spectral features in this region, thus high-resolution spectral images become a requirement for input to discrimination algorithms Fig 4-10 illustrates this problem through a presentation of absorption spectrums for several agents and a common dust

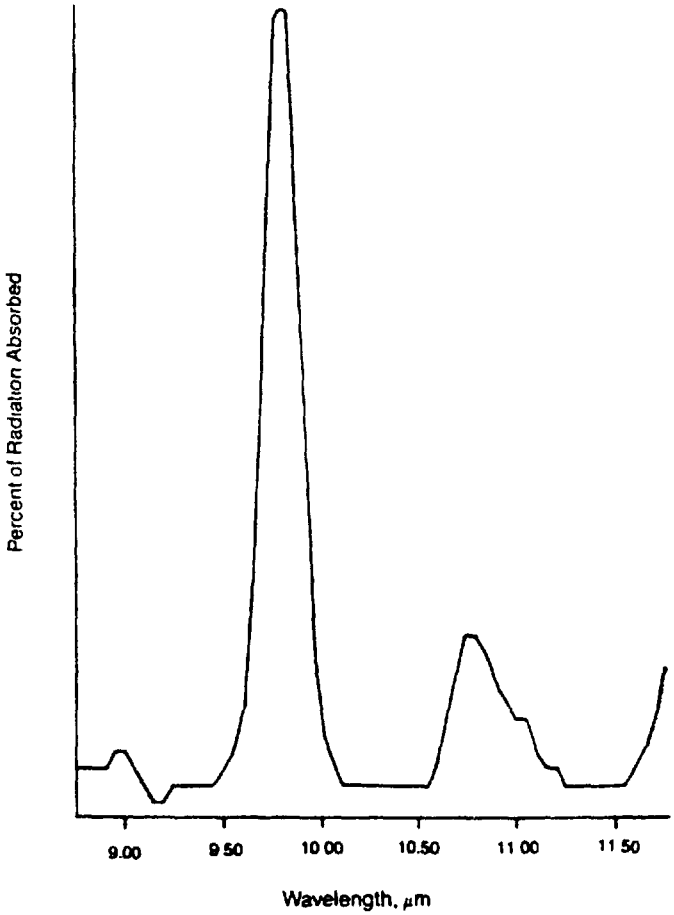


Figure 4-9. GB Spectrum (Ref. 7)

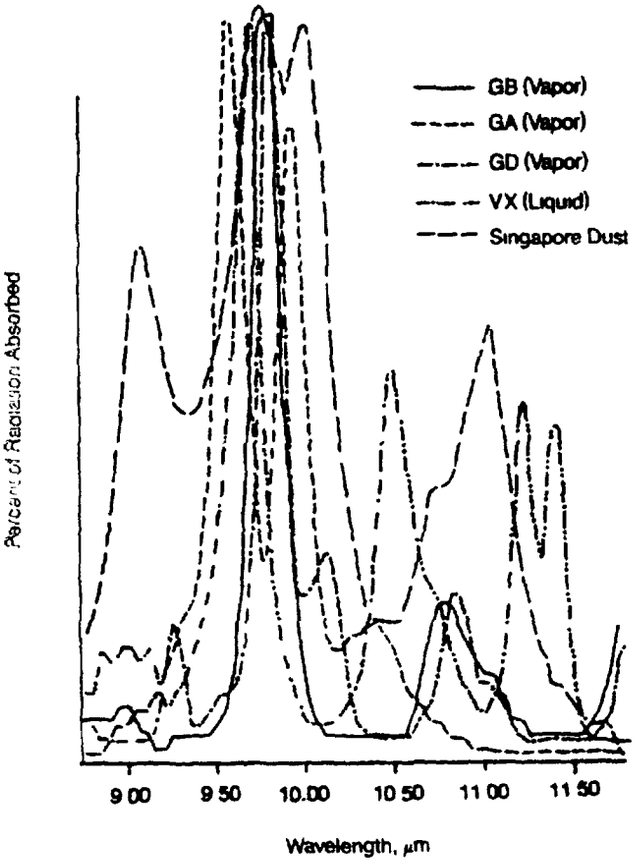


Figure 4-10. Discrimination of Nerve Agents Versus One Type of Dust (Ref. 7)

Vibrational overtone and combination bands dominate the spectra in the near infrared region (0 7-2 5 μm) The spectra of CB agents in this region are approximately 100 times weaker than those encountered in the middle infrared region and thus limit the usefulness of the near infrared region for CB detection and monitoring systems

Spectral characteristics in the visible region (0 4-0 7 μm) are caused by electronic transitions Few molecules have absorption bands in this region, so its usefulness for CB sensing is limited Beyond the lack of agent absorptive bands in this region, significant scattering due to aerosols and dust particles in the atmosphere further restricts the applicability of this region

Electronic transitions determine the spectral features in the ultraviolet region (0.25-0 4 μm) Although all molecules have electronic absorptive bands, few molecules have characteristic resolvable bands in the ultraviolet region

Several agents of interest, particularly biological agents, exhibit the phenomenon of fluorescence when irradiated by ultraviolet energy When these agents are irradiated with electromagnetic energy in the UV region, they often fluoresce or emit radiation in the IR region Fig 4-11 graphically depicts the fluorescence phenomenon Several promising new technologies that use ultraviolet radiation may be particularly applicable to detection of biological agents

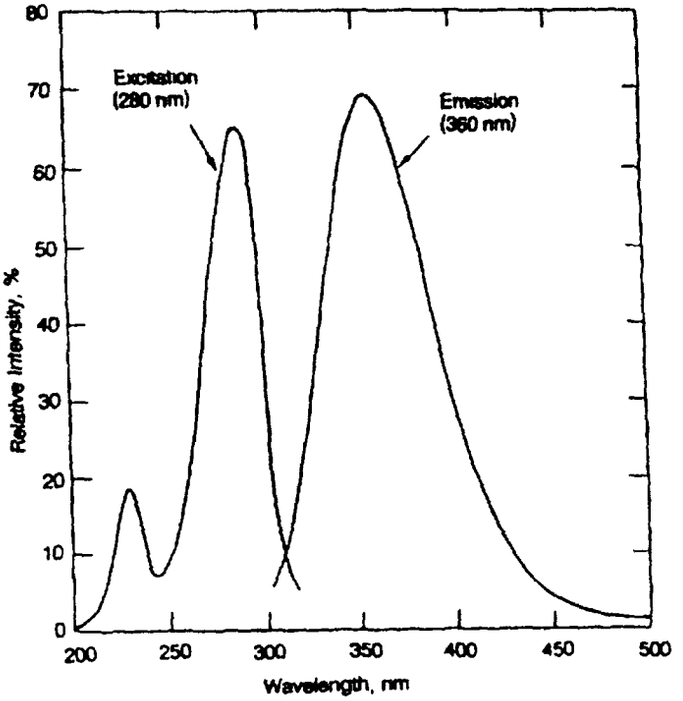


Figure 4-11. Fluorescence Phenomena (Ref. 8)

Analysis of the scattering and fluorescence phenomena for CB detection systems usually requires the use of an active source, such as a laser. Like absorption, scattering of incident radiation is dependent upon numerous parameters The most significant parameters are the agent of interest, the particle size, and the wavelength of the incident energy Rayleigh scattering occurs when the wavelength of the incident radiation is much larger than the particle size, but Mie scattering is characterized by a sharp increase in the amount of energy affected and occurs when the particle sizes are of the same order of magnitude as the incident wavelength Of special interest is Raman scattering, in which the scattered light is shifted in frequency according to the particular agent

Another major component of a spectroscopy-based detection system is the receiver, or detector, of the radiation signal Several spectroradiometric detection approaches and concepts have been and are being pursued The receiver configuration depends largely upon the wavelength region and the characteristics and properties of the physical phenomena being monitored

Due to the strong and unique spectral features exhibited by the traditional chemical agents in the IR region and the low natural attenuation of radiation in this region, numerous concepts, both active and passive, have been and are being developed to exploit these features Of particular interest is the 8-12 μm segment of the infrared region, in which the chemical agents exhibit their strongest absorptive bands The spectral data base of CB agents in this region is quite thorough

By contrast, spectral characteristics of biological agents are more pronounced in the ultraviolet region. For this reason, several spectroradiometric approaches have been studied for biological agent detection using ultraviolet radiation

The paragraphs that follow summarize the major spectroscopy-based concepts that have been and are being researched for CB detection systems

4-3.1.1 Interferometry

The Fourier transform interferometer is probably the most fully developed remote detection system operating in the infrared region of the spectrum This passive concept produces interferograms of the radiance observed in a narrow band filtered region of the infrared spectrum to obtain absorption spectrums Systems based on this concept measure and store the spectral information that characterizes the scene, or background When an agent cloud intervenes between the detector and background, the spectral characteristics are altered by the absorption and emission properties of the agent Fig 4-12 presents a schematic of this principle The altered spectral image is compared to the known spectral images of CB agents, and detection occurs when the two images coincide

4-3.1.2 Differential Absorption Light Detection and Ranging

Many in-use and developmental systems employ differential absorption LIDAR (DIAL). These systems measure the relative absorption of laser energy at two or more wavelengths For chemical agent detection, laser energy in the 8-12 μm region is directed through the atmosphere and reflected back to the light detection and ranging (LIDAR) system from background terrain (topographical reflection) or atmospheric gases (distributed reflection) Fig 4-13 presents a schematic of this principle. The returned laser light is collected by an optical receiver, and the intensity is measured by an infrared detector

Laser wavelengths are selected that exhibit large differences in absorption characteristics by the target gas and/or aerosol and are affected by background gases resident in the atmosphere By subtracting an absorbed return from a nonabsorbed return, the detector can determine the presence of an agent cloud, identify the agent, and measure its relative concentration. A more complex spectral pattern analysis of many different laser

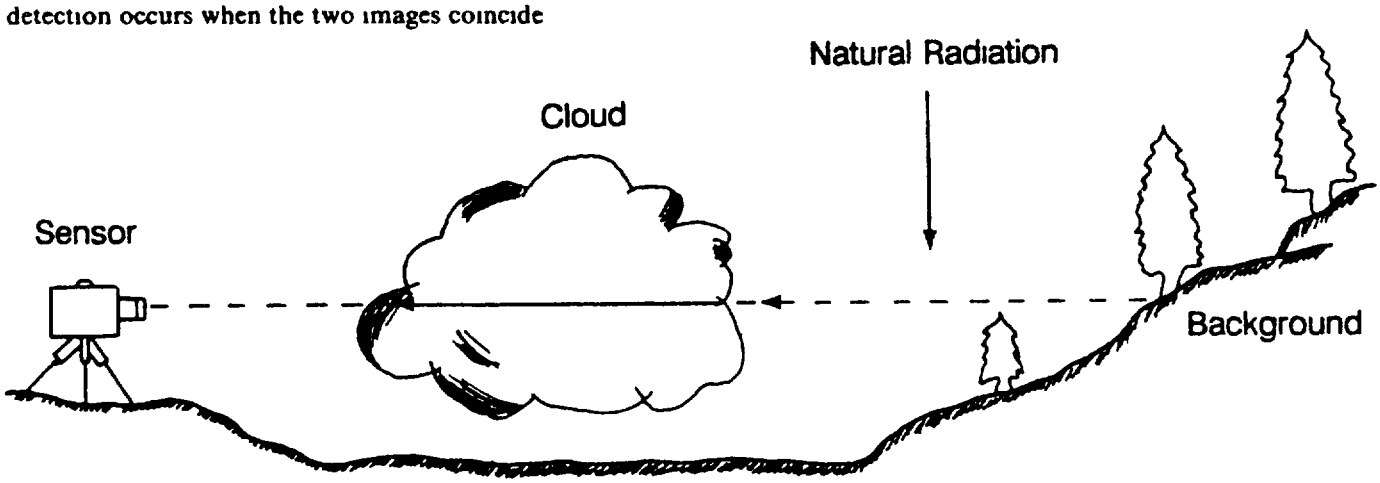


Figure 4-12. Passive Infrared Detection Schematic (Ref. 9)

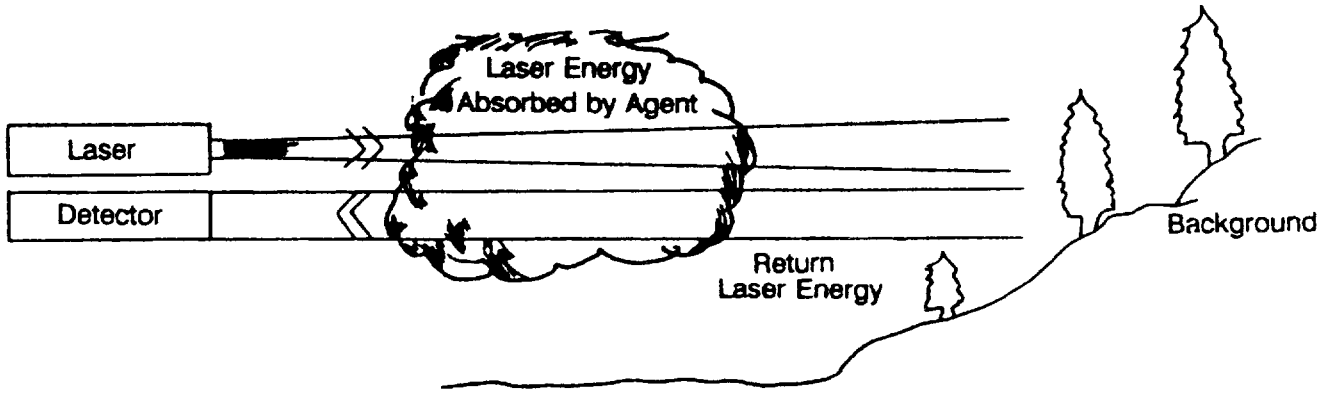


Figure 4-13. Differential Absorption (Ref. 9)

wavelengths enables pattern recognition algorithms to discriminate between interferences and agent clouds

DIAL concepts have been tested and proven to be very effective for detection of chemical agents in the vapor phase, however, detection probabilities for chemical agent aerosols, liquids, and biological agents is limited

4-3.1.3 Differential Scattering (DISC)

As discussed in par 4-3 1, the scattering of radiation is dependent on the particulate and its size, as well as on the wavelength of the incident radiation DISC relies on the characteristic spectral backscatter signatures of chemical agent aerosols and surface contaminants Fig 4-14 illustrates this concept The differential in reflected or backscattered laser energy is monitored by an infrared detector and is processed by computer to identify the aerosol or surface contaminant This technique is quite effective for detection of chemical agent aerosols and liquids Although detection of biological agents through DISC concepts is theoretically possible, its effectiveness has not been proven

4-3.1.4 DISC/DIAL

State-of-the-art detection systems have combined both differential scattering and differential absorption LIDAR (DIAL) techniques to provide chemical agent detection capabilities for all forms of the agent, including vapor, aerosol, liquid drops, and surface contamination Current systems are large and lack the ruggedness required for field use, but extensive efforts are in progress to reduce their size and increase their ruggedness DIAL concepts readily enable detection of agents in the vapor phase, whereas DISC provides detection capabilities for agents in the aerosol or liquid phase Thus the combination of these two concepts provides for detection of chemical agents and for identification of the agents, quantification of the agents, and the range to the chemical agents

Fig 4-15 depicts the results of a chemical agent simulant DISC/DIAL test conducted at Dugway Proving Ground, UT Fig 4-15 shows how DISC/DIAL can be a very powerful tool to detect, quantify, and monitor selected chemical agents

4-3.1.5 Raman Scattering

LIDAR systems using Raman scattering are theoretically capable of measuring concentrations of certain gaseous agents in the atmosphere As laser light is scattered by gaseous molecules, its frequency shifts The magnitude of the frequency shift is agent dependent, thus the measurements yield identification of agents, their concentrations, and ranging information The efficiency of Raman scattering is low, however, so that only relatively high concentrations of gases can be detected, and very powerful lasers are required to achieve even this level of detection

4-3.1.6 Laser-Induced Fluorescence

Laser-induced fluorescence techniques have been used primarily to perform water contaminant measurements and mineral surveys The technique is also applicable in theory to the detection of aerosols (chemical or biological) dispersed in the atmosphere or deposited on the ground or on vegetation

The system configuration is not unlike a LIDAR system A laser pulse of a specific wavelength is directed toward the target, and the return light is collected and analyzed The fluorescent return from the target is of a longer wavelength than the transmitted pulse, and it is easy to separate the fluorescent signal from the light scattered by the target Three types of information associated with this type of fluorescent measurement provide the basis for discrimination and resulting detection (1) the wavelength of the interrogating laser transmitter, (2) the spectrum of the return light, and (3) the temporal aspects of the fluorescent process

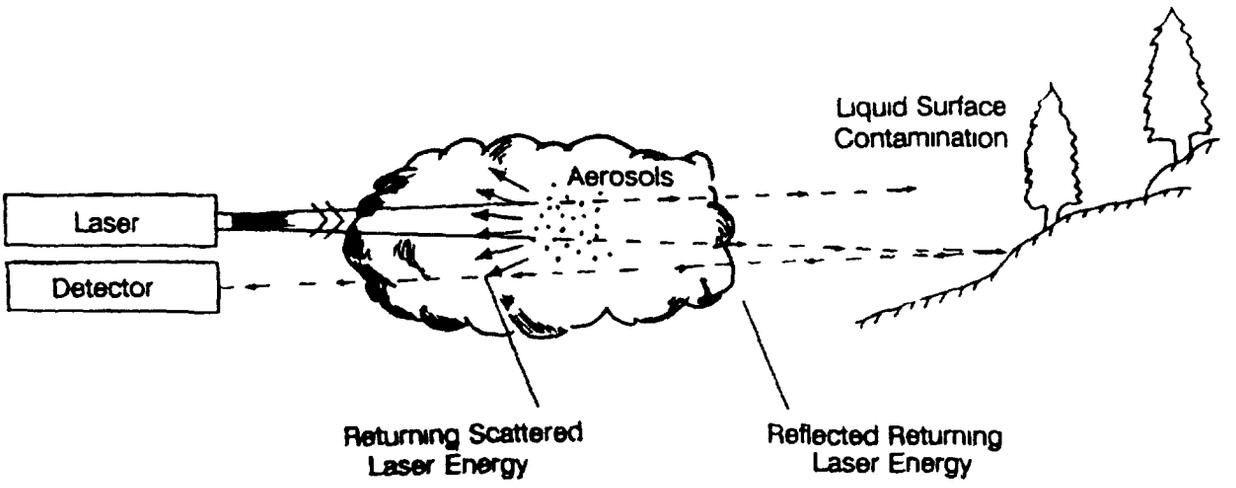


Figure 4-14 Differential Scattering Principle (Ref. 9)

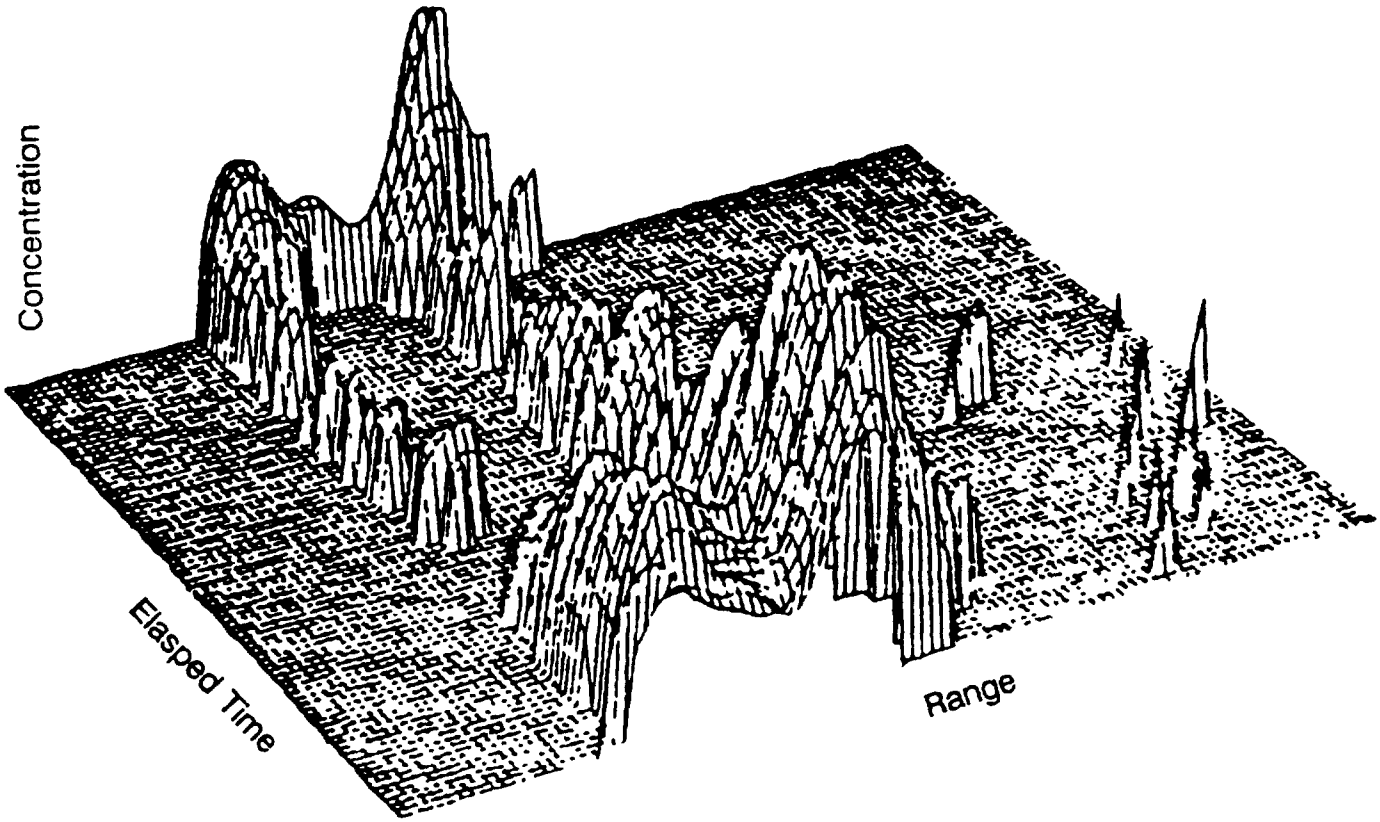


Figure 4-15. DISC/DIAL LIDAR Experimental Results (Ref. 10)

This technique appears promising for detection of biological agents that exhibit fluorescence when irradiated with ultraviolet radiation Many biological agents emit infrared radiation when stimulated in the ultraviolet region

4-3.1.7 Laser-Induced Breakdown Spectroscopy

Laser-induced breakdown spectroscopy (LIBS) uses a focused laser beam to vaporize aerosol particles, induce molecular dissociation, and excite atomic and ionic spectra Elemental emission spectra of agent signature constituents, such as phosphorus, chlorine, fluorine, and arsenic, have already been measured to the parts per million level The specificity and sensitivity for selected agents should be assessed in order to determine whether or not LIBS is a potential remote sensing technique for CB agents

4-3.1 8 Circular Intensity Differential Scattering (CIDS)

CIDS is a technique whereby circularly polarized light is scattered A sample is illuminated by left circularly polarized light and then by right circularly polarized light of equal intensity The difference between the intensity of the scattered left circularly polarized light and the intensity of the scattered right circularly polarized light divided by the sum of the intensities of the scattered left and right circularly polarized light is the CIDS signal

The CIDS signal for a particular sample varies with wavelength and angle of scatter and yields a CIDS signature that is characteristic of a particular sample The theory behind CIDS organism detection indicates that CIDS will result from samples that have a chiral or deoxyribonucleic acid (DNA) structure The specific signature depends on the physical dimensions of the chiral compound, such as radii and pitch

CIDS has some promise as a very sensitive, fast single particle detection and identification technique for sensing biological pathogens

4-3.1.9 Photoacoustic Spectroscopy (PAS)

When a molecule absorbs IR radiation, vibrational energy states in the molecule are excited When the vibrationally excited molecule collides with another molecule, the vibrational energy can be transferred to the second molecule as increased translational energy The increased translational energy of many such molecules is manifested as increased temperature of the gas If the gas is in a confined space, the result of the increased temperature is an increase in gas pressure When the IR radiation is turned off, the gas pressure returns to normal

If the IR absorbing molecules are sorbed onto a

surface, some of their vibrational energy is transferred to other molecules above the surface Thus laser-generated incident radiation, which is usually in the form of a gas or surface laser beam containing IR absorbers, results in a pulsed pressure or a sound wave This phenomenon is the basis of PAS An acoustic microphone can be used to sense the presence of the agent absorbing the radiation PAS is, therefore, an IR spectroscopic technique that can be used to detect extremely low levels of organic materials that are (1) in an aerosol or vapor state in the atmosphere or (2) adsorbed on and absorbed in surfaces It can be used for both sampling alarms and monitors for surface contamination The sensitivity of PAS is high and its specificity is moderate

4-3.1.10 Photothermal Beam Deflection

This detection technique is based on the same principles as photoacoustic spectroscopy The pulsating pressure of the gas around the absorbing molecules also results in a pulsating index of refraction of the gas A "probe" laser beam (separate from the excitation beam) passing through the gas is refracted or deflected because of this changing index of refraction The pulsed deflection of the probe laser beam can be detected relatively easily However, if an absorbing material is not present, the probe beam is not deflected

Both point sampling and short-range standoff sensing applications have been investigated Standoff sensing is currently not feasible because of insensitivity and extreme noise problems Point sampling applications of this technique are promising in the areas of airborne and surface sorbed material Sensitivity and specificity are expected to be essentially the same as those of PAS

4-3.1.11 Optical Waveguide (OWG)

Optical waveguides rely on total internal reflection of light within a coated optical fiber to detect the presence of chemicals or other materials Some of the incident light is absorbed by the exterior coated surface because the evanescent wave projects slightly beyond the surface of the fiber Therefore, this device is capable of detecting small changes in the optical properties of the coated surface, such as absorption or scattering

Coatings can be designed for either direct or indirect detection of toxic agents Direct detection requires a highly selective coating that undergoes a change in optical properties as a direct result of interaction with the agent Indirect detection can be achieved by using a coating that interacts with a common signal molecule that is specifically released from other recognition surfaces or elements in the presence of one or more of the agents of interest

The overall optical waveguide sensor can be very small and compact, can have low power consumption, and can be configured for use in either a vapor or liquid detection system

4-3.2 MASS SPECTROMETRY (MS)

When molecules of a gas lose electrons by exposure to an electric discharge or some other ionizing process in a mass spectrometer, positive ions of different masses are formed One of the properties of both positively and negatively charged particles is that their paths become curved as they pass through a magnetic field Thus the paths of positive ions are bent in the mass spectrometer as they pass between the poles of the magnet The extent to which their paths are bent, however, depends on the masses of the ions As a result, heavy ions emerge from between the poles of the magnet along different lines than those of the lighter ions In effect, an entering beam containing ions of various masses is sorted by the magnet into a number of beams, each containing ions of the same mass This expansion of the ion beam produces an array of different beams called a mass spectrum

This technique provides a very powerful tool for the identification of unknown materials in the laboratory (Ref 3) To support this work, a large data base of spectra has been compiled and is constantly being expanded Fig 4-16 is a simplified representation of this device

Laboratory mass spectrometers are large, complicated systems that require highly skilled personnel for their operation In particular, mass spectrometers that use high current density, low-voltage field ionization sources have been fabricated using microfabrication techniques (Ref 11). Although thin-film field emission cathode (TFFEC) arrays have not exhibited good stability and lifetime in the presence of contaminants, these devices are promising as future ionization sources for miniaturized mass spectrometers

Because mass spectrometry could be a sensitive, selective, and adaptable detector, various modifications of the basic equipment, each offering advantages for certain applications, have been explored Each technique

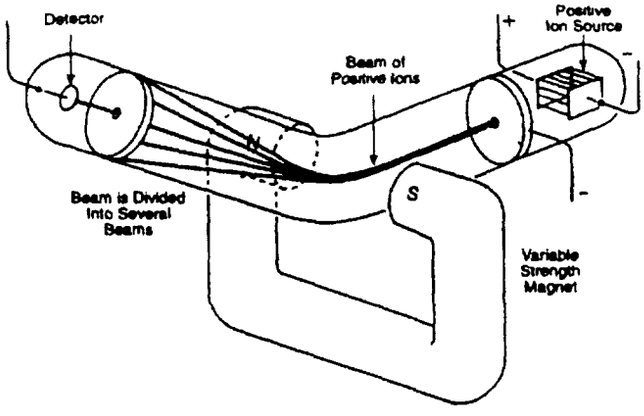


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Figure 4-16. Mass Spectrometer Principle (Ref. 3)

attempts to separate the chemical agent from possible interferents before analyzing its chemical composition The tandem mass spectrometer (MS/MS) achieves this goal through two stages of mass selection This complicated laboratory instrument has been miniaturized to an overall dimension of 370 mm × 180 mm.

MS/MS systems have also been constructed using a dual quadrupole mass spectrometer arrangement One device uses an atmospheric pressure inlet system with ionization by corona discharge (Ref. 11) Other novel features of this equipment include dual cryopumping arrays and a gas membrane interface to the atmosphere

The ion mobility spectrometer/mass spectrometer (IMS/MS) uses ion mobility to make the initial discrimination between agents The selected agent is then identified by the follow-up mass spectrometer stage A miniature of this device is possible by the use of highly miniaturized IMS devices and a miniaturized quadrupole MS

Mass spectrometer analysis with multiphoton ionization uses a laser to ionize the sampled atmosphere at atmospheric pressure The ions are then analyzed by various combinations of ion mobility or quadrupole mass spectrometers This technique is of interest because the laser may offer a high degree of selectivity for chemical agents However, the miniaturization of high-power lasers is well behind the miniaturization of other system components Also lasers require great quantities of power Future developments are necessary in order to reduce laser requirements before they can be the basis of a truly portable apparatus for field use

4-3.3 OTHER TECHNOLOGIES USING PHYSICAL METHODS

4-3.3.1 Piezoelectric Crystals

Materials adsorbed onto the surface of a piezoelectric quartz crystal cause the fundamental electrical oscillation of the crystal to shift The magnitude of the frequency shift is proportional to the amount of material adsorbed The crystal can be coated with a material to allow selective adsorption of materials of interest Small, inexpensive detectors can be fabricated using this concept, but their sensitivity is only fair Achieving specificity will require an array of crystals with various coatings and microprocessor analysis of the responses of the members of the array

4-3.3.2 Surface Acoustic Wave (SAW) Devices

A radio frequency (RF) signal can be propagated along the surface of a quartz crystal at a resonant frequency If some foreign material is adsorbed on the surface, this frequency shifts in wavelength, phase, and amplitude The surface can be coated with a specific material, usually a polymer, that allows selective sorption of organic compounds of interest

Because only the surface of the crystal transmits the RF signal, significant frequency shifts can occur with extremely small amounts of organic material SAW devices can be prepared by using microfabrication techniques and can be studied in arrays with various coatings by using pattern recognition techniques to analyze signals. The potential is very good for sensitivity and moderate for specificity

4-3.3.3 Ionization-Based Concepts

Systems that depend on the combination of ionized agent molecules in a selective fashion with clusters of water molecules form the basis for the first point sampling automatic alarm that does not use wet chemical processes These charged aggregates alter the electrical potential in a cell, and when this potential changes by a prescribed threshold level, an alarm is triggered. A more elaborate version of this concept uses the principles of ion mobility spectroscopy The instrument detects other agents and provides an identification capability by using a drift tube (a cylindrical tube containing a linear electrical field).

During developmental work with the M43E1 detector, an ionization detector known as the Army ionization detector was investigated for detection sensitivity and the required minimal detectable concentration The developers studied a number of interfering compounds (Interferences interact with the detection system similarly to the actual target agent. They affect the sensitivity of the detector and sometimes cause "false positives") Of those studied, only a few were detected at the same low concentrations as GB

One method by which to determine the detectability of a compound in an ionization detector is to form an ion-molecule cluster, as illustrated by the following reaction (Ref 12)

$$GB + H^+(H_2O)_n \rightarrow GB{\cdot}H^+(H_2O)_m + (n - m)\,(H_2O)$$

The detectability of an agent is dependent on its ability to pass unimpeded through the cluster The relatively large aggregates formed with nerve agent molecules have lower diffusion rates than those formed with molecules normally present in the air because diffusion rate is inversely proportional to molecular mass Therefore, the agent aggregates are more likely to pass through the cell and less likely to impact outside the cell on the baffle surfaces (Ref 13) The geometry of the cell and the movement of air and agent through the cell are shown on Fig 4-17

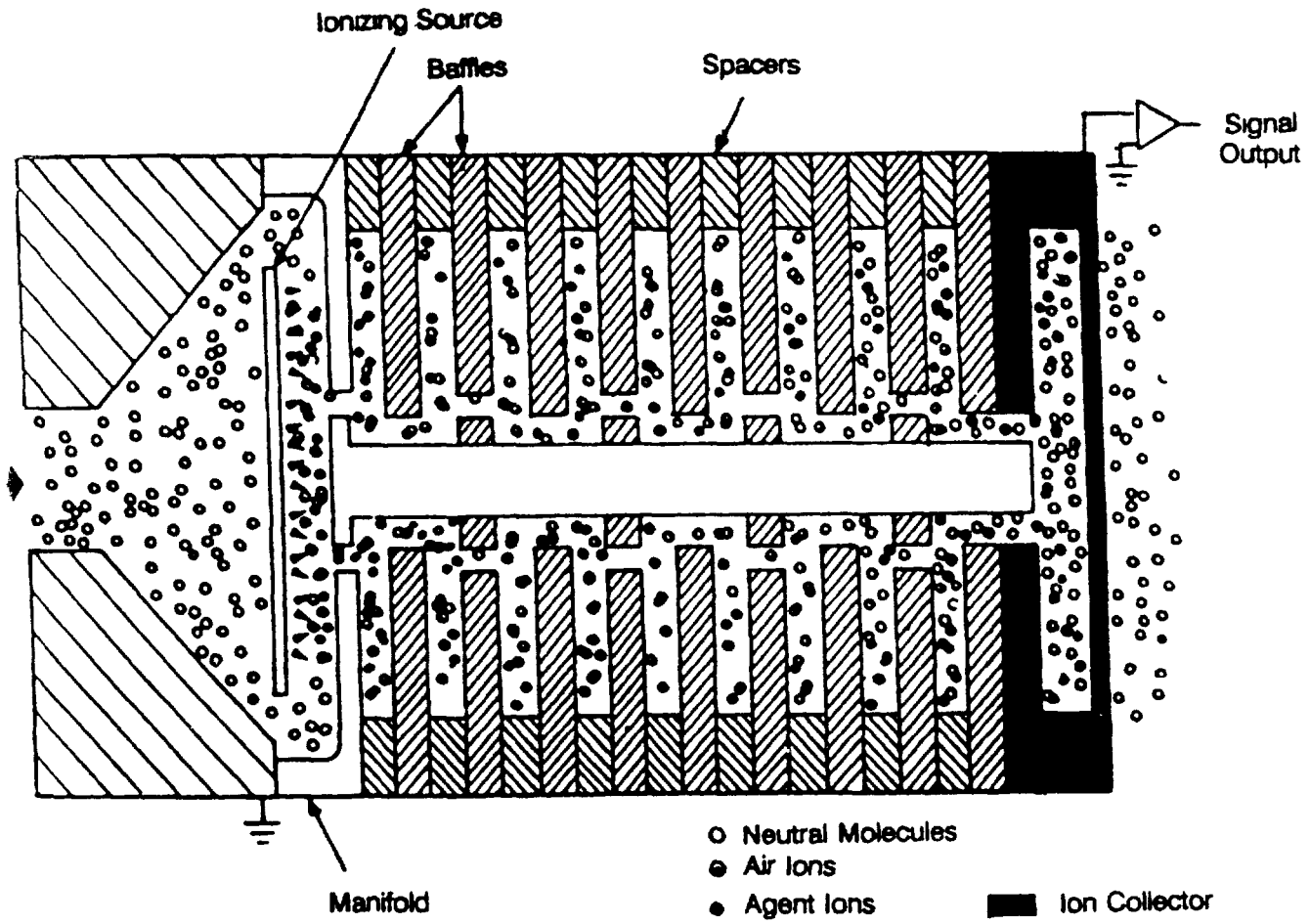

Figure 4-17. Ionization Detection Concept (Ref. 12)

In clean air, positive ions and negative ions have nearly the same molecular weights, so nearly equal numbers of ions reach the collector Because there is little net charge reaching the collector, only a small current is induced in the preamplifier circuit When a nerve agent is present, however, large positive ion clusters are formed near the source, and the negative ions are virtually unaffected

The positive ion clusters diffuse more slowly More of them survive the transport through the baffles and reach the collector more efficiently than the smaller negative ions Thus there are much larger currents in the preamplifier circuit when agent molecules are present. Common interferents generally produce lighter ions or less abundant ions than do agents, so the net currents from interferents are smaller even when their concentrations are orders of magnitude higher (Ref 13)

Under certain circumstances the specificity of the cell to a particular agent can be improved by using a voltage bias on the radioactive source This technique alters the ratio of positive and negative ions that reach the collector It allows the cell, for example, to be "tuned" to the negative ion-forming agent, lewisite In another circumstance a negative bias desensitizes the cell to smoke, but it retains significant sensitivity to nerve agents All of these effects can be used to attain a high degree of specificity to the agents

The ionization principle response, by its very nature, tends to be nonspecific Field testing revealed responses to some common interferents, such as smoke and vehicle exhaust It is, however, difficult to assess the consequences of these observations accurately from a practical point of view For example, standard test procedures expose the detector to very high levels of interferents when it is positioned just downwind of a smoke grenade

In contrast, when typical detectors based on this concept were operated in a field environment where no interferent was artificially introduced, excellent performance was observed In one test 10 Ionization Detecting System (IDS) units were operated continuously for 14 days under field conditions at the US Army Chemical Research, Development, and Engineering Center (CRDEC) (Ref 13) During these trials no false alarms occurred and only one unit experienced interrupted operation Outdoor testing yielded a probability of 0 9555 (confidence level of 90%) to complete a 168-h mission successfully A total of 26,000 h of operation was obtained

under a variety of laboratory and field conditions with a resulting probability of 0.9852 (confidence level of 90%) to complete a 168-h mission successfully. Significant false alarm problems, however, may occur when ionization detector systems are operated indoors.

The addition of a drift tube provides a means of "sorting" the ion clusters according to their mobilities, i.e., their charge and mass. The drift tube expands the capabilities of the initial ionization detection concept from nerve agent molecule detection to the inclusion of blister agents. Due to the sorting provided by the drift tube, nerve and blister agent ion clusters can be sorted and differentiated for specific detection.

4-4 BIOTECHNOLOGY METHODS

During early research efforts biotechnology methods for detection concentrated on three areas. Those areas were (1) combined biochemical and microbiological techniques, (2) electro-optical principles, and (3) scintillation counting techniques.

A major problem in detection of biological agents is the degree of background interference picked up by the detector. Vegetative cells and spores in the 1 to 2 μm range constitute a background problem. Aside from attempts to reduce complexity and cost and to improve reliability of the mechanical functions, several measures have been examined as possible solutions to the background problem.

One of the most recent innovations involves the use of pattern recognition methods to aid in the discrimination process. Pattern recognition takes advantage of the distinctive clustering characteristically displayed by particles of biological organisms when they come in contact with a tape. A pattern recognition algorithm is included in the software package of the detector to process the data from the tape-scanning optics and then to use the results of this analysis in the decision-making process.

4-4.1 CHEMILUMINESCENCE

One of the most successful approaches to the development of a detector for biological agents is based on the principle of chemiluminescence. Light is produced when hematin iron, a constituent of biological material, is reacted with luminol and peroxide in an aqueous medium. The reaction has been extensively studied and achieves high sensitivities. Examples of sensitivities are:

1. Hemoglobin 1×10^{-10} g
2. Hematin 6×10^{-12} g

These sensitivities equate to detected levels of 10^4 to 10^6 organisms with no pretreatment. Over a period of nearly 20 years, a great deal of effort was devoted to the incorporation of this concept into hardware that would satisfy the military requirements for a field detection system. These efforts were directed at:

1. Packaging
2. Sample processing
3. Optics
4. False alarm reduction
5. Field testing (simulants)

4-4.2 PARTICHROME

The particulate* nature of airborne biological agents led to the investigation of detection methods based on light scattering. These methods are potentially quite sensitive and possibly could detect single particles of a biological airborne cloud in a suitably designed electro-optical device. The partichrome system is a highly sensitive optical technology that continuously samples ambient air. Airborne particles are deposited on clear plastic tape, subsequently treated with a highly specific protein stain, and scanned for stained particles. These stained particles suggest the presence of a bacteria (Ref 14).

Light scattering theory is a well-developed area of physical optics. Its most serious problem, however, is discrimination between the agent and the naturally present background. All airborne particles could conceivably be detected and thus lead to a high frequency of false alarms.

Several schemes have been used to improve discrimination. One involves establishing a reference size range and an analytical size range. In spite of all the revisions in sample treatment, tape handling, and optical systems, the problem of false alarms persists.

4-4.3 ELECTRO-OPTICAL METHODS

Another important approach to biological agent detection uses electro-optical techniques. Screening the particle size in the sampled air, which imposes an upper limit on the size of particles in the sample, and exploiting the property of proteins to accept staining reagents achieve discrimination.

Staining is commonly used to enhance the visibility of organisms under a microscope. Staining also facilitates identification because different organisms respond to different staining reagents. In a detection system the sample is collected by impaction on a sticky tape, treated to improve the reception of the stain, and then counted. Discrimination is enhanced during the counting step by viewing the sample field through colored optical filters that accentuate the stained hue of the organism.

4-4.4 TAGGED ANTIBODIES

Two concepts using tagged antibodies have resulted in major development efforts in biological detection. One of

*Refers to the fact that biological organisms are small particles of matter. All known dissemination methods for biological agents result in an airborne cloud in which the particles consist of clusters containing varying numbers of organisms.

these methods involves fluorescent dyes for the tag, the other uses radioactive isotopes

The concept of tagged antibodies presents an extremely sensitive detection technique for biological agents It is also specific because it offers relative freedom from interference and false alarm problems This method can be adapted to new organisms whenever they present themselves

The tagging process can be described as, "When bacteria are injected into an animal, it responds by producing in the bloodstream soluble substances which will combine with the bacteria The injected bacteria are the antigen, and the soluble substance is the antibody, the combination of antigen with antibody is a serological or an immunological reaction It is possible chemically to couple the antibody to a fluorescent dye such as fluorescein When the fluorescein-labeled antibody combines with bacterium—and this specimen is viewed by fluorescent microscopy—the organism appears luminescent indicating that an antigen-antibody reaction has occurred "(Ref 15) The tagging process is the basis for the fluorescent antibody staining technique (FAST)

The radioactive version differs only in that the fluorescent tag is replaced by a radioisotope and that the method of observing and recording the organisms uses a scintillation counter rather than an optical system (ultraviolet microscope) Detections, based on extrapolated data, indicate sensitivities as low as 0 4 cells per liter This version is the basis for the radioactive-labeled antibody staining technique

The major problems associated with these approaches are

1 Production of large quantities and types of antibodies
2 Viruses and rickettsia are not readily detectable
3 Radioactive waste disposal
4 Antisera are difficult to store and very expensive
5 Nonspecific attachment of antibodies to ambient background materials

Some of these problems have been overcome First, there is the prospect of using monoclonal antibodies developed and produced in the commercial market These antibodies have highly defined specificity Second, a new measurement technique involving a laser-powered flow cytophotometer will greatly improve the quality of the data base The cytophotometer should allow the study of fluorescent antibody staining to be extended from bacteria to the much smaller rickettsia and viruses

4-4.5 OTHER BIOTECHNOLOGY METHODS

Other concepts have been or are currently being researched and developed (Ref 16) These schemes are based on biochemical principles, and in many cases they have the potential for high sensitivity and specificity It is interesting to note that in all cases these approaches differ from the systems of earlier years that were dominated by electro-optics

4-4.5.1 Polarization of Fluorescence

Using polarization of fluorescence to detect biological agents was investigated because it offered a fast, simple physical method for quantifying the nucleic acids present in all biological agents The minimum amount of deoxyribonucleic acid (DNA) that can be detected is 1×10^{-6} mg/mL, which is equivalent to approximately 10^3 organisms. Improved instrumentation could detect lower concentrations of DNA Specificity studies showed that both types of nucleic acid found in cells, DNA and ribonucleic acid (RNA), cause polarization effects Proteins, however, such as bovine serum albumin and ribonuclease, do not cause any measurable fluorescence

Direct staining of bacterial cells and of cells stained with dilute fluorescent dyes specific for nucleic acids produces polarization of fluorescence If appreciable polarization values can be obtained in this manner, extracting the nucleic acids from the cells will not be necessary and a considerable amount of time will be saved

Problems have been encountered with this technique, e.g , light scattering effects caused by the cell suspensions and high levels of instrumental "noise" present in the commercial apparatus Also the polarization values produced by the direct staining technique are rather low, but it is hoped that further studies on dye binding will result in higher values (A proposed instrument with lower noise levels and optical improvements may result in more accurate and more reproducible measurements)

For detection purposes, this technique achieves a sensitivity of between 10^4 and 10^5 cells/mL or 10^{-6} mg/mL of extracted nucleic acid The projected overall response time is 1 to 5 min when the technique is used in conjunction with a high-volume air sampler Because both bacteria and viruses contain appreciable percentages of nucleic acid, detection by this method may be feasible

4-4.5.2 DNA-RNA Hybrids

The use of DNA-RNA hybridization as a tool for detecting biological agents is based on the fact that hybrids will form between the RNA and DNA of one organism and that these hybrids can be retained by nitrocellulose membranes This process has broad multiagent capability and great specificity for detecting particular pathogens The DNA-RNA hybrid method appears promising because of its apparent specificity Although the ultimate time response is expected to be less than 15 min, it may be too slow for practical use in the field

4-4.5.3 Esterase Methods

Esterase methods are sensitive to as few as one bacterium and have a response time of 5 to 10 min Several studies have been conducted to evaluate and improve the method prior to instrumentation One of these studies explored detection of bacteria after their aerosolization and collection In each case the viability of the cells and the esterase activity were determined The results indicate that esterase activity has a specificity corresponding to the viability of the vegetative microorganisms present For example, aerosolization in low humidity killed many of the organisms and yielded a corresponding decrease in esterase activity Impaction created problems with viable cell counts and gave low esterase values. Impingement, however, was less destructive than aerosolization to viability and esterase activity Spores, whether freshly prepared or heat shocked to destroy vegetative forms, were inactive to the esterase assay, but upon being placed in storage they showed good esterase activity

4-4.5.4 Vapor Phase Chromatography

Gas chromatography has been studied with the intent to automate the process into a sensitive detection device if the sample could be properly prepared Progress has been made in the use of a thermal degradation technique for sample preparation instead of the earlier esterification method, which was difficult to instrument. Although these thermal degradation experiments were preliminary, a workable device was constructed and applied to a number of samples

The degradation products obtained with *Bacillus globigii*, for example, are considerably different from those obtained with *Serratia marcescens* In general, most of the specificity characteristics formed with previously used methylation procedures are retained with the new procedure for sample preparation

4-4.5.5 Virus Detection Approaches

Virus detection has been pursued by both indirect and direct approaches The indirect approach is dependent on finding virus-associated materials that are characteristic of virus production Studies on the cellular effects of virus infection show a number of specific changes Three of them have been selected as possible sensing techniques

1 Lipid changes
2 Presence of polymerase
3 Presence of interferon

Response time for the indirect approach depends on the specific substance and on the readout system

Lipid differences have been demonstrated with vapor phase chromatography between normal and infected KB* cells with vaccinia virus The concentration and type of phospholipids appear to be independent of the nutrient medium metabolized by the infected cells The lipid composition of HeLa** cells infected with vaccinia increases even under lipid-free conditions Thus the lipid is directly related to the virus growth process and not to the concentration of lipid intake by the infected cell.

The direct approach to virus detection depends on the biological and physical characteristics of the virus The time required to grow virus in cell culture and organ culture has been reduced from weeks to a matter of days. Sensitivity has been reduced to less than 100 viruses, and specificity has been found to be reasonably narrow

4-4.5.6 Fluorometric Assay of Heme Proteins

An assay method for porphyrins based on conversion of a nonfluorescent heme protein to its fluorescent analog by treatment with oxalic acid has been evaluated as a detection scheme for bacteria Porphyrins, which are important in the metabolism of most microorganisms, can occur either in the free state or as a metalloporphyrin complex, usually of iron or copper The iron porphyrins form the prosthetic group of heme proteins, such as catalase, peroxidase, or the cytochromes, all of which are connected with the respiratory system Although iron porphyrins are not fluorescent, they can be made so by acid treatment, which removes the iron from the porphyrin nucleus

The sensitivity of 10^4 to 10^5 bacteria/mL attainable by this method (10-min reaction at 120°C) is at least one order of magnitude lower than the target objective Other objectionable features include the high reaction temperature, the high noise level, and the erratic behavior of the phototube when it is operated at maximum sensitivity

*KB, or *killer bursa*, cells are an extract of avian cells that function similarly to human liver cells

**HeLa cells are a unified cellular line that has been adopted as a standard for cancer and toxicology research HeLa cells produce polysaturated lipids in reaction to certain compounds

REFERENCES

1 TM 3-6665-205-10/2, *Operator's Manual, Sampling and Analyzing Procedures, Sampling and Analyzing Kit, CBR Agent, M19*, Department of the Army, September 1966

2 TM 3-6665-307-10, *Operator's Manual Detector Kit, Chemical Agent M256 and M256A1*, Department of the Army, January 1979

3 J E Brady and J R Holum, *Fundamentals of Chemistry*, John Wiley and Sons, Inc , New York, NY 1984

4 John Epstein, John Stevens, and John Renda, *Studies to Upgrade the M8 Alarm*, Report No ARCSL-TR-79024, US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, August 1979

5 R P Bauman, *Absorption Spectroscopy*, John Wiley and Sons Inc , New York, NY, 1962

6 A Panel Report (Numerous Authors) for US Army Chemical Systems Laboratory, *Application of Advanced Electro-Optics Technology to NBC Defense*, Report No IFAORS-216, Deepak Publishing, Hampton, VA, 1983

7 V James Cannaliato, *Remote Sensing of Chemical/Biological Warfare Agents*, ARCSL-TR-79067, US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, March 1980

8 *Review of Remote NBC Detection Using Infrared and Ultraviolet Technologies*, by SRI International, Menlo Park, CA, for US Army Armament Research and Development Command, Aberdeen Proving Ground, MD, 7 December 1982

9 R W Shaw, *Workshop on Remote Sensing for Chemical Defense*, US Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, 16-17 April 1985

10 Edward R Murray *et al*, *Exploratory Development of Remote NBC Detection Using Infrared Technology*, Second Annual Report, Report No CRDC-CR-86003, by SRI International, Menlo Park, CA, for US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, November 1985

11 Committee on Chemical and Biological Sensor Technologies, Board on Army Science and Technology, National Research Council, *Assessment of Chemical and Biological Sensor Technologies*, National Academy Press, Washington, DC, 1984.

12 Leo G Appel, R B Quillin, B C Schluter, and V O Meir, *M43E1 Detector Unit, Chemical Agent, Automatic Development Report, Special Progress Report*, ARCSL-CR-79002, by Honeywell, Inc, St Petersburg, FL, for US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, December 1978

13 Daniel M Nowak, James C Chalcraft, and John H Nickle, *Developmental Test/Initial Operational Test and Evaluation of the Automatic Chemical Agent Alarm Set, A/E 23D-1, IDS*, Edgewood Arsenal Technical Report, ED-TR-76114, Edgewood Arsenal, Aberdeen Proving Ground, MD, December 1976

14 A H Sarrafian and W H Hartung, *Pattern Recognition-Partichrome*, Final Report, 1107F, AMB Medical and Biological Systems, El Monte, CA, 27 September 1974

15 S Yaverbaum and A Pital, *Comparative Status of Radioactive and Fluorescent Antibody Methods as Applied to Biological Detection*, US Army Biological Laboratories, Fort Detrick, MD, August 1965

16 D J Sibbett *et al*, *New Concepts for BW Detection, Volume I---Technical, Covering Period 5 January 1966 to 4 January 1967*, Report No SGC 908R-2, Space-General Corporation, El Monte, CA, April 1967

BIBLIOGRAPHY

Baier, R E, *Survey of Remote Sensing Techniques for CB Detection*, ARCSL-CR-81024, by Calspan Corporation, Buffalo, NY, for US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, January 1981

Boyce, E W, Mumford, S A., *Report of Preliminary Testing of Rapid Chemiluminescence Breadboards*, ARCSL-TR-82079, US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, January 1973

Grant, W B, *Optical Bases for Remote Biological Aerosol Detection*, ARCSL-CR-77045, by SRI International, Menlo Park, CA, for US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, December 1977

Grant, W B, Witham, C L, *Remote Biological Aerosol Detection*, ARCSL-CR-78061, by SRI International, Menlo Park, CA, for US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, March 1979

Greenburg, David B, and Snyder, A, *Initial Study of the Laser-Induced Fluorescent Detection of Bacterial Metabolites*, ARCSL-TR-83042, US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, June 1983

Guire, P E, Wolfe, M A, *Aerosol System for the Biological Detector and Warning System*, ARCSL-CR-78016, by Midwest Research Institute, Kansas City, MO, for US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, November 1977

Lowenstein, Jack G, *et al*, *Detector, Analyzer, and Sampling Kits for Chemical Warfare Use*, Engineering Agency Special Report (ENASR) No PR16, Chemical Corps Engineering Agency, US Army Chemical Center, Aberdeen Proving Ground, MD, April 1965

Pital, A, Janowitz, S L, Hudek, C E., Lewis, E E., *Preliminary Observations on Fluorescein Isothiocyanate in Biological Detection*, Technical Memorandum 58, Project No 1C622401A071, US Army Biological Laboratories, Physical Defense Division, Director of Medical Research, Fort Detrick, MD, September 1964

Sarrafian, A H, O'Conner, J J, *Continued Development of Pattern Recognition Techniques*, ED-CR-76102, by Organon Diagnostics, El Monte, CA, for Edgewood Arsenal, Aberdeen Proving Ground, MD, January 1977

Shepel, Michael, *et al.*, *Discriminating Spore and Nonspore Bacteria by Use of Heat Coupled With a Spore Filter Tetrozolium Test*, ARCSL-TR-82020, US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, June 1982

Sibbett, D J , Carleton, L T., Nyborg, W L , Tenoso, H J , Witz, S , *New Concepts in BW Detection*, Quarterly Status Report No 3, Report No SGC 908R-3, Space-General Corporation, El Monte, CA, October 1966

Strange, R E , Benbough, J E , Hambleton, P , Martin, K L , *Joint US/UK Detection Trials The UK Manual Radioactively Labelled Antibody Technique ("RAST")*, MRE Report No 60, Microbiological Research Establishment, Portadown, United Kingdom, February 1972

Tribble, H , Shaffer, R , Shepel, M., Kraybill, W , Pital, A , *Detection of Broad-Group Biological Substances by the Time-Rate Chemiluminescence Reaction*, ARCSL-TR-77019, US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, July 1977

CHAPTER 5
DETECTION PROCESSES

This chapter discusses chemical and biological (CB) detection and how detection technologies are incorporated into the design of the detection processes of sample acquisition, sample analysis, and response or warning. The process of selecting the detection components for sample acquisition, sample analysis, and response is explained. Sample acquisition, how the sample responds to the detection technology, and how the collected sample is analyzed and processed are discussed. The response function includes the visual and audio alarm signal needed to warn troops of the presence of CB agents, as well as the electrical signal used to provide information after the alarm.

5-0 LIST OF SYMBOLS

A = cross-sectional area of agent cloud, m^2
C = agent concentration, mg/m^3
D_{LOS} = line-of-sight detector dose, mg
D_p = point sampling detector dose, mg
e = sampling efficiency (%) of detector, dimensionless
L = agent cloud path length (depth of cloud), m
Q = air sampling rate, m^3/min
t_r = detector response time, min
δ = efficiency of energy return, dimensionless

5-1 INTRODUCTION

In the design and development of CB agent detectors, the detection technology governs the design of the entire system from the sample acquisition process to the signaling process. This stage of design also may include other engineering aspects, such as the use of heated sampling lines, cases, or the ultimate size and weight of the final system.

Thus choice of the detection technology should receive major emphasis as the initial and most important part of development. Every aspect of the operational use of the device and the characteristics required by the user must be considered in the selection. The engineer must make careful projections of the detection technology laboratory performance into field operation. For example, as operational use requirements call for detection of lower and lower agent sensitivity levels, the selection process must include consideration of projected stability performance levels for use under field conditions.

In general, the greater the sensitivity of a technology, the greater the number of false alarms. In some cases, however, this tendency can be modified and reduced by selection of the proper detection process. A complete understanding of these processes is essential to selection of the detection technology.

The operational use concept for the detector defines how a device or item of equipment is to be used in the field to accomplish mission requirements. The operational use concept for the detector, therefore, has a major impact on the choice of the detection technology and the design of the detection processes. Thus this concept must be carefully analyzed before any selections or designs are undertaken. For example, if the operational use concept requires a device to monitor the inside of shelters, where personnel could be exposed to low concentrations of agents for relatively long periods of time, the detection technology must possess high sensitivity to agents but may not require a very high speed of response. Use of this type of detector would also allow design of detection processes that emphasize sensitivity and reliability rather than size and weight. On the other hand, if the operational use concept states the need for a device to protect frontline troops moving in a rapidly changing combat environment, simplicity may be most important and detection processes should be designed for minimum size and weight.

The designer must examine the operational use concept for a given detector in relation to the operational use concepts for all other detection systems in order to minimize the proliferation of such equipment and the accompanying cost, maintenance, and logistic considerations. Modifications to another detector may meet the use concepts for a new detection system so that both use concepts are fulfilled with a single detection system.

The major operations of a detection process are:

1. Sample acquisition, defined as the method by which the device obtains a portion of the atmosphere for examination.
2. Sample analysis, which is the actual examination of the atmosphere through chemical or physical means.
3. Response or alarm, by which the results of the analysis are processed and made known to the user.

Requirements in the operational use concept govern the selection of one of two broad classes of detectors: (1) point sampling or (2) remote or line-of-sight (LOS) sampling detectors. Fig 5-1 illustrates the major operations of the detection process.

The key difference between these broad classes of detectors, point versus line-of-sight, is in the sample

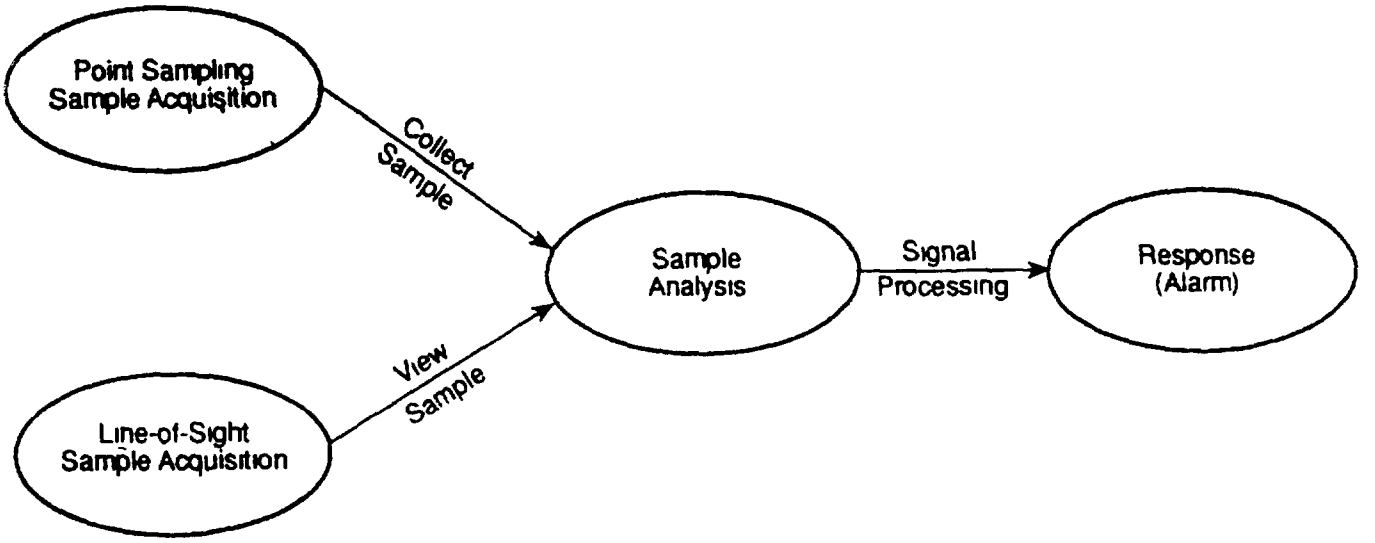

Figure 5-1. Major Operations of the Detection Process

acquisition process A point detector acquires the sample from a point in the atmosphere and then passes the sample continually or by batch to the sample analysis cell The M8A1 Alarm System is an example of a point detector

The M8A1 system, which is a fielded item, consists of the M43 or M43A1 detection unit and the M42 alarm As the air sample passes through the detector, the presence of an agent is determined by a chemical reaction that occurs among an oxime solution, a silver analytical electrode, and a platinum reference electrode The alarm is activated when the potential between each electrode, triggered by the chemical reaction, is increased

In line-of-sight detection the detector views a portion of the atmosphere along a line that extends to some point in space The detector processes a physical change in the atmosphere along this line when an agent intercepts it An example of a line-of-sight device is the XM21 Remote Sensing Chemical Agent Alarm (RSCAA) This system automatically scans for changes in the infrared (IR) spectrum differentiated between agent clouds and remote objects on the horizon Table 5-1 highlights some of the differences between point and line-of-sight detection

TABLE 5-1. COMPARISON OF POINT VERSUS LINE-OF-SIGHT DETECTION PROCESSES

SYSTEM CHARACTERISTICS	POINT DETECTION	LINE-OF-SIGHT DETECTION
Sample acquisition	Small area view Viewed at source Collected at source	Large area viewing at points in the atmosphere Remote location No collection
Sample processing	Batch processing—sample can be collected over time	Complex signal processing required
Sample analysis	Uses simple analytical techniques Can use prefilters to separate interferents	
Employment options	Small, lightweight, and portable Battery powered (limited)	Fixed and mounted on tripod or vehicle Adjunct power available

5-2 SAMPLE ACQUISITION

Point sampling of a chemical or biological agent involves acquiring a sample of the atmosphere from a point in space and then processing the sample through a detection cell

Devices using the point sampling acquisition process offer maximum flexibility in design at the present time For example, if the atmosphere contains interfering materials that could cause false alarms or mask a true alarm, a prefilter can be designed to remove the interfering material while allowing the agent to pass through Similarly, if greater sensitivity is required for the detector, the sample can be collected for a time and then passed to the analysis cell in a batch, this method effectively raises the concentration in the cell The sample atmosphere can also be separated from atmospheric dust by means of filters or separators of other types Because of these features, comparatively simple analytical techniques can be used on the collected sample to provide the required alarm

Line-of-sight sample acquisition involves viewing a portion of the atmosphere along a line that extends some distance in space and observing a physical change in the structure of the atmosphere where the agent is intercepted by this line An example is the change in infrared absorption between normal atmosphere and atmosphere containing agent The most important aspect of this type of detection is the fact that the agent need not be in the same location as the detector. The agent can be viewed from a distance so that advance warning of an agent attack can be accomplished The detector can be designed to sweep its detection line-of-sight across large segments of the battlefield so that large areas of atmosphere can be viewed and analyzed as long as the view is not obstructed by terrain features, such as hills, dense tree growth, or buildings

From an instrumentation standpoint the lack of flexibility in the LOS sample acquisition process is its major disadvantage Because the atmosphere is only viewed and not collected, dust cannot be filtered, interferents cannot be removed from the sample, and the sample cannot be heated or cooled Instead, the sample analysis or response detection processes must compensate for these shortcomings For example, without dust or interferent filtration, a more selective technology and/or a more complex and sophisticated signal processor must be used

The problems involved in the detection of biological agents are unique due to high sensitivity requirements and associated specificity problems Currently available detection technologies require a massive concentration of the agent in the sample acquisition stage and highly selective treatment to achieve specificity during sample analysis In addition, these technologies detect not only live pathogenic organisms but also respond to specific features of any biological material Thus the comparatively high concentrations of inert biological material normally occurring in the atmosphere must be considered Genetic engineering may lead to the development of specific immunoassay techniques for biological agents These technologies may alleviate the sensitivity and specificity problems associated with detection of these agents. Without the ability to concentrate an agent and filter out interferences, LOS detection of biological materials within the proper sensitivity range will require a major breakthrough in LOS detection technology

5-2.1 POINT SAMPLING COLLECTION

5-2.1.1 Chemical Agents

Point sampling devices require a certain amount of chemical or biological agent be collected from the atmosphere into a cell The ease or difficulty with which collection (sample acquisition) is accomplished depends on a number of factors One of the most important of these is the physical form of the agent, i e , gas, vapor, fine aerosol, large liquid drop, or solid particle

If the agent is present as a gas or vapor, it will pose no particular problem to sampling Agents in the form of fine aerosols up to about 5 μm in diameter can also be collected easily and efficiently A simple aspirating sampling tube will collect the agent as it collects the air without loss or bias because movement of the agent as gas, vapor, or as a fine aerosol is totally controlled by the movement of the air in which it is being transported

However, as the particle size increases, the behavior of liquid or solid particles becomes more and more dependent upon the increasing gravitational and inertial forces As particle size increases above 5 μm in diameter, gravity and inertial forces begin to overcome the forces exerted by the movement of air At 100 μm in diameter the rate and direction of fall are totally controlled by gravity and inertial forces at practical wind speeds Sampling such particles must rely on either simple fallout or very high aerodynamic sampling velocities, which in turn require very large expenditures of energy

Point sampling detectors are used primarily in the portable mode, therefore, size and weight are important characteristics If not powered by a generator, the devices are limited in the amount of energy—which translates into battery weight– that can be used to acquire the sample This need to conserve energy limits point sampling detectors to an airflow collection rate of 1 to 2 L/min, which does not provide sufficient energy to draw the large particles into the sampled airstream of the detector A typical sampling efficiency curve for gases and particles is shown in Fig 5-2

Liquid agent detectors must be used for large particles and thickened agents These liquid agent detectors have no vapor or aerosol sampling capability, they simply use a flat collector onto which the agent falls Liquid agent detectors are not capable of reliably detecting liquid

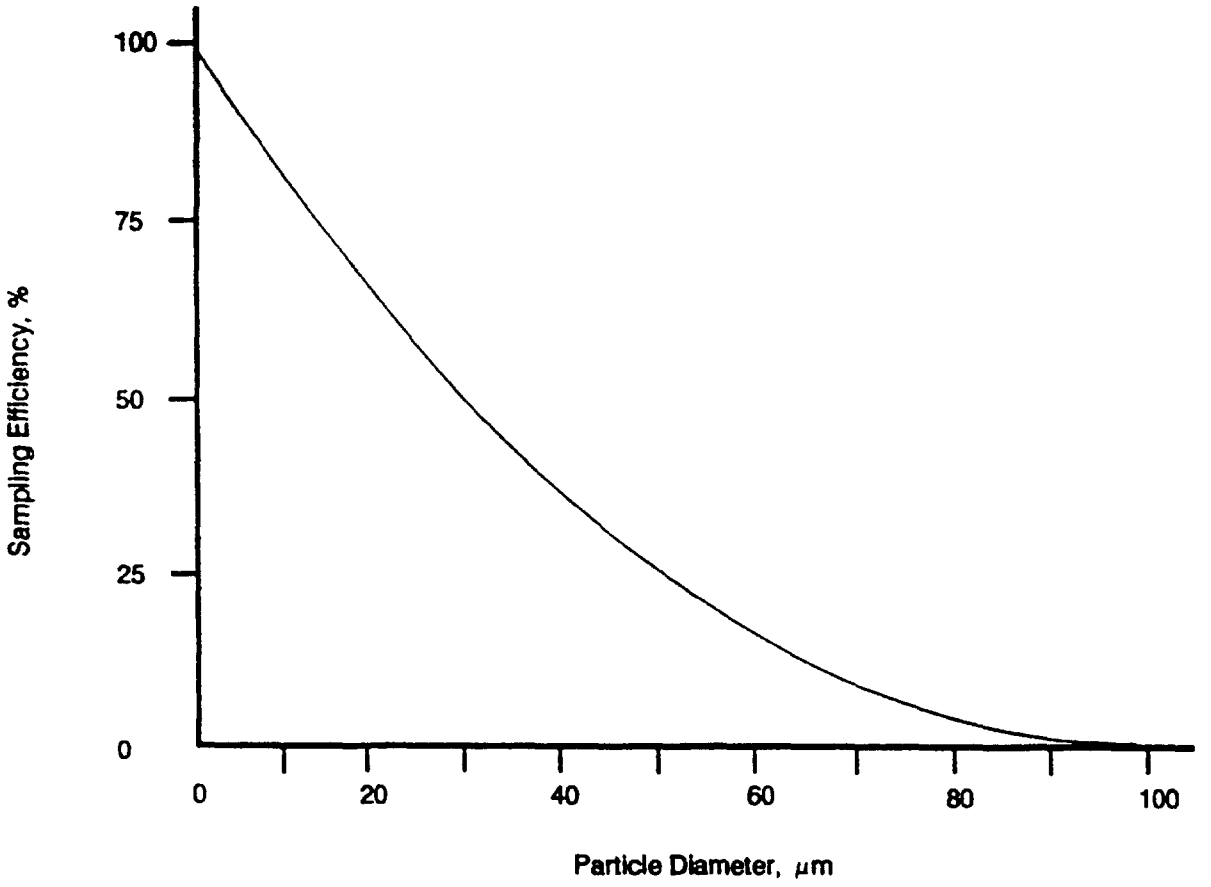

Figure 5-2. Illustrative Sampling Efficiency for a Typical Detector Sampling Nozzle

droplets less than 200 μm in diameter Comparison of the sampling efficiency of point sampling detectors (shown in Fig 5-2) to the detection efficiency of liquid agent detectors reveals a sample acquisition to detection efficiency gap for particles from approximately 50 to 200 μm in diameter

Whatever detection technology is used, the sensitivity of the device i e , minimum detectable concentration depends, in part, on the amount of agent that is collected in a given time frame D_p This relationship is illustrated by

$$D_p = eCQt_r, \text{ mg} \qquad (5\text{-}1)$$

where

D_p = point sampling detector dose, mg
C = agent concentration, mg/m^3
Q = air sampling rate, m^3/min
t_r = detector response time, min
e = sampling efficiency (%) of detector, dimensionless

Dose is the terminology used in toxicology for the mass of a drug administered to a subject The mass required for detection in the alarm is defined in the same manner, i e , detector dose The relationship between the dose (the concentration of agent in the target area) and detector dose (the concentration of agent received by the detector) determines the warning effectiveness of the detector

Eq 5-1 implies that any detection technology, however insensitive, can be made to respond to a given agent concentration regardless of how low it is, merely by allowing sufficient time to pass to accumulate the necessary dose In actual practice, however, this is not the case As time increases, other interfering materials, which are either brought in with the sampled air or produced as breakdown products within the sensor cell, will frequently cause false alarms The sensor cell must be periodically flushed of these substances This requirement limits the amount of agent that can be accumulated Thus in practical applications each detection technology is limited to a minimum concentration that it can detect This level is called the threshold sensitivity

Fig 5-3 is a block diagram representation of the various components that can be incorporated into point sampling acquisition These components are discussed in the paragraphs that follow

Figure 5-3. Components of Chemical Agent Point Sampling Acquisition

5-2.1.1.1 Heater

Some type of heater for the sample airstream is needed if the selected detection technology requires one of the following

1 *Prefilters* Prefilters remove atmospheric dust that can be present in high concentrations due to winds or battlefield conditions when the device is to be used around or on vehicles Prefilters also may be required if there is a need to remove interfering materials before they reach the detection cell. The addition of heat prevents any sampled chemical agent from condensing or being sorbed on the prefilter matrix Heat must be controlled to provide sufficient heat to prevent agent retention but not so much heat that it affects or destroys the prefilter material or agent sample

2 *Humidity Control* Some detection technologies show reduced sensitivity at high relative humidities (generally above 70%). Furthermore, if the detector design is such that sample lines between the air inlet and the detector cell are long and the temperature drops below the dew point, water will deposit on the walls and absorb chemical agents The simplest method of reducing the incoming airstream relative humidity is to heat it to a temperature 11 to 17 deg C above the ambient temperature Such a system is used in the M43A1 detector

Any electrical heater required for a detector design must be capable of being operated continuously by battery power This requirement means additional weight for a portable device and an increased logistic burden A number of different chemical heater designs have been tried in the past with little or no success Even if such a chemical heater system could be designed, the consumable chemicals used would cause a greater logistic burden and increase weight more than the batteries needed for an electrical heater

To keep the weight and logistic burden to a minimum, it is necessary to achieve an efficient heater design The simplest and most rugged design would be to heat the tubing walls and allow radiant energy to heat the gas stream Unfortunately, this design is not efficient from an energy standpoint because it requires large inputs of electrical energy to heat the air a few degrees

Of the numerous designs that have been studied, heating a wire directly in the airstream is the most efficient The wire is coiled and placed on a plastic frame for support Such a design, using 305 mm of resistance wire, can heat ambient air approximately 17 deg C at a flow rate of 1 L/min for an average expenditure of 1 5 W of power A thermistor selected to provide maximum resistance change in the desired temperature range with a simple electronic control circuit provides adequate thermostatic control of the heater

5-2.1.1.2 Dust Prefilter

All existing point sampling detectors for chemical agents require some type of dust separator to avoid introducing large quantities of dirt and dust into the detector In the early 1960s tests were conducted that revealed that dust concentration as high as 64 g/m^3 developed in an area near the tracks of a combat vehicle when operated on sandy, light soil A more realistic location on the vehicle for a chemical agent point detector is around the commander's cupola of a tank. With the detector on the turret, the same tests showed a reduction in dust concentration to about one one-hundredth of the track concentration, or 0 64 g/m^3 (Ref 1). This concentration is equal to 0 64 mg/L of sampled atmosphere If a continuously operating device, such as a point sampling alarm, were run for 100 h (about 4 days), the device would ingest 64 mg of dust in its air-handling system. Point sampling alarms are designed to be small and lightweight; consequently, sampling lines and detector cells—which are also small—would become plugged with dust in a short period of time

A dust prefilter that is easily changed by the operator on a 12- to 24-h basis is the best solution to this problem Ideally, such a prefilter should be inexpensive to produce, have good efficiency for particle removal, be inert to chemical agents and constituents of the sampled air, be rugged and easy to handle, and cause minimum pressure drop when introduced into the air-handling system Some of the prefiltering materials used in respirators and collective protectors, such as Type 5 filter paper, most closely meet these requirements (Type 5 paper is used as a dust prefilter medium in the M8 detector) There are also a number of suitable commercial plastic and cellulose fiber filters on the market

5-2.1.1.3 Chemical Prefilters

Chemical prefilters are used to remove interfering materials in the sampled atmosphere before they reach the detection cell Interfering materials are compounds that are not chemical agents, but they do cause a positive response in the sample analysis chamber or inhibit a positive response when a chemical agent is present. Chemical prefilters can be combined with dust prefilters

in a sandwich arrangement Generally, chemical prefilters react with and remove gases, whereas dust prefilters remove particles. Because chemical prefilters remove gases, their pore size must be much smaller than that of dust prefilters Also chemical prefilters must be thicker than dust prefilters so that the interfering gases do not penetrate The designer must make a tradeoff between the smaller pore size and greater thickness and the resulting pressure drop induced into the air-handling system This tradeoff enables the air pump to move air at the desired flow rate without significantly raising the power requirements of the pump

The E21 Point Sampling Alarm provides a good example of chemical prefilter development (Ref 1) The E21 used the Schoenemann reaction as the basis for detection technology The Schoenemann reaction is based upon the reaction of a nerve agent with sodium pyrophosphate peroxide in a basic medium to produce a strong oxidizing agent In the E21 this agent oxidized *o*-dianisidine to form a compound with a color read by a photodetector

During the course of research and development of the E21, false alarms began to occur with increasing frequency The ozone concentration of the atmosphere was increasing and was due primarily to increased automobile emissions Ozone is an extremely powerful oxidizer and was oxidizing the *o*-dianisidine directly to form a colored compound A number of antioxidant materials were found that, when supported on a matrix of Type 6 paper (similar to Type 5 paper), removed the ozone but allowed nerve agent to pass This prefilter was adopted and successfully used in the M6/M6A1 (E21) alarm

The development of this prefilter illustrates how *all* detector requirements must be considered during the development of *each* component in the system The Type 6 filter paper used as the support matrix for the chemical was primarily alpha cellulose fiber, but it also contained about 10% Peruvian Blue asbestos, which is a critical material that may not be available during mobilization for war Therefore, another program was required to replace the Type 6 paper A plastic fiber material was found to replace the Type 6 paper, but significant effort could have been saved if the problem of the availability of the asbestos had been considered during the original development

5-2.1.1.4 Transfer Lines

The transfer lines, or piping, used to connect the various detector components during sample acquisition must be selected carefully to prevent agent adsorption or interaction These lines should be as short as possible and designed to achieve a laminar flow in the airstream Sharp bends should be avoided because some agents that tend to adsorb will make contact with the walls and be retained in regions in which flow becomes turbulent Any retention of agent in the tubing reduces the amount of agent in the sample analysis. This adsorbed agent later may desorb and cause false alarms The tubing diameter should be kept relatively small (8 to 12 mm) to reduce the dwell time of the sampled agent and decrease adsorption

5-2.1.1.5 Detection Cell

Design of the detection cell is dependent upon and important to the detection technology selected. Cell design is also very important to sample acquisition For example, in a technology that depends upon extraction of the agent sample from the sample airstream, e g , a wet chemical reaction system or a gas chromatograph adsorption column, efficiency of agent sample extraction is as important as the efficiency of sample acquisition from the surrounding atmosphere For wet chemical detection technology some type of bubbler or impaction system can be used

In either case the surface area of the extracting solution or solid adsorber should be as large as practical and the flow rate of the device should be as small as practical to maximize dwell time and achieve the greatest efficiency For example, the detection cell used in the M8 alarm, a wet electrochemical device, is shown in Fig 5-4 Sampled air is drawn into the reaction chamber of the cell at a nominal flow rate of 1 25 L/min This air impacts into a conical reservoir containing the liquid reagent, which is replenished at a flow rate of 0 25 mL/min The comparatively high airflow rate combined with the low solution flow rate causes vigorous bubbling to occur and

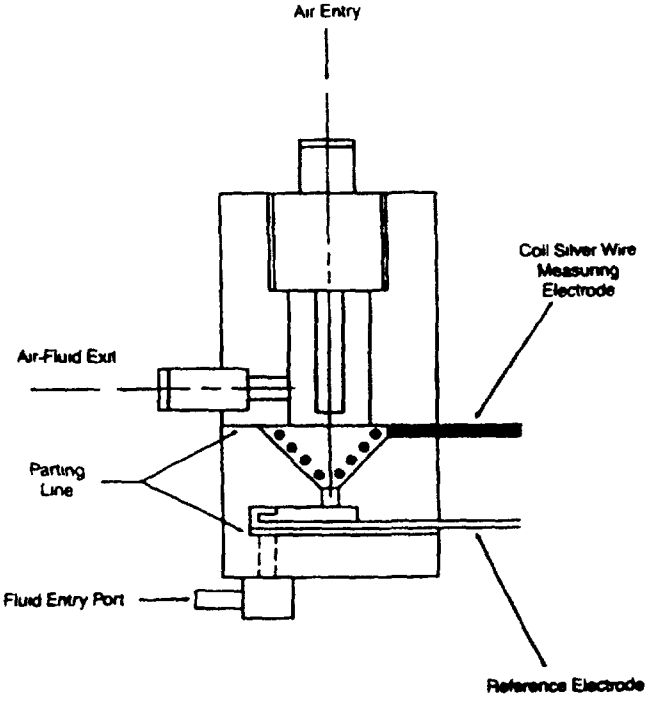

Figure 5-4. M8 Alarm Detection Cell (Ref. 2)

presents maximum surface area for adsorption in a minimum amount of the detection solution (Ref. 2) Fig 5-5 shows the final design of the complete plug-in detection cell module.

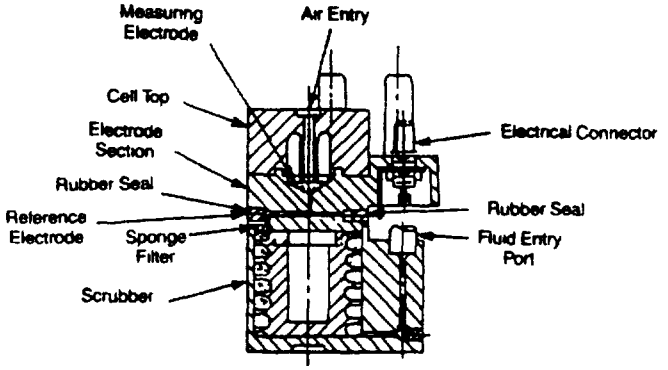

Figure 5-5. M8 Detection Cell Module Design (Ref. 2)

5-2.1.1.6 Air Pump System

Selection or design of an air pump system for sample acquisition requires a tradeoff between the amount of sampled air per unit time needed in the sample analysis and the amount of electrical power drawn by the pump motor to obtain that sample volume. The electrical power requirement dictates battery size and therefore influences weight Table 5-2 provides a comparison of various pump and motor characteristics under various voltage input conditions for the air and solution pump used in the M8 alarm

If the system requires the use of dust and/or chemical filters or if the detection cell imposes an appreciable pressure drop, the pump should be designed as a positive displacement unit This design requires significantly more energy than a vane-type blower or other designs Air slippage is dependent on the pressure head

Selection or design of the air pump system can affect other total system requirements, such as weight, size, reliability, servicing, and component life.

5-2.1.1.7 Agent Filters

Many, if not all, chemical point sampling detectors may be used indoors, e.g., in a shelter, to draw outside air that may be contaminated with a toxic agent Unless the sample air is vented to the outside, any remaining toxicity must be removed from the sample airstream before it leaves the device so that contamination is not released inside. The most straightforward method to ensure this result is to use an activated charcoal filter

Care should be used, however, in designing the charcoal filter so that it is efficient but does not produce significant back pressure on the air-handling system The design should also insure the filter is easy to service or replace

5-2.1.2 Biological Agent Point Sampling Collection

The detection of biological agents is much more difficult than the detection of chemical agents This difference is due to the extreme sensitivity requirements for biological agent detection The required sensitivity is many orders of magnitude greater than that required for chemical agents. In addition, the atmosphere normally contains relatively high concentrations of similar but nontoxic materials from spores and pollens that can cause false alarms.

Biological agents (with the exception of toxins) usually are disseminated as solid aerosols with particles in the size range 0 5 to 2 μm, whereas naturally occurring spores and pollens (possible interferents) are larger The use of a separator for the appropriate size range during sample acquisition greatly reduces this problem

TABLE 5-2. COMPARISON OF PUMP AND MOTOR CHARACTERISTICS UNDER VARIOUS VOLTAGE INPUT CONDITIONS (Ref. 2)

VOLTAGE INPUT, V	MOTOR CHARACTERISTICS		PUMP PERFORMANCE		
	Current, mA	Motor, rpm*	Pump Pressure Drop, Pa	Airflow, L/min	Fluid Flow, mL/5 min
16 0	28	2690	523	0 85	0 88
18 0	32	2960	623	0 93	0 98
20 0	36	3210	723	0 96	1 02
22 0	40	3450	872	1 05	1 08
24 0	44	3660	996	1 14	1.15
26.0	48	3850	1145	1.20	1 20
28 0	52.5	4050	1270	1.23	1 25
29 3	55 5	4180	1345	1 26	1 28

*revolutions per minute

In addition, because present detection technologies and those of the foreseeable future cannot meet the sensitivity requirements, a significant concentration technique must be used in sample acquisition A good example of this type of system is the previously developed XM19 Biological Agent Detector In this detector, atmospheric air is sampled at a flow of 1000 L/min and drawn through a particle separation device The output air from the particle separator is mixed with a small quantity of sprayed solution, which is then impacted on a slowly moving plastic tape (At a sample flow of 1000 L/min, a particle filter cannot be used in place of the particle separator because the increase in pressure drop across a filter for spores and pollen would require the use of a positive displacement air pump with prohibitive power requirements) The small amount of solution impacted on the tape is then moved into a detection cell.

The other components of a sample acquisition device discussed in par 5-2 1 on chemical sample acquisition also apply to biological agents

5-2.2 LINE-OF-SIGHT SAMPLE COLLECTION

5-2.2.1 Chemical Agents

LOS CB agent detectors use electro-optical detection technologies to view the atmosphere along a path, detect agent at some distance from the detector, and provide an early warning capability to the user Fig 5-6 illustrates how a LOS detector can intercept and monitor an agent cloud

Fig 5-6 shows the sensor monitoring a small portion of the agent cloud as the cloud starts to intercept the detection path of the sensor (solid lines) The detection path travels through the cloud until it is stopped by trees (dotted lines) The relationship of the parameters of LOS detector dose is given by

$$D_{LOS} = \sigma CLA, \text{ mg} \qquad (5\text{-}2)$$

where

D_{LOS} = line-of-sight detector dose, mg
L = agent cloud path length (depth of cloud), m
A = cross-sectional area of agent cloud, m^2
σ = efficiency of energy collected by the sensor, dimensionless

The cross-sectional area A of the agent cloud within the field of view (FOV) is influenced by partial obstructions from terrain features that can occur within the FOV A is also reduced if the agent cloud fills only part of the FOV For practical purposes the amount of agent detected is directly proportional to the amount of obstruction in the FOV For example, if an obstruction, such as a tree or a building, occurs between an agent cloud and a detector and blocks two-thirds of the FOV, then the ability of the device to detect that agent cloud is reduced by a factor of 3.

To date, the only electro-optical detection principle that has been successfully exploited for LOS detection is IR energy absorption of nerve and blister agent vapor in the 8- to 12-μm region The IR energy absorption of gaseous agent clouds is directly proportional to agent concentration and can be measured by very sensitive IR detection devices Although mustard agents also have absorption bands around 9 μm, they are much weaker than the nerve agent absorption bands Other areas of the electromagnetic spectrum that have been investigated are

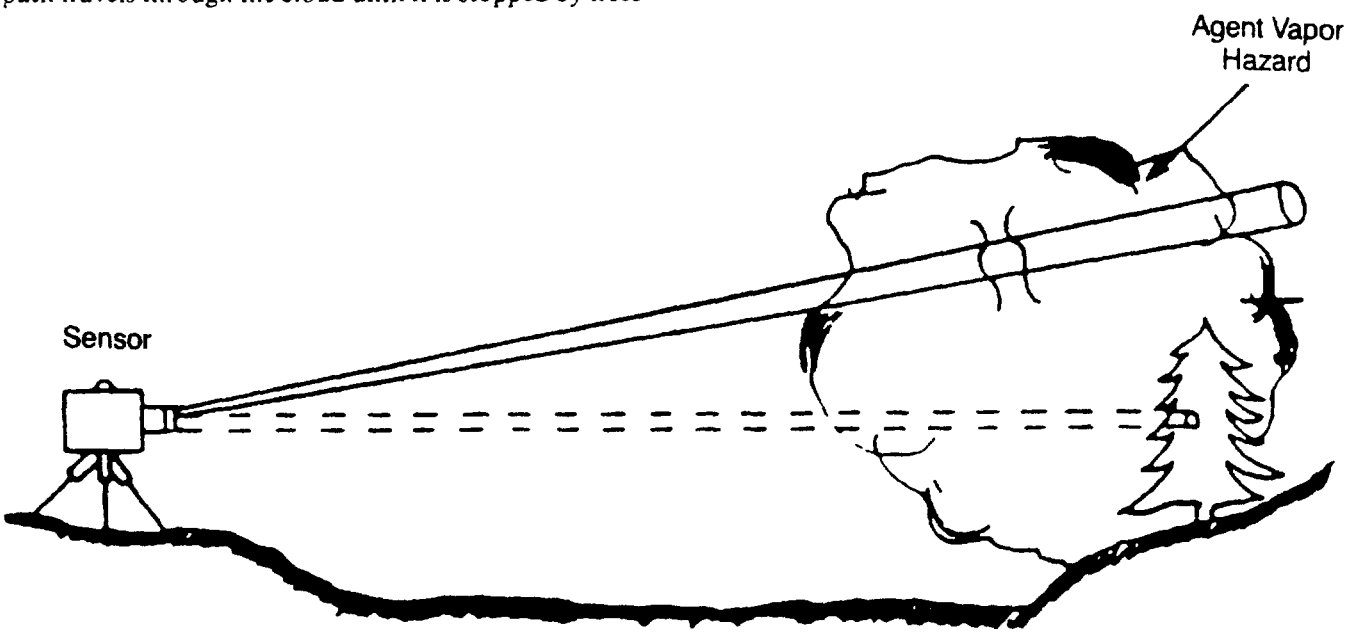

Figure 5-6. Monitoring One Agent Cloud by LOS Detection

in the millimeter and the ultraviolet (UV) range These tests were not successful due to the lack of specific energy absorption in those areas of the spectrum

LOS detectors can be operated in either an active or a passive mode An active mode uses an energy source (such as a laser) to generate the IR energy necessary for detection The passive mode involves focusing the detector on a terrain feature or on the sky, which will be at a slightly different temperature (either hotter or colder) than the agent cloud, and using this energy differential as the energy source necessary for detection

The amount of energy returned to the sensor depends upon the physical form of the agent being detected Agent vapor clouds do not present a problem in this area, but larger aerosols do As aerosols increase in size, more and more of the detection energy is scattered, and this scattering reduces the efficiency of energy absorption by the agent cloud If the device is used in an active mode, differential scattering (DISC) techniques can be used to detect agents disseminated as larger aerosols Tests can be conducted to illustrate this technique Two sample chambers are set up One contains the simulant dimethyl methylphosphonate (DMMP) vapor, and the other a combination of DMMP vapor and aerosol As illustrated in Fig 5-7, an active (laser) remote sensing device is used in the DISC mode The backscatter signal from the sample chamber is nearly equivalent to the return from a control test chamber without DMMP The DMMP vapor absorbs the laser energy and reduces the energy past the chamber Fig 5-8 shows a duplicate test using DMMP aerosol and vapor in the chamber At 350 m the DMMP aerosol causes a large backscattered signal from the sample chamber as compared with the signal from the control chamber containing no DMMP The DMMP vapor in the sample chamber absorbs the laser energy and reduces the signal return from the range past the chamber (Ref 3)

LOS detection offers several significant advantages over point sampling detection Most important of these is that the agent is sampled at a considerable distance from the detector so that early warning of the oncoming agent cloud can be accomplished In addition, because the detector does not require a sample to be collected, almost instantaneous detection is achieved and there is no need for an air-handling device (air pump) with its associated electrical power consumption. By using the more sophisticated laser systems that employ differential absorption, lidar, and differential scattering technologies, the cloud size and concentration of the agent cloud can be determined, and the cloud can be tracked as it moves across the battlefield

The use of LOS detection technologies does pose some important application problems Because the LOS detector requires a path or FOV that is not obstructed (or is only partially obstructed) by terrain features, there are some limitations on its use in field operations For example, in densely forested woods with undergrowth, the range or path length of the detector is too limited to

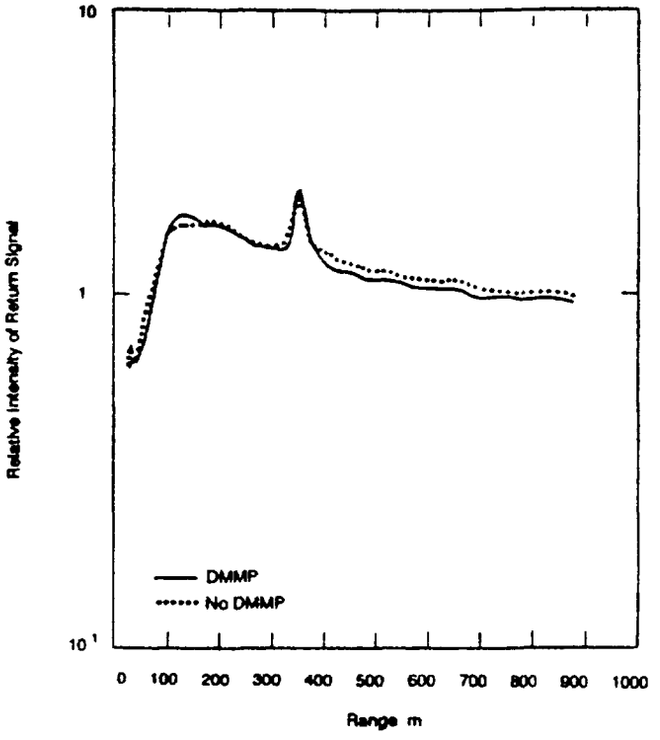

Figure 5-7. Signal Return With DMMP Vapor in Chamber (Ref. 3)

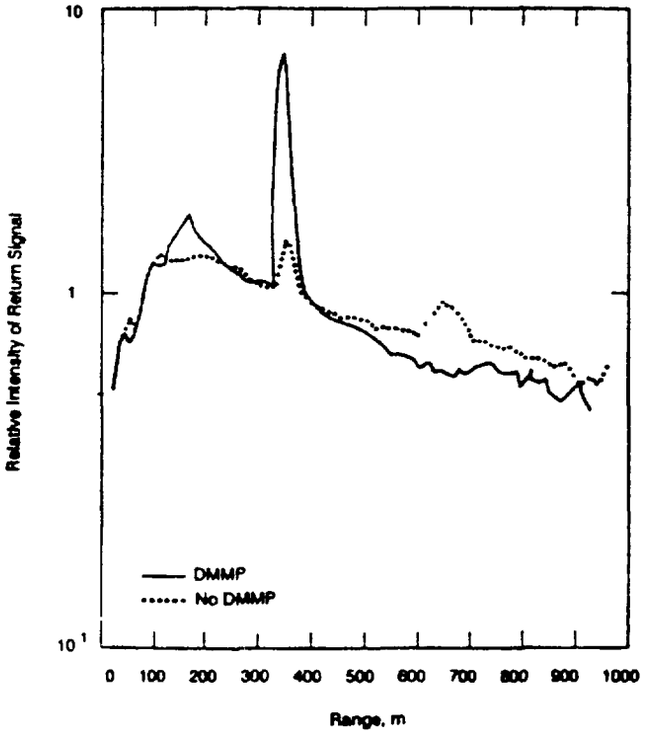

Figure 5-8. Signal Return With DMMP Vapor and Aerosol in Chamber (Ref. 3)

provide adequate detection This problem can be partially overcome by using a number of path lengths that are focused either manually or semiautomatically on partially cleared openings This technique, however, requires additional set-up time and may require significant power if performed automatically Only those detection technologies that have inherently great selectivity can be used for LOS detectors Interfering material cannot be removed from the acquired sample by physical methods, e g , prefiltering Sophisticated discrimination techniques, however, are available in signal processing that improve the selective response of the detectors

Another problem encountered using LOS detectors is that the agent cloud may never reach the troops, who have been warned and placed in mission-oriented protective posture (MOPP) with its attendant performance degradation This situation becomes a possibility whenever the wind is not blowing directly toward the unit protected by the LOS detector The problem can be resolved if the detector has ranging capability, which indicates the distance to and size of the cloud so that its subsequent path can be followed

5-2.2.2 Biological Agents

Electro-optical techniques in LOS detectors for sampling and detection of biological agents have never been successfully exploited because of the extreme sensitivity requirements for biological agent detection. In addition, these compounds have diverse compositions and do not offer strong absorption bands in the electromagnetic spectrum For example, tests performed using a UV system in which the agent cloud was irradiated with UV energy around 280 nm caused the cloud to give off energy (fluoresce) in the ultraviolet part of the spectrum (~360 nm) (Ref 4) Excitation and response frequencies for *Escherichia coli (E coli)* and tryptophan are shown in Figs 5-9 and 5-10, respectively (Tryptophan is an amino acid that is commonly associated with the production of niacin in the human body) This system is not a satisfactory detector due to the large number of naturally occurring compounds in the atmosphere that also fluoresce when irradiated with similar UV energy Another problem for LOS detection of biological agents is the fact that most biological agents exist as solid aerosols and must be detected by aerosol scattering techniques These methods are not as efficient or specific as direct absorption and further reduce the sensitivity of the technique

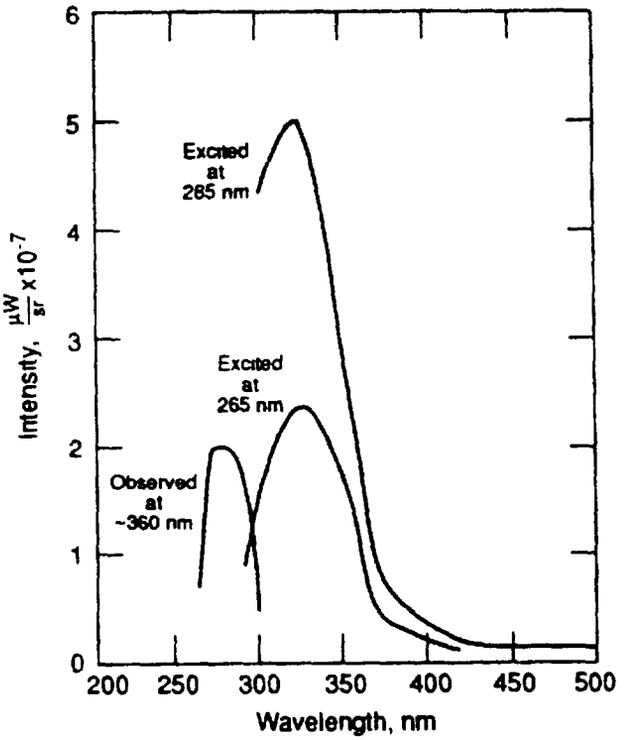

Figure 5-9. Excitation and Fluorescence Spectra of a Biological Simulant *Escherichia coli* in Water (~5×10^6/mL) (Ref. 4)

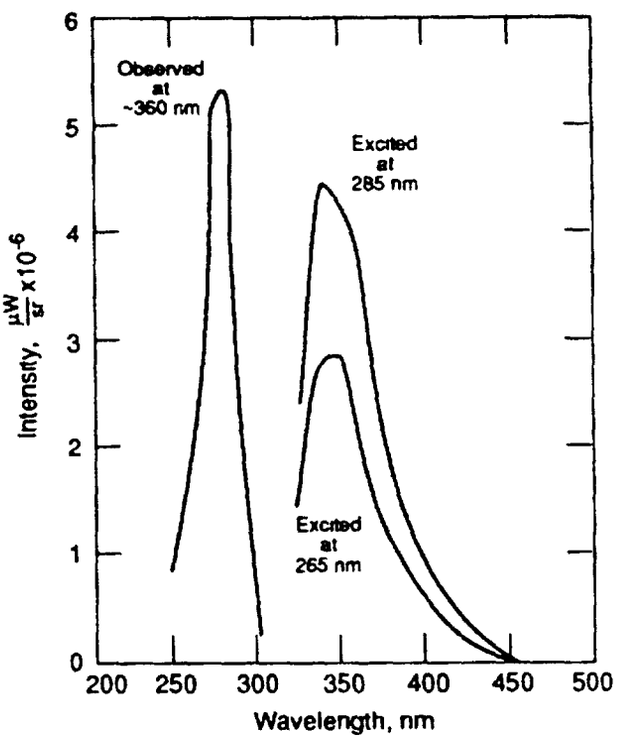

Figure 5-10. Excitation and Fluorescence Spectra for Tryptophan in Water (0.001 g/L, pH ~7) (Ref. 4)

5-3 SAMPLE ANALYSIS

Analysis of the acquired sample in the detection cell depends on the detection technology selected, that is, whether the cell is a closed cell used in point sampling detection or an open-air cell used in LOS detection. After the operational use concept for a detector has been carefully reviewed with the user and the performance requirements are known, the various options in detection technology can be evaluated. Priority should be given to inherent technology sensitivity, response time, and specificity and should include signal processing techniques to enhance these parameters Once these parameters have been established for the various technologies under consideration, others must be examined, such as projected ultimate system simplicity and cost, reliability, size, weight, power requirements, and potential logistics burden Fig 5-11 illustrates the components of the sample analysis process

Consideration of detection technologies for a specific operational use concept should include an evaluation of the potential for analysis of a broad spectrum of existing agent classes as well as for detection of new agents directly or by a simple modification The evaluation for new agent detection potential includes a tradeoff between broad agent detection capabilities and specificity For example, the use of gas chromatography for detection offers the potential for extremely good sensitivity and specificity but only limited applications for broad agent detection

Fig 5-12 shows a comparison of the detection limits and linear dynamic range for various gas chromatography detectors The vapor pressure can vary for any given agent within a class of agents or between agent classes Vapor pressure of the material to be detected is one of the most important parameters to be considered when designing gas chromatography columns Although relatively small gas chromatographs that use multiple columns are available, they do not have enough columns for detection of all required agents In addition, the specificity of a gas chromatograph deteriorates when a very large number of columns are used

Considerable improvement in the sensitivity and specificity of sample analysis can be accomplished if the proper processing of the signal is selected. Sensitivity of the selected technology in a device depends on the signal-to-noise ratio required for the device to operate under a broad range of climatic conditions in various battlefield atmospheres that contain compounds not found in a normal atmosphere

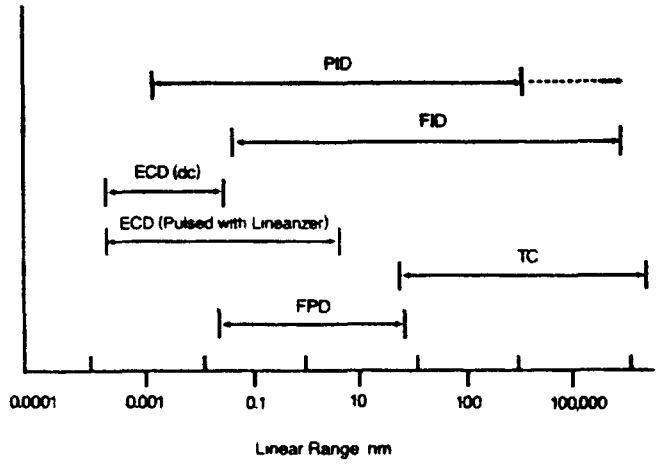

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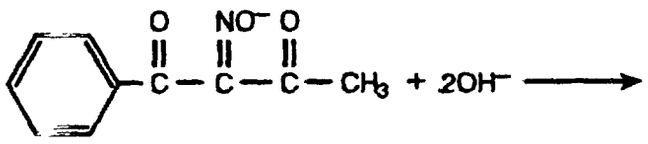
Figure 5-12. Comparison of the Linear Dynamic Range and Detection Limits for Various Gas Chromatography Detectors (Ref. 5)

For example, in the development of the M43 Electrochemical Detector, the detecting oxime solution was slowly broken down by autocatalytic degradation of the oxime to cyanide ion, which was the ion used for detection of nerve agents in the electrochemical cell As shown in Fig 5-13, the decomposition of the oxime producing cyanide ion occurs under basic conditions

The three-step process that occurs in the detection of nerve agents by interaction with the oxime solution and produces the cyanide ion is shown in Fig 4-7

Much of the cyanide ion from the decomposition reaction can be eliminated by passing the oxime solution through a silver scrubber just before use to remove the bulk of the cyanide ion A small amount of cyanide ion does pass through, however, and over time it could accumulate in sufficient quantity to cause the cell to sound a false alarm (Ref 6) Thus a simple drift network was designed into the signal processing of the device so that an extremely slow buildup of signal is cancelled out and only rate-of-change signals above a designed threshold are processed A schematic of a drift network appears in Ref 1

Figure 5-11. Sample Analysis Process



$$CH_3COO^- + C_6H_5COO^- + CN^- + H_2O$$

Cyanide Ion

Figure 5-13. Decomposition of Oxime Reagent (Ref. 6)

Depending upon the technology selected, the signal generated by interaction with the acquired sample can be processed by visual or electronic readout For example, in selecting the detection technology for use in an inexpensive, expendable detector kit, the designer selects reactions that produce visible colors The signal processing for the color changes actually depends on the ability of the operator to observe the color change and to evaluate its significance (signal processing) If the detection technology does not produce a signal that is readily discernible by the operator's senses, the output must be processed electronically, which makes it unsuitable for detector kit applications For example, the E41 alarm used a color change for detection, but since the operational use concept for alarms is to operate unattended and automatically, the visual signal monitor required a light source, an optical filter, a photocell, and electronics for a readout

5-3.1 VISUAL

Visual readout of the sample analysis in detector kits is usually restricted to technologies that require an operator to observe a color change and interpret its significance The development of color for any chemical reaction is very dependent on the temperature at which the reaction takes place The hotter the temperature, the faster the color changes take place Conversely the colder the temperature, the slower the color change One example of this fact is the nerve portion of the M256 kit When this portion of the kit functions at a room temperature of 21 1°C (70°F), it requires about two min for color to develop But at a temperature of −28 9°C (−20°F), nearly five min are required for the same intensity of color to develop This example illustrates the importance of temperature on the speed of color change for chemical agent detection systems

Having an operator perform these functions greatly simplifies the design of or eliminates the electronics required for a detection device Similarly to static sampling, this approach results in the potential for a kit that requires no battery power for operation and produces a significant savings in size, weight, and cost, and improved reliability For example, the M256 Chemical Agent Detector Kit is small in size (0 006 to 0.008 m^3), light in weight (0.91 to 1.36 kg), and relatively inexpensive to produce (Ref. 7)

As indicated, detector kit operation does not require instantaneous acquisition, readout, and warning of the presence of a chemical or biological agent Therefore, static sampling can be used To produce a color that can be observed by the operator, the acquired sample must undergo a chemical reaction that produces a visible color The simplest kit design requires the operator to add the reagent to the sample manually This method eliminates mechanical components and electrical power With this design approach the resulting kit can be simple and comparatively low in cost and therefore can be widely issued to troops

Static sampling includes such methods as waving the detector by hand in the suspected contaminated atmosphere or merely allowing the detector surface to remain exposed Agent is brought to the detector surface by molecular diffusion of the contaminated air Static acquisition is not very efficient, however, when compared to samples acquired by mechanical collectors or LOS devices The detection technology selected should produce vivid colors in that range of the spectrum easiest for the human eye to discern because, in poor light or under the stress of combat operations, the user may not see the developed color In night operations a shielded artificial light source (flashlight) or night observation device may be used for viewing.

Table 5-3 summarizes key parameters for visual readout

5-3.2 ELECTRONIC

5-3.2 1 Signal-to-Noise Ratio

In processing the electronic signal output from the sample analysis, the most important factor to be considered is the signal-to-noise ratio of the system Signal-to-noise ratio is defined as the total signal generated by the interaction of the minimum detectable concentration of agent with the detection technology divided by the sum of the instantaneous and long-term (drift) signal caused by noise from the output of the sample analysis and supporting electronics If a sufficient signal-to-noise ratio cannot be developed from the sample analysis, enhancement techniques, such as pattern recognition or other discriminating functions, can be used to improve the signal-to-noise ratio Without a satisfactory signal-to-noise ratio, frequent false alarms will occur in the device that will cause the user to take needless protective actions and to lose confidence in the equipment

Electronic design can be relatively simple for those devices with high signal-to-noise ratios compared to those devices with low signal-to-noise ratios However, because

TABLE 5-3. PARAMETERS FOR VISUAL READOUT (M256 KIT DEVELOPMENT PROGRAM)

PARAMETER	DESCRIPTION
Ease of operation	Kit should be easy for field soldier to operate without any accessory devices
Color development time	Color development should be as rapid as possible in order to warn the operator of the presence of any chemical agent
Positive color	Chemical reaction should be one that produces a positive color (i e., color will develop when agent is present), not a negative color (i e , color will develop when agent is not present)
Optimum color	Color development should be a color that is in the range of the spectrum easiest for the human eye to discern
Night operation	Kit should be easy to operate, and results should be easy to observe or read with only a field flashlight
Stability	Detector kit should have both chemical and temperature stability for field operation

of the number of functions that must be controlled electronically, circuitry design for the simpler devices can be extensive Electronic circuit design develops from the detection technology that is selected and from the operational use concept of the CB detection system with its attendant requirements

The major problem in determining the signal-to-noise ratio of a device is determining both the instantaneous and the long-term noise of the system under all operating conditions for an alarm in the field Temperature changes, rough handling, and small changes in the other operating parameters of the device can affect the system noise

For example, in the development of the M8 Alarm, to keep the sample analysis electronics as simple as possible, a high signal-to-noise ratio of 10 to 1 was used This ratio accommodated changes such as small variations in the detection solution flow rate caused by pulsations in solution flow from the solution pump or noise generated by air bubble formation in the solution lines and sample analysis cell Because autocatalytic degradation of the detecting chemicals plus the effects of temperature change in electrochemical systems resulted in noise variations that exceeded even the large signal-to-noise ratio (10 to 1) that was selected, a compensating drift network had to be developed

Parameters that affect system signal-to-noise ratio vary with the detection technology selected In the M8 alarm the most significant parameters affecting performance are shown in Table 5-4.

TABLE 5-4. PARAMETERS THAT AFFECT SIGNAL-TO-NOISE RATIO (M8 DEVELOPMENT PROGRAM)

DETECTION SOLUTION	PERFORMANCE DEGRADATION
Chemical stability	Degradation of chemical due to temperature causes increase in long-term noise
Electromechanical stability	Short-term pulsation or bubbles in solution flow lines cause increases in short-term or instantaneous noise
Cell electrode stability	Long-term drift results from increase in noise due to temperature effect on electrochemical reaction as temperature rises and noise output increases
Electronic stability	Instantaneous noise from electronics is caused by mechanical or thermal shock
Detection technology	Signal output depends on the interaction of the chemical agent with the selected detection technology Signal output can vary by orders of magnitude depending on detection technology, but in general, the more sensitive the technology, the more noise is associated with it. Thus technology selection becomes a tradeoff between sensitivity and noise

5-3.2.2 Pattern Recognition

If the desired sensitivity yields only small signal-to-noise ratios from the sample analysis, various signal processing techniques can be used to improve and enhance the signal (See appendix for techniques) Pattern recognition using the IR spectrum is one of these techniques

If the exact IR absorption spectrum developed from a LOS device can be duplicated electronically, additional noise generated by the system, which does not fall within the spectrum, can be rejected in the signal processing This technique is also used to eliminate false alarms caused by interfering compounds that have absorption spectra similar to that of the agent to be detected For example, although various airborne dusts contain silica oxide whose primary IR absorption band occurs in approximately the primary absorption band of the nerve agents (9.8 μm), side band absorptions are different If the absorption spectrum picture (pattern) of dust and agent can be duplicated electronically and compared, the agent spectrum can be processed and the dust spectrum can be rejected Long- and short-term system noise can be handled in the same way

The main problems encountered in using this technique for a portable field device are the availability of data, microprocessor storage, and processing capability For example, the IR spectra of chemical agents in the same class or between classes of agent can vary either slightly or grossly Also system noise can add to or cancel features of an absorption spectrum in a number of ways The problem then becomes obtaining a specific absorption spectrum for each agent, data on spectrum changes caused by system noise, and data on the spectrum of atmospheric interferents that could cause false alarms The collected data must be stored and then processed by comparing the received signal to the stored data Such a system requires a microprocessor capable of storing and processing relatively large quantities of data, as well as controlling and operating other functions of the detector

5-3.2.3 Other Discriminating Functions

A number of techniques have been developed to aid the discrimination of the signal for detection devices Two such techniques, which were used in the M8 development program, were a nulling system and a rate of change circuit The nulling system was developed to decrease the noise in the signal of the system and thus create a greater differential between the noise and the agent signal

The rate of change circuit was developed to compensate for the M8 drift The M8 signal tended to drift slowly upward, so a circuit was developed to recognize the drift The circuit, however, also recognized a sharper rise of the signal as an agent response, consequently, the alarm was triggered

Another technique used in the ionization detector was a "time of flight to be" A tube with various potentials imposed across it is placed between the ionization and detection plates, this tube strips off all unwanted materials and thus allows only agent molecules to reach the detector plate

A final technique being used in detection devices is sophisticated mathematical discriminating functions, or algorithms These algorithms use statistical methods, such as least square fit, to analyze signal processes

Techniques that aid in discrimination functions are summarized in Table 5-5

5-4 RESPONSE (ALARM)

The response, or alarm, process accepts the signal from the signal processing part of the sample analysis and converts it into a signal that is readily perceptible by the human senses. The concepts of use and the requirements for most automatic detection devices specify both an audible and a visible response In the past, some limited work was done on small personal detectors that signalled an alarm by applying a small electric shock or skin prick to the user These techniques were unreliable, however, when used under the stress of combat conditions In addition to the audible and visible responses, some detectors also provide a remote alarm located some distance from the detector

Initially, the response process was specified as a simple go or no-go type of alarm In the no-go (no alarm) condition, the user knew that the agent concentration in the atmosphere was below the minimum detectable concentration for the device If a go (alarm) response was signalled, the user knew the agent concentration exceeded the minimum detectable agent concentration for the

TABLE 5-5. FUNCTIONS THAT AID DISCRIMINATION IN DETECTION DEVICES

TECHNIQUE	PROBLEMS
Algorithm development	Extensive testing required to develop final algorithm
Null system	Characterization of battlefield contaminants needed to define null technique
Rate of change	Limited to systems that have long-term drift
Time of flight tube	Limited to ionization detection techniques

device As concepts of use become more sophisticated and new detection technologies appear that are capable of providing more diverse output, more complex requirements are placed on the response process For example, in addition to providing the go or no-go-type response that tells the operator to take immediate protective action, increasingly sophisticated detectors may be required to determine whether the threat agent is a contamination hazard (persistent), the location of the contamination, the extent of the hazard, and whether decontamination is needed Fig 5-14 is a block diagram of the response process

5-4.1 VISIBLE INDICATION

A visible indicator in an automatic CB detection device is used as a response (alarm) device and/or as an indicator of the concentration of the agent being sampled, and it will consist of a light and/or a meter for readout A visible indicator may also be used by the operator in the setup of the equipment to mark the sample analysis circuitry at a zero gain or null position If the detection technology supports such use, visible indicators also may be used either to provide additional information to the operator, such as the relative path direction of a detecting FOV in an LOS detector or as a fail-safe device that signals the operator of a problem or component failure

Many of the design restrictions that apply to audible indicators also apply to visible indicators when used in the response (alarm) mode Although operating power should be kept to a minimum, light intensity should be strong enough for the indicator to be seen in bright sunlight Conversely, an intensity control or shield must be available for use in night operations to prevent position disclosure to the enemy

When a visible indicator is desired to provide quantitative to semiquantitative data on agent concentration, the simplest design, which is similar to that used in the British chemical agent monitor (CAM), is to use a ruggedized meter that shows an increase in output signal with increasing agent concentration. Selection of a visible display for agent concentration depends largely on the operational concept of use for the system In developing the operational concept of use and accompanying system requirements, only information that is absolutely necessary should be specified With the availability of the versatile microprocessor design, it is a temptation to specify additional information because of the relative ease with which the design can be modified to provide it However, the extra, unnecessary information can lead to operator confusion and most certainly adds to the design, procurement, and operating costs of the system

5-4.2 AUDIO ALARM

The audio alarm is the primary response, or alarm mode, for automatic detectors It is the only indicator that does not require the user's direct visual attention The audio signal frequency and volume (Fluctuating volume is best) should be selected to achieve maximum carry on the battlefield It is more discernible than a visual indicator, particularly in bright sunlight. The detector design should include a way to reduce or turn off the volume to prevent discovery of the location by the enemy.

The electronics necessary to convert the output of the signal processing into an audible alarm is relatively straightforward and easy to accomplish with the wide selection of methods available from previously developed equipment Of primary concern in circuitry design and

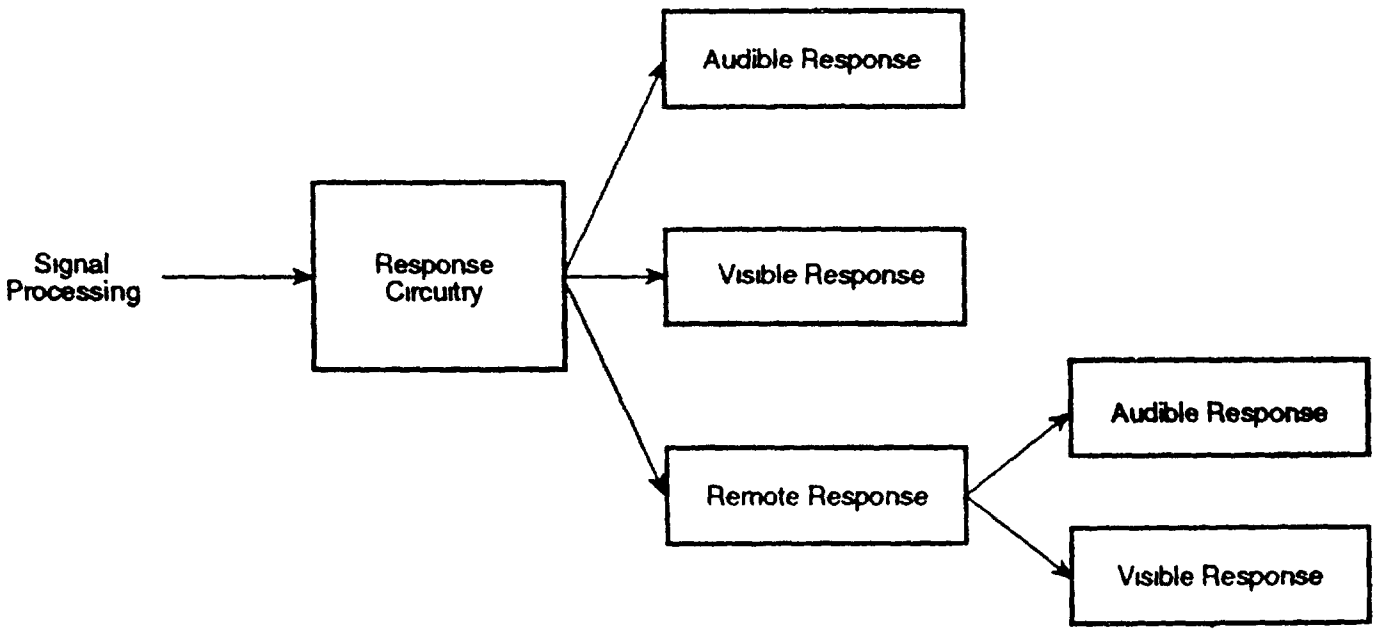


Figure 5-14. Block Diagram of the Response Process

component selection is the power required for operation Automatic devices generally require unattended operation Most operational concepts of use require that when a detector goes into the alarm mode, it remain in that mode until turned off by the operator This feature ensures that the user knows an agent has been used Because of these requirements, the audible or visible indicator may run for a long time and cause a large power drain on the battery primarily from the horn or light bulb that is used The audio alarm device selected must have sufficient sound output to be heard over battlefield noise, i e , average of 88 dB

5-4.3 ELECTRICAL SIGNAL

Many operational concepts of use require employment of an ancillary alarm that is remote from the detector An example is a detector that provides warning for a fixed site and feeds information to a central location Such situations are applicable to both point sampling and LOS detectors In addition, there are many occasions when the point sampling detector should be placed some distance upwind from the troop location to provide early warning This situation requires that the alarm signal be communicated back to the using troops

Transmission of the detector response signal to the remote alarm can be accomplished by use of electrical wire or by radio transmission Transmission through electrical wire is the simplest design The major considerations are to use a wire that has low resistance to minimize signal loss and is rugged enough to withstand field use In addition, fail-safe circuitry should be included to provide operator warning if the wire is cut

Radio transmission of the response signal simplifies operation because wire does not have to be hooked up or laid over significant distances Laying wire becomes a significant problem when frequent wind shifts occur that require movement of the detector so that it remains upwind from the troops If radio transmission is used, an operating frequency must be assigned, and care must be taken in the design to insure sufficient power output to transmit the signal over the required distance under various atmospheric conditions Power output cannot be so large that it interferes with other radio equipment The radio signal also must be coded to identify which detector is responding when several detectors are used in an array Radio transmission can be further complicated if the transmitter must remain free of enemy jamming or interference

REFERENCES

1 John F Wroten, Jr , and Francis D DeMarco, *Development of a Spontaneous Electrolysis Portable Chemical Agent Alarm*, Report No BF32-5005-9-3, by Bendix Corporation, Baltimore, MD, for US Army Edgewood Arsenal, Chemical Research and Development Laboratories, Aberdeen Proving Ground, MD, August 1966

2 John F. Wroten, Jr., and Walter Schmitz, *Development of a Spontaneous Electrolysis Portable Chemical Alarm*, Report No BF-32-5005-9-1, by Bendix Corporation, Baltimore, MD, for US Army Edgewood Arsenal, Chemical Research and Development Laboratories, Aberdeen Proving Ground, MD, February 1966

3 D D Powell and J E van der Lann, *Studies of DIAL/DISC Remote Sensing Techniques for Chemical Agent Detection*, Report No ARCSL-CR-80043, by SRI International, Menlo Park, CA, for US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, May 1980

4 William B Grant, *Optical Bases for Remote Biological Aerosol Detection*, Report No ED-CR-77025, Stanford Research Institute, Menlo Park, CA, March 1977

5 John N Driscoll, "Applications of a Photoionization Detector in Gas Chromatography", American Laboratory 8, No 10 (1976)

6 Robert B Moll and John C Young, *An Electro-Chemical Method for Detection of Microgram Quantities of Nerve Agents*, Report No EATM 321-17, US Army Edgewood Arsenal, Aberdeen Proving Ground, MD, November 1968.

7 Vincent N Cammarata and Jerry L Sessions, *Application Handbook Chemical Agent Detection and Alarm Equipment (CADAE) for Combat Vehicles*, Report No ARCSL-CR-81031, by Honeywell, Inc , St Petersburg, FL, for US Army Chemical Systems Laboratory, Aberdeen Proving Ground, MD, December 1980

BIBLIOGRAPHY

AMCP 706-127, Engineering Design Handbook, *Infrared Military Systems Part One*, April 1971

AMCP 706-128, Engineering Design Handbook, *Infrared Military Systems, Part Two*, May 1974

Donald B Keidan, *Development of a Spontaneous Electrolysis Portable Chemical Agent Alarm, Assumptive Reliability Study*, Report No BF32-5005-9-5, by Bendix Corporation, Baltimore, MD, for US Army Edgewood Arsenal, Chemical Research and Development Laboratories, Aberdeen Proving Ground, MD, August 1966

William L Wolfe, Ed , *Handbook of Military Infrared Technology*, Office of Naval Research, Department of the Navy, Washington, DC, 1965

CHAPTER 6
DETECTOR PERFORMANCE CRITERIA

This chapter describes the required detection and monitoring characteristics that form the basis for detector performance criteria. The role of detection and monitoring characteristics in research and development (R&D) programs is explained and the characteristics are placed in the context of the users and developers. The roles of sensitivity in detection of chemical and biological (CB) agents and of sensitivity performance criteria measurement in relationship to other measures are explained. Response time and its relation to protective measures, e.g., masking time, are defined. Discrimination and specificity and their roles in detector design are discussed, and other design considerations that are unique to CB detection and monitoring are introduced. The relative importance of agent identification and quantification as compared to sensitivity and response time is also discussed. Integrated logistic support (ILS) characteristics and requirements are defined.

6-0 LIST OF SYMBOLS

A_b = surface area of body exposed to agent, m^2
A_d = area receiving agent fallout, m^2
B = protective barrier efficiency of clothing or other protective cover, dimensionless
C = concentration, mg/m^3
C_d = contamination density, mg/m^2
CL = concentration path length, mg/m^2
Ct = dosage, $mg \cdot min/m^3$
D = deposited dose, mg
D_{BA} = body exposure dose attributed to airborne agents, mg
D_{BG} = body exposure dose attributed to surface contamination, mg
D_I = inhalation dose, mg
ICt_5 = threshold incapacitating dose, $mg \cdot min/m^3$
ICt_{50} = median incapacitating dose, $mg \cdot min/m^3$
L = path length, m
LCt_{50} = median lethal dose, $mg \cdot min/m^3$
s = settling velocity of agent drops, m/min
t = time concentration is present, min
t_c = communication and decision time, min
t_e = exposure time, min
t_{ec} = exposure time when $t_c = 0$, min
t_{er} = exposure time with remote sensor, min
t_p = time to don protective mask and clothing, min
t_r = detector response time, min
t_s = scanning time, min
t_t = time for agent cloud to travel from detector to personnel, min
β = breathing rate, m^3/min
γ = wind speed transporting agent, m/min
ϵ = efficiency of deposition onto skin, dimensionless
ρ = efficiency of agent retention in respiratory tract, dimensionless

6-1 INTRODUCTION

The operational characteristics and performance criteria for a system form the standards by which the military effectiveness of that system is measured. Operational characteristics are the basic functions that a system is required to perform in response to its stated mission. Performance criteria establish required operational characteristics (Ref. 1). Thus the system characteristics and performance criteria stated in materiel requirements documents become design goals for research, development, test, and evaluation (RDT&E) of new or improved military systems.

AR 70-1, *System Acquisition Policy and Procedure*, (Ref. 2) establishes the Army system acquisition program, which includes the Army streamlined acquisition process (ASAP) for low-risk programs that integrate mature technologies or proven components into new systems. Coupled with AR 71-9, *Materiel Objectives and Requirements*, (Ref. 3) the ASAP program, if used, has a goal to progress from program approval through low-risk development to a production decision in four years.

The US Army Training and Doctrine Command (TRADOC) is the combat developer representing the Army users and trainers. The US Army Chemical School (CMLS) is the TRADOC school designated for combat development of training, doctrine, and materiel requirements for CB systems. The US Army Materiel Command (AMC) is the Army materiel developer and also the lead Department of Defense (DoD) agency for research in chemical warfare and chemical and biological defense. The US Army Chemical Research, Development, and Engineering Center (CRDEC) is the AMC lead laboratory for chemical warfare and CB defense.

In 1985 the CMLS and CRDEC jointly published the *Reconnaissance, Detection and Identification Master*

Plan (RDIMP) (Ref 4), which assessed the chemical, biological, and toxin (CBT) detection and monitoring needs of the Army on the battlefield * The RDIMP states that the US Army has an urgent need for improved systems that detect and monitor agent vapors, aerosols, large droplets (toxic rain), and surface contamination on vehicles, equipment, facilities, terrain, and vegetation This need was recognized in the Combat Support Nuclear, Biological, and Chemical (NBC) Mission Area Analysis (MAA) This MAA identifies serious deficiencies across the battlefield in existing methods of providing commanders with timely and accurate CB information for hazard assessment and operational decisions (Ref 4)

The RDIMP team developed a list of characteristics and subcharacteristics for CB detection and monitoring systems and selected those detector performance criteria shown in Table 6-1 that are science or engineering limited Based on requirements for the battlefield situations discussed in Chapter 3, the levels of performance necessary for these characteristics were given These levels ranged from the ultimate (desirable) performance to the minimum, acceptable (critical) performance for each battlefield situation as perceived by the user representatives (Ref 4)

These efforts resulted in a list of qualitative and quantitative detector performance criteria for each of the battlefield situations and weighting factors for each characteristic and subcharacteristic, which indicate their relative importance to one another This list is the yardstick by which to measure currently fielded detector performances and projected performances of candidate detection technologies (Ref 4)

Current requirements for development of CB detection and warning systems based on the RDIMP are stated in the Operational and Organizational (O&O) Plan for the NBC Reconnaissance System (NBCRS) (Ref 5) and the Fixed Site Detection and Warning System (FSDWS) (Ref 6) These plans specifically address the problem of chemical detection and monitoring, however, biological and toxin agent attacks also generate similar requirements

The requirement for an O&O plan was changed in 1991 (Ref 7) For new systems a Mission Needs Statement (MNS) is required initially that defines a broad operational capability need (The O&O Plan not only identified the need but also proposed a materiel solution to the need) After approval and acceptance of the MNS, the Operational Requirements Document (ORD)** is prepared. The ORD identifies minimum acceptable performance requirements to satisfy the operational need It also includes performance objectives that would provide operationally meaningful increases in capability The ORD establishes the design goals for the new system in terms of the required critical, or minimum acceptable, and desirable performance criteria These criteria are based on the need and the estimated technical capability of the materiel developer to achieve these goals within the required materiel acquisition lead time

Critical characteristics are those characteristics that have been rated by the combat developer as mission essential and by the materiel developer as achievable within the current state of the technology based on verifiable research Desirable characteristics are those characteristics that would greatly enhance the capability of the system to perform its mission if the forecasted technology indicates they can be achieved The design engineer also considers using preplanned product improvement (P^3I) programs to achieve desirable characteristics requiring further R&D efforts

The materiel designer prepares and staffs a test and evaluation master plan (TEMP) (Refs 7 and 8). The TEMP is the basic planning document for all test and evaluation (T&E) of a system throughout the materiel acquisition process. The TEMP must contain information on the required operational and critical technical characteristics and performance criteria, critical test objectives, and the evaluation process of the system It is used as a guide for evaluating achievement of the critical technical characteristics for a system as specified in the ORD

The materiel developer addresses each of the required system characteristics, e g , those listed in Table 6-2, in the TEMP and other related program management documents (PMD) (Ref 8) Technical characteristics are the quantitative and qualitative system parameters approved by the user These might not be direct measures of, but should always relate to, the capability of a system to perform its required mission The US Army Test and Evaluation Command (TECOM) is AMC's independent evaluator responsible for ensuring that the developmental materiel meets the required technical characteristics specified in the ORD and TEMP

The technical characteristics of CB agent detection and monitoring systems are stated in quantitative, semiquantitative, or qualitative terms Quantitative measurements are used for characteristics that can be easily measured For example, agent quantification refers to the quantity in milligrams or concentration in milligrams per cubic meter of the agent present

Semiquantitative measurements are general statements of required performance criteria for a characteristic or

*National policy dictates biologic materials such as pathogens and viruses, as well as materials derived from biologic sources, such as toxins be treated similarly For purposes of the RDIMP however a distinction was made between infectious and/or living organisms, biological (B), on one hand and their nonviable products such as toxins (T), on the other This was done because the chemical and physical properties of many T agents are distinct from those of chemical (C) or B agents Therefore, detection of T agents poses challenges distinct from those encountered with C or B agents

**The ORD replaced the Required Operational Capability (ROC)

TABLE 6-1. RESULTS FROM SELECTION OF PERFORMANCE CRITERIA AS SCIENCE OR ENGINEERING LIMITED (Ref. 4)

	PERFORMANCE CRITERIA	PREDOMINANT LIMITATION	
		SCIENCE-BASED	ENGINEERING-BASED
1	Agent detection	X	
2	Response time for detection, identification, and quantification	X	
3	Sensitivity	X	
4	Detector operations		
	a Accuracy	X	
	b Size (volume and weight)		X
	c Data transmission		X
	d Service and setup		X
	e Consumables		X
	f Power		X
	g Alarm		X
	h Environment		X
5	Survivability for conventional attack, NBC environment and RAM*		X
6	Agent identification	X	
7	Operator input and qualifications		X
8	Ruggedness		X
9.	Range and/or coverage	X	
10	Mobility		X
11.	Agent quantification	X	
12	Reset time	X	
13	Time for prototype production		X
14	Sensor cost		X
15	Producibility		X

*RAM = reliability, availability, and maintainability

subcharacteristic, they are not expressions of numeric values These empirical measurements of performance rely on the judgment of technical experts that is based on practical experience, doctrine, experiments, and observations Semiquantitative statements use such descriptions as all, some, or none or low, medium, or high

Qualitative measurements are general statements of performance criteria that describe desired versus critical characteristics in terms of a quality or qualities For example, the characteristic "ruggedness" is stated in terms of a qualitative specification Other characteristics controlled by military specifications and regulations include environmental extremes, NBC contamination survivability, nuclear survivability, system safety, and producibility

TABLE 6-2. EXAMPLE REQUIRED SYSTEM CHARACTERISTICS

Technology	Describes the science and technology (e g , chemistry, biology, microbiology, physics, computer science, engineering, producibility, and human engineering considerations) that may contribute to a high program risk
Reliability, availability, and maintainability (RAM)	Describes the RAM engineering requirements and operational needs that must be addressed and evaluated during development and RAM testing
System safety	Describes the critical safety requirements that will be evaluated
Logistics supportability	Describes the logistics supportability requirements that will be evaluated during developmental test and evaluation (DT&E)
Software test and evaluation	Describes the software testing of mission-critical computer resources that will be required in order to demonstrate product quality, including postmilestone updates
Nuclear survivability	Describes the nuclear-hardening engineering requirements that will be evaluated during DT&E
Nuclear, biological, and chemical (NBC) contamination survivability	Describes the NBC contamination survivability requirements that will be evaluated during DT&E
Susceptibility	Describes the need to determine the vulnerability of the system to electromagnetic radiation threats such as radio frequency interference (RFI), infrared (IR), and nonnuclear electromagnetic pulses (EMP)
Training	Describes the training, personnel, and training devices to be evaluated during DT&E

6-2 SENSITIVITY

Sensitivity refers to the minimum level of agent that a detector or sensor system will detect within its characteristic response time For sample-collecting detectors, such as point sampling alarms and detector kit tubes or tickets, which are designed to detect airborne hazards of inhalational or percutaneously active agent vapors and aerosols, sensitivity is defined as the minimum detectable concentration and is usually expressed in milligrams per cubic meter of air For biological agents sensitivity is frequently expressed as cells, spores, or units per cubic meter because the infectivity of biological agents is related to the number of organisms inhaled For remote sensing IR detectors, sensitivity is expressed as the minimum detectable concentration path length CL The CL is the product of concentration C and the path length L through which the detection is made

For sensors designed to detect surface contamination, sensitivity is defined as the minimum detectable contamination density in milligrams of agent per square meter or kilograms per square kilometer of contaminated surface

For devices that measure agents in water or food, sensitivity is stated as the minimum detectable amount of agent per unit mass of water or food Typical units are milligrams of agent per kilogram of water or food

The sensitivity of devices designed simply to indicate the presence or absence of a specific form of agent, such as liquid drops, is expressed either as the minimum amount detectable in milligrams or as the minimum number of drops detectable and the minimum diameter of detectable drops in micrometers, e g , one 200-μm drop

Generally, CB detection systems are designed to detect specific forms of agents and to perform certain detection functions required by unit missions on the battlefield Although to provide a sensor system to Army units in the field that will detect detoxification levels of all agents in any form, e g , vapor, aerosol, droplets (toxic rain), or liquid is a desirable goal, achieving this goal without

sacrificing other essential characteristics is very unlikely At the other extreme, procedures previously used to set sensitivity design goals were sometimes totally based on known or perceived limitations of the technology being used

A more significant method is to set sensitivity requirements at levels that will ensure detector response at agent dose levels that do not produce serious toxic effects in humans, even though some exposure risk still exists In practice, sensitivity levels are usually set at a compromise level that is as low as possible for safety but sufficiently high to accommodate the technology being exploited without excessive false alarms Clearly, the human response to CB agents must be the fundamental basis used to establish sensitivity criteria for detection systems

6-2.1 RELATION TO *Ct* AND ICt_{50}

Human response to CB agents is measured in terms of dose and exposure dosage Dose is the amount of agent that is taken into or absorbed by the body. A chemical dose is expressed as either milligrams per kilogram of body mass (mg/kg) or milligrams absorbed by the whole body (mg) Dosage Ct is the concentration C of a chemical agent in the atmosphere multiplied by the time the concentration is present t, expressed as milligram minutes per cubic meter ($mg \cdot min/m^3$) and shown by

$$Ct = C \cdot t, \ mg \cdot min/m^3 \qquad (6\text{-}1)$$

where

C = concentration, mg/m^3
t = time concentration is present, min

For airborne vapor or aerosol agent clouds, the exposure dosage encountered by an individual depends upon his time of exposure t_e to the concentration The respiratory exposure dosage (in $mg \cdot min/m^3$) is equal to the time (in minutes) that an individual is unmasked in an agent cloud multiplied by the concentration of the cloud The skin exposure dosage is equal to the time of exposure (in minutes) of an individual's unprotected skin multiplied by the concentration of the agent cloud The sum of the respiratory dosage and the skin exposure dosage is generally accepted as the effect upon the whole body

The physiological effectiveness of skin and respiratory aerosol dosages are influenced by particle size as well as exposure time t_e and concentration because penetration of the respiratory tract and deposition on the skin are both dependent on particle size These dosages are usually expressed in $mg \cdot min/m^3$ for a particular particle size (Ref 9)

Agents in the form of large aerosol particles and liquid drops that are not inhalational pose a hazard because a dose can be deposited by settling out of air onto the exposed individual A secondary hazard exists when the individual picks up deposited agent from surfaces as he traverses the contaminated area

The deposited dose D of a liquid agent is related to the exposure dosage Ct by

$$D = Ct \cdot S \cdot A_d, \ mg \qquad (6\text{-}2)$$

where

S = settling velocity of agent drops, m/min
A_d = area receiving agent fallout, m^2

The actual dose received by an exposed individual is related to the exposure dosage by two relationships

1 *For Inhalation*

$$D_I = \rho \cdot Ct \cdot \beta, \ mg \qquad (6\text{-}3)$$

where

D_I = inhalation dose, mg
β = breathing rate, m^3/min
ρ = efficiency of agent retention in respiratory tract, dimensionless

The efficiency of agent retention approaches one for vapor agents and drops as particle size increases. At about 50 μm, ρ approaches 0

2 *For Body Exposure*

$$D_{BA} = \epsilon \cdot Ct \cdot A_b \cdot \gamma, \ mg \qquad (6\text{-}4)$$

where

D_{BA} = body exposure dose attributed to airborne agents, mg
γ = wind speed transporting agent, m/min
A_b = surface area of body exposed to agent, m^2
ϵ = efficiency of deposition onto skin, dimensionless

ϵ the efficiency of deposition, is a complex parameter determined by the physical form of the agent, i e , as a vapor or aerosol, the temperature and humidity, the type of agent and its physical properties including diffusivity and vapor pressure, the nature of the clothing worn by the individual, and, if the agent is an aerosol, the windspeed transporting the agent particles and the particle size

Liquid agents fall as drops to form surface contamination The amount of surface contamination resulting from a given attack by liquid agents is called the contamination density C_d, which is measured in milligrams of agent per square meter of contaminated terrain The dose of agent received on the body of an exposed person D_{BG} attributed to surface contamination is related to contamination density as

$$D_{BG} = B \cdot C_d \cdot A_b, \ mg \qquad (6\text{-}5)$$

where

D_{BG} = body exposure dose attributed to surface contamination, mg
C_d = contamination density, mg/m^2
B = protective barrier efficiency of clothing or other protective cover, dimensionless

The value of B can range from zero to one For impermeable clothing or food protected in cans, $B = 0$, whereas for bare skin, $B = 1$ For various clothing systems or protective barriers, B can be given various intermediate values

The dose of agent that produces minimal effects in exposed persons is defined as the threshold effects dose The threshold effects dose for agents of interest is frequently the basis used to establish the sensitivity levels for detectors

The threshold effects from inhalation of chemical agent vapors and aerosols are normally expressed as two values (1) eye effects only and (2) excluding eye effects Eye effects are usually the first noticeable symptom in mammals of exposure to nerve and blister agents For nerve agents, the eye threshold effect is characterized by prolonged or excessive contraction of the pupil For blister agents such as mustard (H), the eye effect is a localized conjunctivitis or inflammation

The threshold effects for percutaneous and oral routes of exposure are given in units of total dose contamination The human effect is assumed to be directly proportional to the mass of agent either on the skin or ingested (Ref 9)

The critical data base describing the physiological effects of chemical agents in humans is very limited The literature, although extensive, mainly describes acute lethal exposures in animals, there are limited data on sublethal levels or on human responses to agents (Ref 9) The effect of agent on mammals is a nonlinear process This fact restricts the direct calculation of no-effect levels from high-dose exposures and complicates extrapolation of animal data to humans (Ref 9)

More data are needed on the toxicity of low doses by the various possible routes of entry into the body for threat agents, especially soman (GD) and toxins Studies are currently being conducted using animal experiments as a basis for theoretical modeling of the human response (Ref 10)

Chemical Agent Data Sheets, Volume 1, (Ref 11) contains a compendium of data on human and animal responses to chemical agents These data are given by the routes of entry (1) ocular (through the eye), (2) percutaneous (skin absorption), (3) inhalation, (4) ingestion (swallowing), and (5) injection Dosages for the chemical agents are given as median lethal dosage LCt_{50}, median incapacitating dosage ICt_{50}, threshold limit values (maximum allowable Ct for skin and eyes), and minimum effective dosage

Because the sensitivity of chemical agent detectors is based on concentration, a transformation of the data from dosage to the sensitivity criteria for the detector is required. For example, in the RDIMP (Ref 4) the transformation of data was calculated by dividing by an assumed exposure time of 10 min The Bliss slope* was used to compute the sensitivity requirement for an incapacitating dosage affecting 5% of the exposed population ICt_5

$$ICt_5 = \frac{ICt_{50}}{\text{Log}_{10}\left(\frac{2}{\text{Bliss Slope}}\right)}, \text{ mg·min/m}^3 \qquad (6\text{-}6)$$

where

ICt_5 = incapacitating dosage affecting 5% of the exposed population (threshold incapacitating dose), mg·min/m^3
ICt_{50} = incapacitating dosage affecting 50% of the exposed population (median incapacitating dose), mg·min/m^3

Threshold levels in the RDIMP are based on eye exposure and incapacitation from inhalation of agent

For biological agents, toxicity is given as an infective dose Agent concentration can be converted to dosage by dividing by an average breathing rate of 15 L/min Dosage is converted to concentration by dividing by 10 min, which is the assumed exposure time in the RDIMP The three levels of acceptable concentration in the RDIMP are those required to detect virtually all agents, most agents, and some agents Toxin agents are rated in the same way as biological agents (Ref 4)

6-2.2 COMBAT CONCENTRATIONS

The RDIMP establishes the dosage levels to be used as the basis to set the sensitivity performance criteria for detectors of chemicals, biological agents, and toxins in all combat situations, i e , combat and combat support, combat service support, reconnaissance, and fixed site installations These performance criteria are summarized in Table 6-3 (See also Chapter 3 on operational situations)

To establish specific sensitivity levels for a particular agent requires application of the method described in par 6-2 1 to agent dosages For example, to determine the Level 2 sensitivity requirement for agent sarin (GB), the threshold eye effects level for 50% of the exposed population of 0 5 mg·min/m^3 and the GB Bliss slope value of 0 028 are used in Eq 6-6 The equation yields a

*The Bliss slope equals 1/Probit slope The Bliss and Probit slopes are used to characterize the relationship between the dosage, or dose received and the probability of casualty occurrence (usually expressed as a lognormal function)

TABLE 6-3. DETECTOR SENSITIVITY PERFORMANCE CRITERIA (Ref. 4)

	AGENT	PERFORMANCE CRITERIA*	
1	Chemical	Level 1	Detoxification level
		Level 2	Threshold response level 5% of affected population
		Level 3	Incapacitation 5% of affected population
2	Biological	5% of affected population infected	
3	Toxin	Level 1	Detoxification level
		Level 2	Threshold response level 5% of affected population
		Level 3.	Incapacitation 5% of affected population

*Level 1 is the desired need in terms of performance as perceived by the user Other levels indicate less than desired but acceptable levels of performance The lowest level is minimally acceptable performance

threshold eye effect for 5% of exposed population ICt_5 of 0 27 mg·min/m^3 Dividing this dosage by the assumed exposure time of 10 min yields a sensitivity requirement of 0 027 mg/m^3

Similarly the sensitivity requirements for other levels of detector performance can be determined for any other chemical, biological, or toxin agent for which dosages that produce the specified effects are known

In summary, sensitivity is a critical design criterion for CB detection devices Once the acceptable exposure dosages are established by the user, they can be transformed into required sensitivity levels The allowable exposure dosages are dependent in part upon the degree of risk the user is willing to accept For some applications, such as monitoring for the presence of GB and persistent nerve (VX) agent in depots, arsenals, and laboratories, risk must approach zero Stringent handling and storage requirements are necessary to meet chemical surety and safety regulations when the allowable exposure dosages approach zero

Table 6-4 shows the relative sensitivity of chemical agent detectors used in monitoring applications Some of these devices, such as the M43A1 detector unit of the M8A1 automatic chemical agent alarm and the M256A1 and M18A2 chemical agent detector kits, are currently authorized for issue to troop units or specialized Army units Others, such as the real-time monitor (RTM) and the "bubbler", are capable of detecting very low concentrations but are neither designed for nor capable of being adapted for use on the battlefield

A design engineer may be required to design detectors for chemical surety operations The M8 and M9 chemical agent detector papers are the only items available that are capable of immediate detection of nerve and blister agents, however, they can detect only liquid contamination

6-2.3 BACKGROUND

One of the major factors influencing whether or not a detector meets its sensitivity goals is the capability of the sensor to distinguish between agents and the various natural or battlefield-induced materials occurring in the operating environment Background materials include naturally occurring pollen and airborne microorganisms, dust, vehicle exhaust, smoke and other combustion products, petroleum, oils, lubricants, industrial air and water pollutants, and decontaminants These materials may be found on surfaces and in the air, water, and/or food supplies

Biological agents are especially difficult to detect, and their infective nature forces the biological agent detector to achieve sensitivity to very low concentrations of microorganisms Distinguishing between toxic biological agents and the numerous naturally occurring microorganisms in the environment compounds the problem of biological agent detector design The detector must screen and reject the many characteristic signals given by the various nontoxic, but possibly harmful, microorganisms while accepting a signal, possibly at extremely low concentrations, characteristic of a biological agent not normally found in nature

TABLE 6-4. DETECTOR SENSITIVITY AND RESPONSE OR PROCESSING TIME FOR NERVE AGENTS (GB AND VX) (Ref. 12)

EQUIPMENT	SENSITIVITY, mg/m^3		RESPONSE TIME
	GB	VX	
Detector ticket, M18A2	0 02-0 04	0 1	3 min
Detector Paper, M8 and M9	Positive or negative only		Immediately
Blue/white band tube	0 2	No capability	3 min
M256A1 detector kit	0 02-0 05	0 05-0 15	10-15 min
Real-time monitor (RTM)	0 0001	0 00001	8-12 min
M43A1 detector unit	0.2	0 4	2-3 min
Bubbler	0 0001	0 00001	4 h

Background and biological agent aerosols usually are differentiated on the basis of particle size and shape, both of which are nonspecific measurements The background particle concentration of naturally occurring microorganisms can range from 200 to 3000 particles per liter Because the number of agent particles may be only a very small fraction (10^{-3} to 10^{-5}) of the background particles, the problems of any biological agent detector are

1 Discrimination, i e , responding only to agents

2 Collection of enough agent samples to produce a measurable response

Release of live biological agent organisms by any means of dissemination and the weather conditions will probably result in a preponderance of dead agent particles in a biological agent cloud This fact can be an advantage for detectors that are able to detect unusual concentrations of particles (dead or alive), organisms which are unrepresentative or atypical of the surrounding environment Although the background is more diverse and difficult to isolate for biological agents, it is still a particularly critical factor in the design of chemical agent detectors

Detection of chemical agents is based upon their characteristic chemical or physical responses, but many chemical substances present in the atmosphere react or respond similarly to agents For example, detector tickets in the M256A1 Detector Kit are based upon the colorimetric response to the inhibition of an enzymatic reaction by nerve agents, but many insecticides can also inactivate the same enzyme Infrared remote sensors, such as the XM21 alarm, respond to absorption of specific frequencies of infrared energy that are characteristic of the molecular structure of the nerve agents, but certain natural dusts and some screening smokes also absorb in the same region of the electromagnetic spectrum

Failure to discriminate naturally occurring or battlefield interferents from agents and the resulting signal from interferents cause a false positive signal, which produces a false alarm To reduce the background problem in the design of detector systems, the performance criteria for these systems must always address the elimination of background-induced false alarms These criteria may be stated as

1 The detector must not give false alarms or be inhibited by chemicals or vapors normally present as a result of battlefield, fixed site, or nearby industrial or mechanical activity, e g screening or signaling smokes gasoline, oils, lubricants engine exhaust, hydraulic fluids, fertilizers, insecticides, and herbicides (Ref 13)

2 The detector must not give false alarms or be inhibited by atmospheric conditions, e g , dust, smog, haze, smoke, fog, or rain (Ref 13)

3 The detector must not give false alarms or be inhibited by decontaminants (Ref 13)

It is extremely difficult to evaluate the performance of a detector against false alarms set off by detection of background materials versus true alarms caused by the detection of an agent This problem is exacerbated by the fact that open-air agent testing is no longer authorized Therefore, testing of the devices must now be conducted under extremely controlled conditions Environmental impact statements are required even for open-air testing with simulants and for the inducement of battlefield conditions or materials in the testing environment (Ref 14)

6-3 RESPONSE TIME

Response time is the amount of time needed for the detector or sensor system to clear or reset, detect and process the raw information on the agent encountered, and to respond by displaying in some form the required information—such as detection, alarm, identification, or quantification—to be used for operational or decision-making purposes

Response time is dependent on the technology of the various types of CB detection and monitoring devices being fielded These include point sampling alarms, remote sensors, monitors, dosimeters, and various hand-held sampling, detection, analyzing, and identification devices or kits Because these devices have distinct functions and measure different forms of agents, each requires specifications appropriate for its intended use

Point sampling alarms are generally yes or no instruments designed to indicate the onset of an attack or the presence of a potentially harmful level of agent at the site of the alarm

Remote sensors include both active and/or passive standoff detector systems that can detect the presence of agents some distance from the system and thereby provide advance warning of an approaching agent cloud

In contrast to the action level response of an alarm, a monitor provides a continuous readout of agent level Dosimeters measure the total cumulative dose regardless of the concentration or the time of exposure, and they provide information on the fraction of the allowable body dose received by an exposed individual Dosimeters are also used by supervisors to evaluate whether medical treatment is needed and to assess the physical status of highly skilled personnel, such as pilots, munitions safety control specialists, and explosive ordnance disposal (EOD) specialists

The variety of purposes served by hand-held detector kits, devices, and expendable items is

1 The M8 and M9 detector papers respond immediately upon contact with liquid nerve or blister agents to provide an immediate indication of contamination

2 The M256A1 and M18A2 chemical agent detection kits are used to detect hazardous levels of chemical agents in the ambient atmosphere, identify the agent present, and indicate the absence of agents in order to expedite

unmasking procedures

3 The M19 sampling and analyzing kit is used by highly skilled chemical analysts to collect samples of unknown threat agents on the battlefield, analyze them, attempt to identify them quickly in the field, or send unidentified samples back to a laboratory for analysis

The response time of detectors is used only as a baseline The design engineer must consider many other factors, such as agent forms, dosage, exposure time, and masking time

6-3.1 RELATION OF RESPONSE TIME TO HUMAN DOSE RESPONSE (*Ct*)

Sensitivity to agent concentrations and response time provide a measure of effectiveness for detectors Response time is related to *Ct*, *CL*, protective measures in terms of dose received from different agent forms (vapor, aerosols, liquid), and routes into the body (Ref 15)

The specifications for point detectors or alarms designed to measure atmospheric concentrations of agents are in units of concentration *C* Linking this specification to physiological effect levels measured by *Ct* requires an estimate of the exposure time t_e, which is defined as the time personnel will be exposed to the agent cloud This value equals the sum of instrument response time t_r, communication and decision time t_c, and the time it takes a notified individual to take the required protective actions t_p, such as donning a mask and protective clothing Exposure time is computed by

$$t_e = t_r + t_c + t_p, \text{ min} \qquad (6\text{-}7)$$

where

t_r = detector response time, min
t_c = communication and decision time, min
t_p = time to don protective mask and clothing, min

For a point sampling alarm situated next to personnel where $t_i = 0$ the exposure time t_{ec} is the sum of the detector response time and the donning time (Ref 9)

$$t_{ec} = t_r + t_p, \text{ min} \qquad (6\text{-}8)$$

The response time of remote sensors that use active or passive IR to detect agents is essentially instantaneous, $t_r \rightarrow 0$ For scanning-type remote sensors, however, the scanning time t_s of the sensor must be included as part of the sensor response time An advantage of the remote sensor is that the time required for the agent to traverse the distance from the point of detection to the personnel to be protected t_i can be subtracted to yield the exposure time Therefore, the exposure time with a remote sensor t_{er} would be

$$t_{er} = t_s + t_c + t_p - t_i, \text{ min} \qquad (6\text{-}9)$$

where

t_s = scanning time, min
t_i = time for agent cloud to travel from detector to personnel, min

To minimize casualties for any given agent, exposure time t_e must be minimized Response time of a point sampling alarm should be kept as short as possible, but even if it is 0, t_e cannot be reduced below the sum of communication time plus protection time $t_c + t_p$

In addition, it is clear from Eq 6-9 that advanced warning time, provided by remote sensors, offers the potential to offset completely the lost time that results from activities related to scanning time, communication time, and protection time

Generally and if other factors are equal, the higher the concentration, the shorter the required response time For example, specifications for the M8A1-type alarm require a response time to 0 2 mg/m^3 of GB of 2 to 3 min, but at 0 9 mg/m^3 the response time is 0.5 min (Ref 4)

Due to limitations in the available technology, detector design is usually based on a specific form and class of agent Therefore, detectors built to detect low concentrations of agent vapors may not be able to respond to liquid agents but may be able to respond to the agent vapors given off by the liquid agent

Unlike chemical agents, biological agents are living organisms or the toxic by-products of specific organisms (toxins) They are not detectable by the human physical senses, and it may take hours, days, or even weeks before the symptoms of the diseases or the toxic effects of the agents become evident Response time and dosage are critical performance considerations in biological agent detector design Particle size, concentration, viability, virulence, and communicability are all factors that influence the response time required for the design of biological agent detectors and monitors

Response time requirements for biological agents can be established on the basis of the number of agent aerosol particles per liter of ambient air (concentration) a detector can detect or count per minute If the breathing rate of a resting human is about 10 L/min and the median lethal dose of a particular biological agent (infective dose) is about 10 living organisms, an agent concentration of one live organism in 10 L of air inhaled for 10 min could be lethal (Ref 16)

6-3.2 RELATION OF RESPONSE TIME TO MASKING TIME

The time it takes the soldier to mask and don protective equipment forms a baseline for the response time criteria established for CB detection and monitoring systems From Eq 6-8, for vapors and aerosols, even when the signal from the detector is communicated instantaneously ($t_c = 0$), the exposure time t_{ec} is still determined by the

combination of detector response time plus masking time Doctrine states that at the instant an individual is alerted to agent presence, he should *stop breathing*, don his mask with hood, clear his mask, give the alarm, and then finish donning protective clothing Theoretically, this procedure reduces the time to don protective mask and clothing to zero for vapors and aerosols because no exposure to agent exists while breathing is stopped Under these conditions exposure time equals detector response time $t_{ec} = t_r$ Using a point sampling alarm upwind can offset the effect of response time on exposure time for drifting clouds, but this placement may not always be possible

A trained soldier can don, clear, and check his mask within nine seconds and is required to secure the hood within 15 s from the sounding of the alarm Donning the protective clothing ensemble to assume mission-oriented protective posture (MOPP) 4 takes an additional eight minutes from start to complete encapsulation If the soldier is already in MOPP2 or MOPP3, the time to achieve MOPP4 is much shorter Hence for agent in liquid form, even if the detector response time is zero, the soldier must already be in MOPP2 or MOPP3 prior to attack to minimize exposure The shortest possible response time is still important to activate the assumption of MOPP4 promptly In the impact zone of any chemical attack, however, instantaneous detector response is irrelevant except to confirm an agent is present The doctrinal response to take immediate protective action upon a suspected chemical attack is required

In a collective protection shelter where no personal protective gear is worn, the exposure time is the resident time in the environment, which is arbitrarily limited to a maximum of 24 h (1440 min) The requirement to use total exposure times inside collective protection shelters results in very low sensitivity requirements for internal monitors For shelter monitors the response time is keyed to alarming when the cumulative concentration over the period of time the soldier has inhabited the shelter reaches the minimum threshold dosage specified for the system

Masking time also impacts the time required for detectors to respond to enemy employment of biological agent aerosols The RDIMP (Ref 4) establishes "real time" (<5 s) as the desired response time performance criterion for biological agent detection and warning systems The sensors should detect an attack within 1 to 2 min after the aerosol reaches the area Such a time limit is desirable because it involves detecting the fringes of the aerosol cloud, where the concentration is much lower than in the center Personnel in the area can then take protective action and warn personnel downwind of the approaching hazard from that agent

6-4 DISCRIMINATION AND SPECIFICITY

Discrimination is the capability of a detector to distinguish among chemical, biological, and toxin agents or among the various classes of compounds, e.g., nerve, blister, blood, or choking chemical agents. Specificity is the capability of a detector to distinguish a particular agent from other agents, chemicals, or materials in a naturally occurring medium, such as ambient air, water, or food

6-4.1 DISCRIMINATION

In general, to achieve discrimination, chemical agent detection technologies, both chemical and physical, are based upon detection of a specific moiety (a characteristic part of the agent molecule) that is common to a given class of agents For example, for a nerve agent to possess a high degree of toxicity, it must have a pentavalent phosphorus with a double-bonded oxygen and labile halogen or sulfur group attached Chemical methods of detection use chemical reactions that target this specific moiety to produce an end product that can be analyzed by colorimetric, fluorimetric, electrochemical, or chemiluminescent methods

Physical methods of detection, on the other hand, do not use reactions, they measure other characteristics of the chemical moiety For example, in IR detection, the interatomic vibrations of the molecule in the 8- to 12-μm region of the electromagnetic spectrum (an atmospheric window region) can be monitored IR methods of detection are suitable to remote detection technologies in which the open atmosphere is the detection cell for the measurement The capability to discriminate among the various classes of chemical agents using IR technology requires use of frequency-agile lasers Although relatively few wavelengths are needed for detection, e g , nerve and mustard vapors can be detected by four lines, full discrimination of a wide range of agents in various states and in the presence of background interferents takes many more wavelengths (Ref 4)

In the past, most biological agent detection technologies have been based on biotechnology methods, which are limited in number compared to those used for chemical agent detection The difference is due mainly to the complexity of the requirement to discriminate agent particle size, determine particle counts, challenge a large variety of potential agents, and distinguish the agents from a background laden with many similar, naturally occurring organisms

Recently, physical methods of biological agent detection have received more attention In particular, the application of ultraviolet-induced fluorescence (UVIF) has been investigated as a remote detection technique for biological agents

Because toxins are very complex chemical compounds, they are even harder to discriminate than chemical agents Both chemical and physical detection methods for toxin agents are being investigated

Although the RDIMP (Ref 4) and the user community have stated a general requirement for CB detection and monitoring systems to be capable of discriminating among chemical, biological, and toxin agents in a single device, most detectors to date have been designed to detect a specific class of agent, C, B, or T. Except for the hand-held, manually operated chemical agent detector devices or kits that provide a measure of discrimination through chemical methods of detection, none of the fielded systems have been designed to discriminate between agents within a class

Due to the possible threat of attacks of combined C, B, and T agents on troops, considerable emphasis is now being placed on designing systems that discriminate among C, B, and T agents A second, more attainable goal is to develop modules or families of detectors that can be integrated into the overall detection and warning system to provide this capability

6-4.2 SPECIFICITY

Specificity plays an even more important role in CB detector design than discrimination does The key to the success of a system is its ability to establish the levels of specificity within an agent class (chemical, biological, or toxin) while screening out nonagent interferents and background with reasonable assurance of few false alarms This requirement is followed by the desirable, but not critical, ability to identify a single agent within a class

Most of the chemical methods used to detect chemical agents have some inherent design drawbacks in detection system specificity. The alarms that use chemical methods of detection must be point sampling devices capable of drawing samples continually from the ambient air and analyzing the samples to determine whether a chemical or toxin agent is present Chemical reactions are especially subject to problems with airborne battlefield interferents that can cause false responses or mask agent responses Physical methods of detecting chemical and toxin agents also have this specificity-related problem, but assessments in the RDIMP (Ref 4) indicate that physical methods may be able to screen out the natural and battlefield-induced background interferents.

Detection of biological agents involves unique problems because it requires a much more sensitive detector than that required for chemical agents Also most of the methods investigated lack specificity and are inhibited by even greater interference from naturally occurring substances in the air Because biological agents in a relatively narrow size range are disseminated as aerosols, specificity is improved by designing aerosol collection systems that sample only that size range

From the standpoint of physical detectability, two dominant features of the biological cloud are

1 The presence of microorganisms, i.e , composed of proteinaceous material

2 A high concentration of particles in the size range 1 to 5 μm.

The present specificity objective in biological agent detectors is to design a device capable of reliably detecting protein levels comparable to the average atmospheric background levels of protein and particle concentration

6-5 SYSTEM DESIGN CONSIDERATIONS UNIQUE TO CB DETECTION AND MONITORING

Other design considerations unique to CB detection and monitoring systems include agent identification, automatic operation, unattended operation, and agent quantification Compared to detector sensitivity and response time, these design considerations are perhaps less important, but they have special significance for certain types of detector systems and situations

6-5.1 AGENT IDENTIFICATION

Agent identification is the determination of the identities of specific agents present in the environment Agent identification can be divided into two levels

1 *Definitive identification* The determination of the exact identity of a compound or organism through the establishment of a group of unique characteristics

2 *Classification* The determination that a compound or organism is a member of a class of substances, without establishing definitive identification of the material

Rapid identification of agents is necessary to determine the type of agent and threat, decontamination requirements, and possible treatment requirements Identification is also necessary to determine the intentions of the enemy and to avoid technological surprise

As stated in the RDIMP (Ref 4), in tactical situations agent identification is clearly secondary to the ability to detect all agents, known and unknown The current thrust of CB identification R&D is to provide classification, e g , nerve, blister, blood, or choking agent

The two performance criteria for the agent identification characteristic listed by the RDIMP (Ref 4) are

1 Ability to identify all known agents

2 Adaptability to identify unknown agents in all situations

Closely associated with these criteria is the time required to identify the agents. The two levels of agent identification response time listed in the RDIMP (Ref 4) are

1 Level 1 One-min response time on demand is desired

2 Level 2 Ten-min response time is required

Achieving these agent identification design goals depends on the progress made in designing a high degree of selectivity and discrimination into the candidate CB

detection and monitoring systems Although some technological approaches to development of CB agent detector systems eventually may be able to provide an automatic agent identification capability, a family of compatible systems rather than a single system probably will be needed to meet this requirement

Identifying biological agents presents one of the most difficult detector design problems the design engineer will encounter With current technology, identifying biological agents requires a sampler capable of processing large volumes of contaminated ambient air, a holding solution that can preserve the agents for analysis and permit incubation, and an analyzing system to classify and identify the agent as distinct among the many background interferents found in the sample solution (Ref 16)

The only dependable technique available to identify biological threat agents is sampling and analysis conducted under field laboratory or base laboratory conditions This identification process, however, takes too long, it cannot meet the required response time cited in the RDIMP (Ref 17)

Current methods of determining chemical agent identification employ manually operated detection, sampling, and identification devices and kits, which are slow and require a reasonable degree of skill and training to achieve reliable results

R&D currently is being conducted to upgrade these kits to provide a toxin agent identification capability. Development of a biological agent identification kit remains a high-priority item in CB defense R&D efforts

6-5.2 AUTOMATIC OPERATION

With the development of highly toxic, odorless, and colorless CB agents at the end of World War II, both the combat development and materiel development communities perceived this new threat as one requiring the fielding of an automatic alarming and warning capability

Automatic operation is the capability of a system to operate and regulate itself Warning is the timely dissemination of information that a chemical or biological agent attack is present or anticipated in an area where exposed troops are located Without adequate warning exposed troops cannot take effective CB protective measures in time to avoid serious casualties or to operate effectively and confidently in a CB environment

Manually operated detector kits and detector papers generally use colorimetric reactions that are monitored visually by the operator Performing these tests takes time and the results are dependent on the skill and observation of the operator For automatic systems, electronic processing is performed by on-board computers This approach, however, requires signal-to-noise ratios (SNR) such that the signal is sufficiently greater than the background noise in order to preclude false responses Various techniques, such as pattern recognition and algorithm development, are used to enhance the SNR, reduce false alarms, and provide a reliable alarm capability

Alarming is a means of processing the visual or electronic signals into a warning to the user and/or threatened personnel in the area Visible and audible indicators on the detector and alarm units warn the operator monitoring the device who then spreads the alarm For automatic readout, horns or lights can be actuated from the electronic signal to alert the operator and/or those in the immediate area Most automatic detector design criteria now require new systems to telemeter the alarm signal for rapid data transmission over a large area through the NBC warning and reporting system (NBCWRS) network Timely transmission of data to support decision making or for automatic responses such as masking is a critical element of CB detection and warning on the battlefield

Due to the development of rapid warning networks for combat operations and the adaptation of computer technology to military requirements, more emphasis is now being placed on automated battlefield systems Any electronic automated battlefield system designed for use by Army field units contains a computer, which is essential for operation Computers used in such systems range from small computer memory and processing chips to large data processing units The computer in the automated battlefield system controls the operations performed by the various functional modules, components, or assemblies that make up the system

Automatic CB detection and monitoring system computers also are used to control and perform data acquisition, synchronize agent sampling, calibrate the system, calculate agent concentrations, and initiate the transmission of the alarm when the sensor or detector detects an agent Depending on the complexity of the system, the computer also may perform other functions, e g , automatic scanning and printing or transmitting of reports, graphs, and maps of the contaminated or threatened areas

The performance criterion for automatic operation usually is stated as either fully automatic or semiautomatic (man in the loop) Fully automatic implies that the system has an internal computer to control the performance of all of its functions after the initial emplacement and setup except periodic servicing The goal is to reduce the manpower required to support the system so that more soldiers can be released to perform other combat-essential duties Semiautomatic operation, by contrast, requires an operator not only to emplace, set up, and periodically service or reset the system but also to be a significant, interacting part of the detection and alarm chain

Due to the complexity of designing fully automatic

systems that perform reliably on the battlefield, system design usually involves a compromise between automatic and manual reset capabilities An automatic system should be capable of automatically returning to the normal background operating condition after agents have dissipated, but the system also should be capable of being reset by an operator

The speed with which the system can reset itself is important in determining its effectiveness Ideally, the reset time is affected by three factors

1 The actual capability of the detector system to handle successive samples in near real time

2 The capability of an on-board computer to process the tremendous amount of information generated by the samples

3 The capability of the computer to make decisions on individual samples as soon as they arrive (Ref 18)

Table 6-5 summarizes the detector characteristics and performance criteria affecting detection system operation as specified in the RDIMP (Ref 4) service or setup time, alarm, data transmission, and reset time

6-5.3 UNATTENDED OPERATION

Unattended operation is "the capability of a system to operate by itself (without intervention by an operator) while being monitored remotely" (Ref 4) This definition implies fully automatic operation for a long period of time Unattended operation is desirable in most battlefield situations because personnel are needed to perform other mission-essential duties while trying to survive in a CB environment

Combat and combat support units use small, portable point sampling detectors that can operate by themselves and that run on battery or vehicle-generated power Although desirable, unattended operation is not always feasible for the types of mobile situations in which the detectors will be used Technologies are being investigated for development of small remote sensors that can be deployed in matrices covering a wide area to detect agents, alarm, and transmit data to central computer units within the NBCWRS network

Remote sensors are needed for continuous operation around fixed site installations (FSI) to provide a CB detection and warning capability for key installations The main disadvantage of these systems is the requirement for increased power to operate around the clock without continuous servicing and resetting by operators Light detection and ranging (LIDAR) remote detectors, in particular, have high power requirements These remote detection systems that run on power generated by the FSI should be capable of switching to other power sources, such as batteries or stand-alone generators, without false alarms or other loss of capability in the event of a loss of FSI power Remote detection systems for FSI protection can be much larger than the tactical detectors issued to combat and combat support units, if necessary, to provide unattended capability To be most effective, these systems must be compatible with other electronic systems to ensure integration of all alarm and warning systems at a central point

CB detectors designed to monitor for contamination inside collective protective shelters and at their entrances

TABLE 6-5. DETECTOR CHARACTERISTICS AND PERFORMANCE CRITERIA AFFECTING DETECTION SYSTEM OPERATION (Ref. 4)

CHARACTERISTICS AND SUBCHARACTERISTICS	PERFORMANCE CRITERIA
Alarm	Emit or trigger automatic electronic, audible, and/or visible signal
Data transmission	Within unit Interface with warning transmission system network Night vision compatible Battalion or higher headquarters Attack occurred Identity of agent present Location Date and time group
Service or Setup time	Level 1 Instantaneously usable in 1 min Level 2 Usable in 30 min
Reset time between samples	Level 1 Continuous (<15 s) Level 2 2 min for all units except reconnaissance (RECON) units 15 min for RECON units

generally require the capability to operate continuously for a long time without attendance These monitoring devices must be small to be used inside the collective protective equipment systems

6-5.4 AGENT QUANTIFICATION

Agent quantification is the determination of the chemical or biological agent concentration or the amount of contamination The performance criteria can range from measurements requiring either highly specific concentration readings in milligrams per cubic meter (mg/m^3) or contamination density in milligrams per square meter (mg/m^2) to the semiquantitative requirement to quantify "all known and be adaptable to unknown", as stated in the RDIMP for all battlefield situations (Ref 4)

Decision makers need quantitative data to determine the extent of the CB hazard The hazard is the toxic environment produced by a CB attack and is measured either in terms of concentration, deposition, or effect on humans Agent quantification establishes the form—vapor, aerosol, large droplets, or liquid—and persistency of the hazard Agent quantification also is used to predict downwind hazards, to decide the most effective MOPP levels, to assess the potential risk of remaining in a contaminated area, to decide whether to avoid contaminated areas or pass through them, to determine decontamination requirements, to calculate weathering effects, and to determine the cumulative concentration in collective protective shelters Such quantification data by themselves, however, generally have no meaning to the decision makers The concentration or contamination deposition data must be translated into terms of hazard to exposed personnel, i e , exposure dosage or contamination pickup (Ref 18)

At present there are no type-classified detectors that will give an automatic quantitative agent response (Ref 18) The only agent quantification capability on the battlefield today consists of the CB threat predictions made by trained NBC specialists

Although the RDIMP did not stress agent quantification as a critical issue this requirement will gain more attention as detection technology advances and the possibility of achieving stated design goals shows more promise of success

6-6 INTEGRATED LOGISTIC SUPPORT (ILS) CONSIDERATIONS

ILS is the process through which the management and analysis actions necessary to ensure effective and economical support of a materiel system are accomplished both before and after fielding The basic management principle of ILS is that logistic support resources must be developed, acquired, tested, and deployed as an integral part of the materiel acquisition process DoD Instruction 5000 2 (Ref 7) is the basic guidance for ILS considerations AR 700-127 (Ref 19) implements DoD Instruction 5000.2 and adds the elements of design influence and standardization and interoperability

For each new system to be developed, the materiel developer must prepare a comprehensive and responsive integrated logistics support plan (ILSP) in accordance with AR 700-127 and DA PAM 700-55 (Ref 20) The ILSP provides a composite of all support necessary to ensure the effective and economical management of the CB detection and monitoring system throughout its life cycle The ILSP also serves as the source document for summary and consolidated information required in other documents that are part of the system PMD The ILSP is an evolutionary program management document that requires updating as the system moves through the various phases of the system acquisition process The ILS elements are described in the paragraphs that follow

6-6.1 LOGISTICS SUPPORT ANALYSIS (LSA)

The combat developer and the materiel developer are responsible for establishing and maintaining an effective LSA program as part of the ILS program for each developmental system This program is planned, integrated, developed, and conducted in conjunction with, but not duplicating, other design, development, production, and deployment functions to achieve overall program objectives in a cost-effective manner The LSA program for materiel development support includes management and technical resources, plans, schedules, and controls for performing LSA requirements

To assist in complying with supportability and other ILS objectives, the materiel developer conducts LSA as part of the system engineering and design process Scientific and engineering efforts undertaken during the acquisition process are selectively applied to the accomplishment of system ILS design goals through a comprehensive LSA program MIL-STD-1388-1 (Ref 21) provides guidance for performing the various LSA tasks and subtasks MIL-STD-1388-2 (Ref 22) contains the definitions for standard LSA data elements All LSA task analyses must consider both peacetime and wartime operations Although not necessarily applicable in all development programs, LSA elements or documentation required by MIL-STD-1388-1 for the more complex programs such as automatic point sampling detectors and remote detectors include the LSA strategy use study, and tradeoff studies

Through ILS and LSA managers the design engineer is responsible for ensuring that developmental systems are to the extent possible structured for standard Army logistic support and standard test measurement, and diagnostic equipment (TMDE) The LSA team develops and updates, as applicable, an LSA strategy outlining proposed supportability objectives for the system

The LSA strategy lists LSA tasks and subtasks to be performed early in the system acquisition process that will provide both the system and support at an affordable cost As system acquisition progresses, LSA is performed at increasing levels of depth and detail and incorporates such system engineering factors as system or equipment design, maintenance concept, operational approaches, estimates of RAM, operations and support (O&S) costs, logistic support resources, and readiness characteristics of each design and operational approach

The maintenance engineer then develops and documents the maintenance concept and maintenance plan for unit, direct support (DS), general support (GS), and depot maintenance, as appropriate and as prescribed in AR 750-1 (Ref 23)

The LSA team conducts the level of repair analysis (LORA), in accordance with AR 700-27 (Ref 24), to establish the maintenance levels at which modules, components, and parts will be replaced, repaired, and discarded This analysis is done by iteratively describing the maintenance and supply support required by the system to lower progressively assembly or subassembly (indenture) levels, as reflected in the technical data package (TDP) The LSA provides the data for detailed definition of the maintenance plan based on the maintenance concept, reliability and maintainability parameters, maintenance functions--shown in Table 6-6 (Ref 25), maintenance tasks (such as time and skill), support and test equipment requirements, facilities requirements, and cost parameters Mathematical models are used to evaluate the maintenance concept based on life cycle cost and operational availability The LSA team also performs a noneconomic engineering evaluation that examines such factors as item size, safety, human factors requirements, technical feasibility of repair, inventory and stockage requirements, documentation, and disposal (Ref 22)

The LSA team may prepare a use study to develop and establish the ILS requirements for the new system or applications, as appropriate The use study identifies and documents the pertinent supportability factors related to the intended use of the new system or item of equipment For future applications the ILS program is based on the existing system with which the developmental system will be integrated, such as ground-mobile and airborne vehicles and FSIs

The LSA team makes field visits, as necessary, to operational units and support activities that most closely represent the planned operational and support environment for the proposed system applications The LSA team uses previously conducted mission area and weapon systems analyses, where applicable, as inputs to the use studies The LSA team prepares the use study report, which documents the information developed during performance of the use study As more detailed information on the new system becomes available, the LSA team upgrades the use study report (Ref 21)

The LSA team conducts tradeoff studies and recommends preferred support system alternatives while it employs standard logistic support models in accordance with MIL-STD-1388-1 Headquarters, AMC, must agree to the logistic support models required to perform such tradeoff analyses before these tasks can be initiated Tradeoff analyses determine the preferred support system alternatives that satisfy the need and provide the best balance among cost, schedule, performance, readiness, and supportability

The LSA team's assessment of the effects of introducing new materiel to the field is in accordance with Task 402 of MIL-STD-1388-1 Tasks 403, "Postproduction Support", and 501, "Supportability test, evaluation, and verification", are addressed as the LSA progresses Task 402 requires assessing the impact on existing systems of the introduction of the new system or item of equipment, identifying sources of manpower, determining the impact of failure to obtain the necessary logistic support resources, and defining essential logistic support resource requirements for a combat environment

6-6.1.1 Constraints—Environmental Requirements

Although not specifically a part of ILS requirements, each CB detection and monitoring system must be designed for operation and storage in various climates—basic (temperate), hot (tropical and desert), cold, and severe cold (arctic) conditions—in accordance with AR 70-38 (Ref 26) and NAT-STD-2895 (Ref 27)

Designers of CB detection and monitoring systems must provide systems that protect and insulate the operating parts and internal modules from the elements Rain, mud, dust, sleet, snow, and ice can clog moving parts and contaminate the system In hot weather, solutions used in systems that rely on chemical reactions or as reservoirs for holding samples tend to evaporate if the system is not securely capped In freezing weather, moving parts tend to freeze in place and solutions used in the detection process tend to freeze Therefore, portable detection devices usually are designed to include internal heating systems Extreme cold freezes most CB agents and makes it more difficult to detect their presence

CB detection and monitoring systems must be packaged so that the equipment is not adversely affected by prolonged indoor storage under all climatic conditions or by exposure to CB agents A shelf life of 10 years is desirable The packaging must provide environmental protection to the contents for a period of nine weeks in desert, tropic, arctic, and cyclic (three cycles, each consists of one week under each climatic condition in sequence) conditions

TABLE 6-6. MAINTENANCE FUNCTIONS (Ref. 25)

1 *Inspect* To determine the serviceability of an item by comparing its physical, mechanical, and/or electrical characteristics with established standards through examination, e g , by sight, sound, or feel

2 *Test* To verify serviceability by measuring the mechanical, pneumatic, hydraulic, or electrical characteristics of an item and comparing those characteristics with prescribed standards

3 *Service* To keep an item in proper operating condition, i e , to clean (includes decontaminate, when required), to preserve, to drain, to paint, or to replenish fuel, lubricants, chemical fluids, or gases, by periodically required operations

4 *Adjust* To maintain or regulate within prescribed limits by bringing into proper or exact position or by setting the operating characteristics to specified parameters

5 *Align* To adjust specified variable elements of an item to bring about optimum or desired performance

6 *Calibrate* To determine and cause corrections or adjustments to be made on instruments or test measuring and diagnostic equipments used in precision measurement Consists of comparisons of two instruments, one of which is a certified standard of known accuracy, to detect and adjust any discrepancy in the accuracy of the instrument being compared

7 *Remove/Install* To remove and install the same item when required to perform service or other maintenance functions Installation may be the act of emplacing, seating, or fixing into position a spare repair part, or module (component or assembly) to allow the proper functioning of an equipment or system

8 *Replace* To remove an unserviceable item and install a serviceable counterpart in its place

9 *Repair* The application of maintenance services* including fault location and troubleshooting,** removal and installation, disassembly and assembly† procedures, and maintenance actions†† to identify troubles and restore serviceability to an item by correcting specific damage, fault, malfunction, or failure in a part, subassembly, module (component or assembly), end-item, or system

10 *Overhaul* That maintenance effort (service and action) prescribed to restore an item to a completely serviceable and operational condition as required by maintenance standards in appropriate technical publications "Overhaul" is normally the highest degree of maintenance performed by the Army and does not normally return an item to "like new" condition

11 *Rebuild* Those services and actions necessary to restore unserviceable equipment to a "like new" condition in accordance with original manufacturing standards "Rebuild" is the highest degree of materiel maintenance applied to Army equipment The rebuild operation includes the act of returning to zero those agent measurements (hours and miles, etc) considered in classifying Army equipment and components

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*Services Inspect, test, service adjust, align, calibrate, and/or replace

**Fault locate/troubleshoot The process of investigating and detecting the cause of equipment malfunctioning, the action of isolating a fault within a system or unit under test

†Disassemble and assemble Encompasses the step-by-step taking apart (or breaking down) of a spare and functional group-coded item to the level of its least componency identified as maintenance significant for the category of maintenance under consideration

††Actions Welding, grinding, riveting, straightening, facing, remachining, and/or resurfacing

6-6.1.2 Constraints—Size and Weight

Size and weight are significant design contraints for CB detection and monitoring systems regardless of the battlefield situation Mobility is also a critical design factor in relation to the required operational and technical characteristics for a new system The performance criteria for size and weight of CB detection and monitoring systems usually are based on the compatibility required of the system with the transporting vehicles or systems with which it must interface Whenever possible, the detectors must be compatible with both current and planned transporting systems Only minor modifications to existing transportation systems should be required to achieve this capability The design engineer must continually emphasize the need to integrate the equipment with the means of transportation, either a man or a designated vehicle

Individual dosimeters must be unencumbering and lightweight, i e , they must not interfere with the other mission-essential tasks and survival measures the individual must perform on the battlefield Detection and identification kits used by small units and specialized personnel also must be lightweight and compact Portable point sampling detectors used for unit CB defense must be capable of being carried by one soldier in addition to his personal battlefield gear, weapons, and ammunition Devices used to monitor agent concentrations inside collective protection shelters and entrances must be small, particularly those used in mobile shelters

Based on required operational characteristics, remote CB detection and monitoring devices must be capable of being integrated within aerial vehicles where weight and space are at a premium, such as helicopters and other Army aircraft, remotely piloted vehicles (RPV), and/or satellites Attaching and integrating hardware always must be considered in the development process and not as an afterthought before fielding The packaged equipment must be transportable by air, land, and sea using theater distribution systems.

Transportability criteria are developed as part of the LSA process The design engineer is responsible for submitting these data, including size and weight requirements, to the Military Traffic Management Command Transportation Engineering Agency as input to the transportability engineering analysis report in accordance with AR 70-47 (Ref. 28)

6-6.1.3 Constraints—Power

Automatic detector systems usually operate from battery power and/or generator power Power requirements vary depending upon the type and planned location of the system on the battlefield Power requirements of mobile systems include batteries provided as components of, or as accessories to, the system and additional power provided by the batteries in vehicles Some systems use alternating current (ac) electric power supplied by an installation or generators Compact electrical power transformers or power supplies can be used to convert to direct current (dc) power Other systems require dedicated generators to provide the necessary power The design engineer also should consider the need for backup battery power sources to ensure continuity of detector operations if the primary power source should fail As required, the design engineer must ensure that the system is compatible with commonly available US, foreign, and military power sources, including vehicle and aircraft power systems and all emergency power systems

The primary obstacle to meeting power requirements is associated with the performance criteria regarding size and weight requirements for the system Generally the more power the system requires, the larger and heavier the overall system becomes The more complex CB detection and monitoring systems, such as biological agent detection and sampling devices and remote detection systems, usually require considerably more power than chemical agent point sampling detectors The need to sample large volumes of air continuously in order to detect biological agents greatly increases the amount of power required to operate the biological detectors

In particular, LIDAR remote detectors that use lasers require considerable power to operate for even short periods of time More power is needed to move the scanners automatically to cover the required field of view (FOV) specified for remote detection systems Thus power requirements substantially affect technologies and desired characteristics, e g , incorporating a complete chemical, biological, and toxin agent detection capability in one system or providing a remote detection capability for RPVs and satellites

6-6.2 RELIABILITY, AVAILABILITY, AND MAINTAINABILITY (RAM)

RAM are characteristics required to ensure that materiel systems are ready for use when needed, that they will perform their assigned functions, and that they can be operated and maintained within the scope of logistic concepts and policies AR 702-3 (Ref 29) provides guidelines for conducting RAM analyses In accordance with this guidance, all CB detection and monitoring systems should be capable of repeated use during routine operations and training exercises with a minimum of necessary servicing or maintenance High reliability, even at higher cost, reduces or eliminates the operational burden and the O&S costs of maintaining a repair capability

Reliability is the probability that an item will perform its intended function for a specific time under stated conditions (Ref 2) The reliability of a detector system is expressed as mean time between failures (MTBF) To forecast the MTBF, the ILS and LSA teams perform a

functional failure mode, effects, and criticality analysis (FMECA) in accordance with MIL-STD-1629 (Ref 30)

The performance criterion for the reliability subcharacteristic for RAM may be stated as a single, quantitative value such as "500 h MTBF" for a remote detector, or it may be stated as a range of reliability performance values such as "400 h MTBF mission need and 800 h MTBF technical limit" for a biological agent alarm In the past, CB detection and monitoring system design performance criteria were stated in terms of mean time between false alarms (MTBFA) for a specified period of operation during a mission More recently, the MTBFA factors for operational accuracy have been incorporated into the overall requirement specified for the system MTBF because false alarms are also considered system failures

Availability is a measure of the degree to which an item is in a working or committable state at the start of a mission that begins at an unknown (random) time Operational availability (Ao) is stated in terms of the percentage of mission time the detector system is available or as the number of hours of a period of time the system is available for operation For example, the performance criterion for availability can be stated either as Ao is 23 of 24 h or as Ao is 90%

The operator and dependent organizations must know when employed CB detection and monitoring systems are or are not available System availability impacts the capability of units to perform missions in a CB environment Thus the system must be designed to provide automatic notification of a no-signal or inoperative condition in the event of system failure, loss of power, or unauthorized tampering The automatic alarms used in the system to signal these conditions should not only be reliable but also audibly and visually different from those used to alert personnel to the presence of CB agents (Ref 13)

Maintainability is a design characteristic that enables the item to be retained in, or restored to, a specific condition within a given time The designer of CB detection and monitoring systems should consider the maintainability factors addressed in MIL-HDBK-791(AM) (Ref 31)

6-6.3 MANPOWER AND PERSONNEL INTEGRATION (MANPRINT)

The Army has relied increasingly on engineering and technology to obtain quantum leaps in capability to meet the near-term and projected long-term threats Technology is used to replace people whenever possible to optimize the distribution of manpower throughout the force If new system technology is not governed by preestablished MANPRINT guidelines, however, the Army will suffer mismatches among the equipment, the soldiers who are required to operate the items, the soldiers and civilians who must maintain the equipment, and the Army force structure The primary objective of MANPRINT is to influence system design in order to optimize total system performance by enhancing human performance (Ref 32)

AR 602-2 (Ref 33) governs the US Army's approach to fielding total systems by integrating people, structure and environment, and engineering technology into the systems MANPRINT is defined as the entire process of integrating human factors, manpower, personnel, training, health hazard assessments, and system safety throughout the materiel development and acquisition process from preconcept through deployment

MANPRINT is a joint TRADOC, AMC, and industry responsibility The Army MANPRINT Joint Working Group manages all MANPRINT issues and ensures that MANPRINT plans are executed and its objectives met The industry design engineer of a system has the overall responsibility for ensuring that MANPRINT factors are addressed throughout each phase of development MANPRINT requirements are system characteristics and a basis for performance criteria Essential components of MANPRINT include individual and unit training, new military occupational specialties (MOS), and the skills and knowledge required to operate and maintain the system

In the early stages the MANPRINT effort is system oriented Human performance capability and reliability are integrated into total system performance through design influence As the system moves through demonstration and validation, and engineering and manufacturing development, the ability of MANPRINT to influence design decreases The effort becomes more unit oriented by focussing on recruiting, training, distribution, and otherwise enabling the support functions to effect further reductions in costs (Ref 32)

6-6.3.1 Manpower, Personnel, and Training

Manpower and personnel considerations transcend system design considerations The capabilities of the personnel inventory (both quantitatively and qualitatively) and the training base are finite, therefore, systems design must respond to these limitations The ILS and LSA managers conduct MANPRINT analyses to predict system demands on the future personnel inventory These analyses determine whether there are unsupported requirements Unsupported requirements may be the quantity of soldiers to support the system, mental category of the soldiers, task loading, available MOSs, and training burdens—such as, availability of instructors, training areas, and time—associated with the system The system design must compensate for shortfalls Through the MANPRINT analysis process, the interaction of each component with the individual soldier is measured against the system operating parameters in a

mission scenario and the concept for support

Force structure parameters must be provided by the Army to the system developers to ensure that new systems are designed to be easily integrated into the structure and environment If a new system adds a new or significantly increased manpower requirement (qualitative or quantitative) to the force structure, the Army must man the revised force structure by degrading (qualitatively or quantitatively) an existing organization The impact of these changes can be extensive, they can affect the mix of commissioned officer specialties, the enlisted MOS mix and grade structure, and unit authorized levels of organization (ALO) As a result, critical units may not be fully manned due to the prevailing manpower ceilings (Ref 32)

6-6.3.2 Health Hazards and System Safety

AR 385-16 (Ref 34) gives guidance on the Army system safety program for materiel acquisition AR 40-10 (Ref 35), which forms the basis for the Surgeon General's Hazard Assessment Program, covers health considerations for materiel acquisition MIL-HDBK-764(MI) (Ref 36) provides procedures in detail for addressing these safety requirements

The safety engineer is responsible for conducting safety and health assessments of all aspects of a developmental system to ensure that the safety and health hazards associated with operation, maintenance, transportation, storage, and disposal are eliminated or reduced Pars 4 5 1 and 4.5.2 of MIL-STD-882 (Ref 37) define the terms and establish priorities for corrective action to be applied in system safety hazard analyses The order of precedence of risk reduction measures for satisfying system safety requirements and resolving identified hazards is

1 Design for minimum risk
2 Incorporate safety devices
3 Provide warning devices
4 Develop procedures and training that reduce risk

The preliminary hazard analysis (PHA) is used to assess the safety risks, determine hazard severity categories and probabilities, and develop the safety design criteria to be used in system design and performance specifications The PHA identifies catastrophic, critical, marginal, and negligible hazard categories Table 6-7 (Ref 37) shows definitions of these hazard severity categories The category and probability of occurrence of a hazard are then used as criteria in the various safety hazard analyses done on developmental systems. These categories provide qualitative measurements of the worst credible mishap that could result from human error, environmental conditions, design inadequacies, or procedural deficiencies or from system, subsystem, or component failures or malfunctions Catastrophic and critical hazards must be eliminated or resolved before the system can progress in development

Quantitatively derived hazard probability rankings are used when the potential of hazard occurrences can be expressed in terms of specific units of time, events, equipment density, items, or activity, as appropriate. When more definitive data on the system have been developed through test and evaluation, the ILS team conducts follow-on system hazard analyses and subsystem hazard analyses to identify failure modes or faults that could develop into conditions causing critical and catastrophic hazard levels

Typical hazards associated with automatic detector systems include potential electric shock hazards from the power supplies, radiation hazards from radioactive materials or sources, and damage to the sight of operators or observers in the path of IR laser beams from LIDAR remote detection systems Safety engineering can eliminate or control some of these hazards Sometimes, however, proper safety hazard warnings in the operators' technical and maintenance manuals and warning labels on the equipment are the only options Operating and maintenance procedures should stress safety precautions, e g , wearing required safety equipment By using this

TABLE 6-7. HAZARD CATEGORIES (Ref. 37)

DESCRIPTION	CATEGORY	MISHAP INFORMATION
Catastrophic	I	Death or system loss
Critical	II	Severe injury, severe occupational illness, or major system damage
Marginal	III	Minor injury, minor occupational illness, or minor system damage
Negligible	IV	Less than minor injury, occupational illness, or system damage

system safety procedure, the ILS team can eliminate and/or control identified hazards

6.6.3.3 Human Factors

During the design process, human factors engineering (HFE) is carried out on the new system in accordance with the MANPRINT requirements of AR 602-2 (Ref 33) and AR 602-1 (Ref 38) HFE consists of human factors engineering analyses, early comparability analyses, task analyses, personnel skill requirements, and logistic needs assessments for the developmental system The HFE requirements and provisions with which the design engineer should be especially familiar are

1 *DoD Human Engineering Guide to Equipment Design*, (Ref 39)

2 MIL-STD-1472, *Human Factors Engineering Criteria for Military Systems, Equipment, and Facilities* (Ref 40)

3 MIL-HDBK-761, *Human Engineering Guidelines for Management Information Systems* (Ref 41)

4 MIL-HDBK-759, *Human Factors Engineering for Army Materiel* (Ref. 42)

The ILS team develops HFE rating questionnaires used to evaluate the human factors responses of operators and maintenance specialists to the system during operational testing Table 6-8 (Ref 43) lists the types of human factors addressed during an HFE evaluation of a representative CB agent detection and monitoring system The human factors involved in this system include dexterity, portability, and the operator's response to visible and/or audible warning alarms while wearing full individual protective equipment (IPE) in a MOPP4 situation

Test personnel are asked to indicate or rate the ease or difficulty of performing the various tasks and to explain any difficulty they may have had in performing the tasks This information must be obtained from a representative

TABLE 6-8. HUMAN FACTORS ENGINEERING (HFE) EVALUATION OF A TYPICAL CHEMICAL AND BIOLOGICAL (CB) DETECTION AND MONITORING SYSTEM (Ref. 43)

TASK DESCRIPTION	HUMAN FACTORS			
	DEXTERITY	PORTABILITY	VISUAL	AUDITORY
Aligning modules	X			
Grasping and manipulating latch fasteners	X			
Handling power cables	X			
Aligning and connecting electrical cable to power jack	X			
Grasping handle(s)				
a Clearance for hand	X			
b Nonslip grip	X			
Lifting and carrying module(s)				
a Weight within characteristics		X		
b Dimensions within tolerances		X		
Determining meter pointer position(s)			X	
Reading scales or printout				
a From normal distance (0 3-0 6m)			X	
b From normal position			X	
Manipulating controls	X			
Seeing warning lights at specified distance			X	
Hearing alarm sound at specified distance and distinguishing it from background noises				X

sample (number) of personnel in the applicable MOS and at various grade levels to ensure that human factors ratings are based on valid data. The HFE system evaluator then reviews the answers to the questionnaire and initiates corrective action as required to resolve any human factors problems revealed by the questionnaire

6-6.3.4 Tradeoffs

As previously stated, the total system includes all of the personnel, equipment, training, doctrine, and support needed to field and sustain the system in peace and during combat Thus total system includes the principal item, the associated direct support items of equipment, other support equipment, and training devices Each item has its own logistic support requirements, and all the individual items are necessary to sustain the system in the field

The "old" (1950s and early 1960s) approach to fielding a new system did not consider personnel issues in the requirements documents This approach led to the "manning the equipment" concept, which was that the soldier was treated as a support item to be married to the piece of equipment after the essential design direction had been determined Despite the designer's reliance on high technology and system complexity to achieve system performance, too frequently the design capabilities and readiness goals were not met Soldiers could not operate, support, or maintain the equipment In a report to Congress by the General Accounting Office (GAO) in 1981, the GAO "attributed half of the failures of all military weapons systems and support systems to human error" (Ref 32)

The following scenario explains the interrelationships among personnel, manpower, training, and technology An increase in the size or capability of a threat combat force requires an increase in our combat power to ensure our ability to defend ourselves successfully The Army increases combat power by increasing the force structure (manpower) and/or by developing equipment that is more technologically advanced Increases in force structure, however, require a redistribution of the Army's finite manpower Manpower can be shifted from combat service or combat service support units to combat units (changing the "tooth-to-tail" ratio), but such a shift may adversely affect the readiness of the total force by reducing the ability to maintain and sustain the total force (Ref 32)

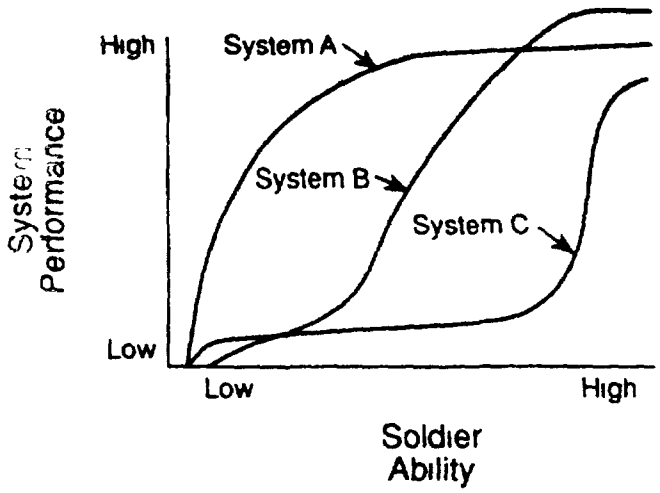
Advanced, technically sophisticated equipment may not, in fact, reduce manpower requirements, because the new system may require the same number of soldiers with greater aptitudes and higher skill levels to operate, maintain, and repair the system If the personnel available lack the required abilities, the Army's options to satisfy the requirements are to increase force structure (This increase would include recruiting not only more soldiers, but more soldiers in higher intelligence categories.), increase manning levels in units, or increase training time But manpower is constrained by Congressionally mandated ceilings, which preclude an increase in the force structure or increased manning levels, and recruiting soldiers in higher intelligence categories can be difficult The Army could increase training time to achieve the enhanced skill and aptitude levels in the existing force structure, but increasing training time requires more instructors and reduces the field strength of the Army This approach also requires more soldiers in the field units who can replace those withdrawn from the field to be trained on the new systems in order to maintain readiness levels This quandary about how to "man the equipment" resulted in the MANPRINT program concept of "equipping the man" (Ref 32)

Human performance capabilities and reliability must be considered when comparing the competing designs and technologies for the new systems Human performance capability and reliability should not be considered static point values, they should be considered a range of values because a soldier's abilities are influenced by all the variables that affect humans

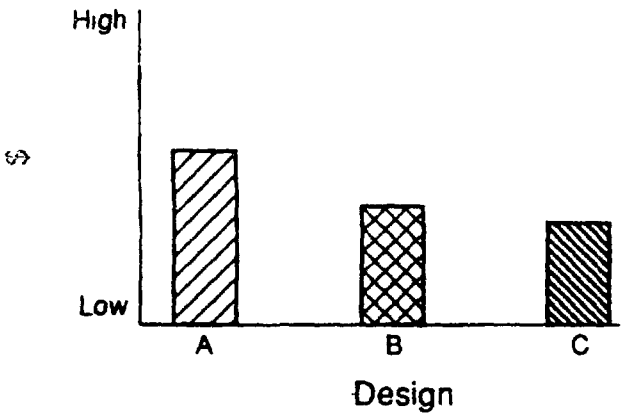
All design decisions are significantly influenced by the life cycle cost of the proposed system But the expense of the system should not and cannot be the sole decision criterion Consider the situation illustrated in Fig 6-1 Three competing designs, A, B, and C, show different life cycle costs and different MANPRINT characteristics System A, which is the most expensive, is operable and maintainable by the soldiers with lower aptitudes (lower skilled) System C is the least expensive system, but it requires highly skilled soldiers to operate and support it System B is in between the two systems in cost and required skill level Which system should the Army select the most expensive but easiest system to use (System A), the cheapest and most demanding system (System C), or should it compromise on both (System B)? The decision is system specific and depends upon the judgment of the decision makers as to which system best meets the Army's needs The final decision is based on the tradeoffs made in system performance, resources, manning, and skill distribution (Ref 32)

6-7 NUCLEAR, BIOLOGICAL, AND CHEMICAL (NBC) CONTAMINATION SURVIVABILITY

AR 70-71 (Ref 44) establishes Army policy and procedures for development of materiel to ensure its survivability and sustainability on the NBC-contaminated battlefield AR 70-71 defines NBC contamination to include both the individual and collective effects of residual radiological, biological, and chemical contamination



(A) Soldier Ability versus System Performance



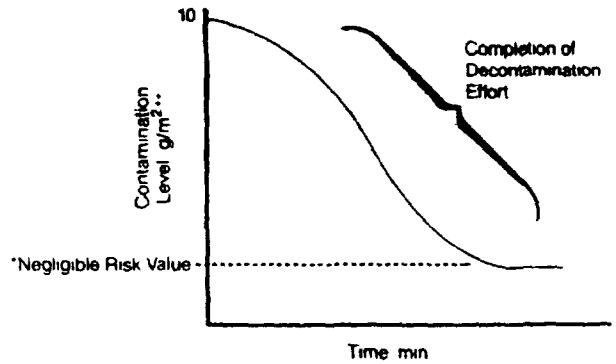
(B) Life Cycle Costs

Figure 6-1. Selection of Alternatives (Ref. 32)

NBC contamination survivability is the capability of a system and its crew to withstand an NBC-contaminated environment, including decontamination, without losing the ability to accomplish the assigned mission The characteristics of NBC contamination survivability are decontaminability, hardness, and compatibility The design performance criteria for these characteristics are

1 *Decontaminability* The equipment must be capable of being decontaminated by using standard NBC decontaminants and procedures available in the field to the point that the contaminant poses no casualty-producing hazard to unprotected personnel exposed during the normal mission profile of the equipment (but not to exceed 12 h) All components of CB detection and monitoring systems must be capable of being easily decontaminated for immediate use, unless the item is disposable Fig 6-2 illustrates the performance criteria for decontamination

2 *Hardness* Mission-essential equipment and



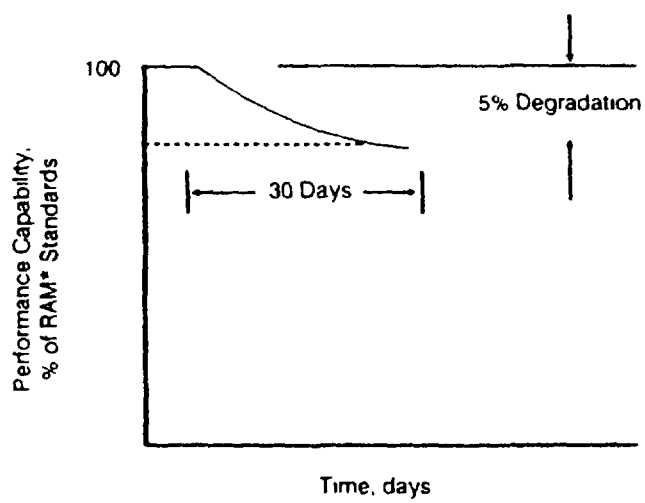
*Negligible risk value (5% mild incapacitation) inside on or 1 m from the item

**Exterior surfaces initially contaminated with 10 g/m² of chemical agent, interior surfaces with 1 g/m² Decontamination occurs 1 h after contamination using standard field decontaminants, equipment, and procedures.

Figure 6-2. Decontaminability Performance Criteria (Ref. 45)

materiel must be hardened to ensure that not more than 5% degradation occurs over a 30-day period in selected quantifiable, essential characteristics, such as MTBF and RAM, in response to five exposures to NBC contaminants, decontaminants, and decontaminating procedures encountered in the field All CB detection and monitoring systems must be designed to be highly resistant to CB agents and decontaminants Fig 6-3 illustrates this hardness criterion for RAM

3 *Compatibility*. The equipment must be capable of being operated, maintained, and resupplied by personnel wearing the full NBC protective ensemble over a typical mission profile in a contaminated environment (not to exceed 12 h) Degradation (excluding heat stress) of the crew's performance of mission-essential tasks (such as adjusting or relocating the detector and sighting target)



* Reliability, availability, and maintainability

Figure 6-3. Hardness Performance Criteria (Ref. 45)

cannot be greater than 5% below the levels specified for those tasks when accomplished in a non-NBC, shirtsleeve environment. Fig. 6-4 illustrates compatibility criteria

The design of CB detection and monitoring systems must consider the use of the equipment with the user in an existing and anticipated NBC protective ensemble The combination of use of the equipment with the user in an NBC protective ensemble must permit performance of mission-essential operations, communication, maintenance, resupply, and decontamination tasks by trained and acclimatized troops for a typical 12-h mission profile in a contaminated environment

The design engineer for CB detection and monitoring systems should be familiar with CRDEC-SP-84023, *Guidelines—Design to Minimize Contamination and to Facilitate Decontamination of Military Vehicles and Other Equipment Interiors and Exteriors* (Ref 46) These guidelines provide for designing military equipment that will minimize NBC agent contamination and increase the effectiveness of the decontamination process Fig 6-5 illustrates cover or cap designs for effective

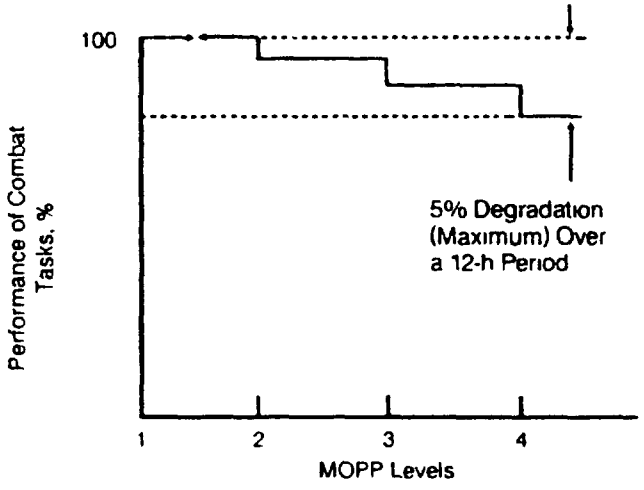


Figure 6-4. Compatibility Performance Criteria (Ref. 45)

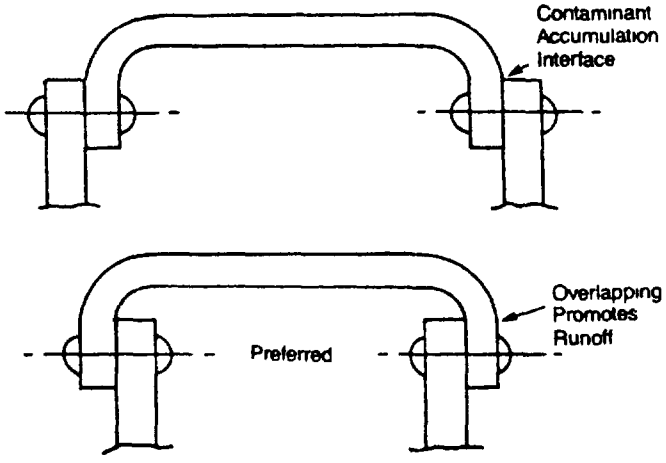
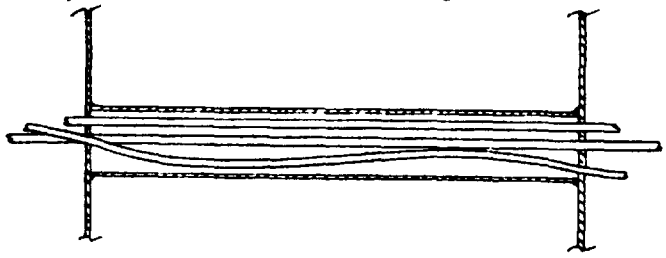
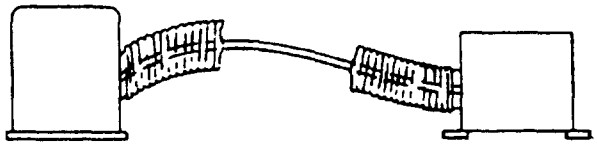


Figure 6-5. Cover or Cap Closure Designs (Ref. 46)

closures that will not accumulate contaminants Fig 6-6 shows methods of covering hydraulic hoses to protect them from contaminants Fig 6-7 illustrates the design of foot pedal linkages that avoid drawing in contaminants.

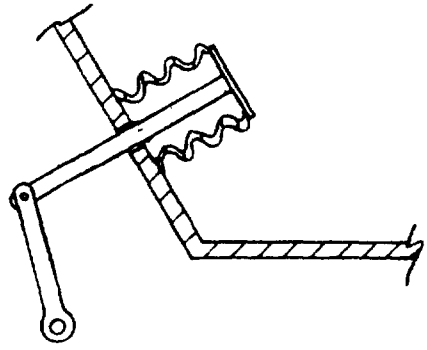


(A) Sealed Tubing or Box Protects Hoses From Contaminants

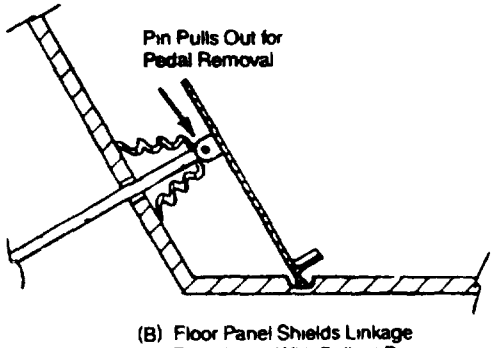


(B) Metal Bellows Allows Relative Movement Between Parts While It Protects Hose Connections

Figure 6-6. Protecting Hydraulic and Hose Connections (Ref. 46)



(A) Floor Panel Shields Linkage Pivot Areas With Metal Bellows



(B) Floor Panel Shields Linkage Pivot Areas With Pullout Pin

Figure 6-7. Protecting Foot Pedal Linkages (Ref. 46)

The *NBC Materials Handbook* (Ref 47) describes testing procedures used to determine the compatibility of Army materiel in the projected NBC environment The handbook contains test results and technical analyses of exposure of elastomers, plastics, coatings, and metallic systems to Decontaminating Solution No 2 (DS2) and to Supertropical Bleach (STB) decontaminating agent The handbook also provides a technical analysis of the interaction of chemical agents with DS2

The Plastics Technical Evaluation Center, Dover, NJ, maintains a computerized file of technical data describing the deteriorating and permeating effects of agents and decontaminants on plastics, elastomers, metals, adhesives, and fabrics This file also provides related information on document sources, chemicals, materials, and test methods Fig 6-8 illustrates the generic types of contamination surface, adsorbed, and absorbed Ways by which agents can alter properties of materials follow

1 Mechanically by affecting tensile strength and compression set For example, distilled mustard (HD) reduces the tensile strength of elastomers by 25 to 40%

2 Chemically by affecting the permeability and diffusion rate For example, HD increases the permeability of acrylics, silicones, epoxies, and urethanes

3 Agents affect the dielectric constant and index of refraction For example, HD causes swelling, hazing, slight crazing on stretched acrylic, and reduced resistivity

Agents also can alter the electronic characteristics of items At a potential of approximately 20 V, positive circuit elements corrode (turn black) when exposed to HD, VX, or GD When an acrylic conformal coating is contaminated, its resistivity diminishes by a factor of 10^5 and becomes conductive

Paints can enhance contamination avoidance by forming a barrier to agent penetration or by being self-decontaminating Fig 6-9 illustrates the properties of standard alkyd paints, which absorb agents; polyurethane paints, which cause agents to bead for easier removal, and self-decontaminating paint (This paint does not currently exist but is under development), which will have an innate capability to neutralize agents deposited on the surface or sorbed into the bulk

The relatively new area of NBC contamination survivability technology is now being emphasized as an engineering design criterion for mission-essential equipment CRDEC has an office available to provide technical assistance on NBC contamination survivability, and it has published a handbook entitled *Nuclear, Biological, and Chemical Contamination Survivability A Handbook for Development/Management of Materiel Programs* (Ref 45) to assist designers The engineer designing CB detection and monitoring systems must keep current with technology when applying NBC survival test procedures, methodologies, techniques, and assessment methods during the development process

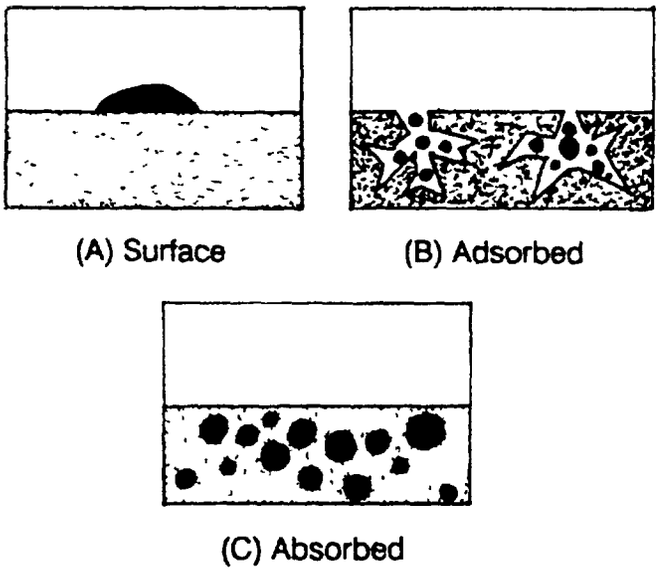


Figure 6-8. Generic Types of Agent Contamination (Ref. 45)

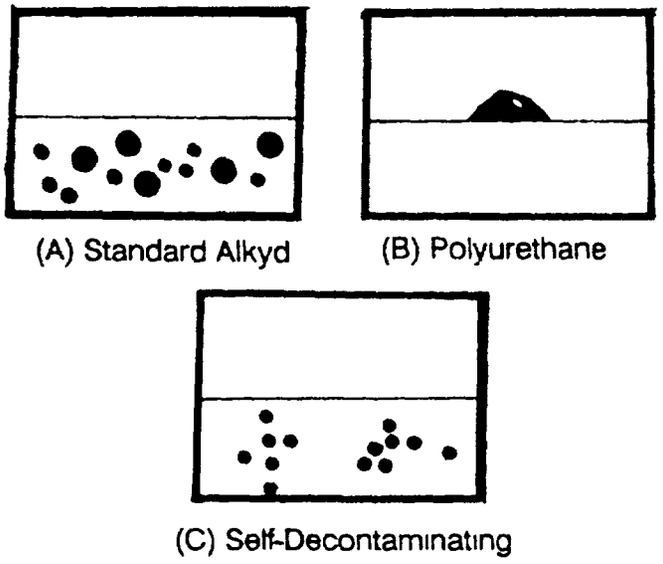


Figure 6-9. Contamination Avoidance: Paints (Ref. 45)

REFERENCES

1 AMC-TRADOC Pamphlet 70-2, *Research, Development, and Acquisition*, AMC-TRADOC Materiel Acquisition Handbook, US Army Materiel Command, Alexandria, VA, and US Army Training and Doctrine Command, Fort Monroe, VA, 26 March 1987 (To be republished as a DA Pamphlet)

2 AR 70-1, *System Acquisition Policy and Procedures*, 10 October 1988.

3 AR 71-9, *Materiel Objectives and Requirements*, 20 February 1987

4 *Reconnaissance, Detection, and Identification (RDI) Master Plan (MP)*(U), CRDC-CR-85032, US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, and US Army Chemical School, Fort McClellan, AL, August 1985, (THIS DOCUMENT IS CLASSIFIED SECRET)

5 Operational and Organizational Plan, *NBC Reconnaissance System (NBCRS)*, US Army Chemical School, Fort McClellan, AL, 1984

6 Operational and Organizational Plan, *Fixed Site Detection and Warning System (FSDWS)*, US Army Chemical School, Fort McClellan, AL, 1985

7 DoD Instruction 5000.2, *Defense Aquisition Management Policies and Procedures*, Office of the Under Secretary of Defense for Acquisition, 23 February 1991.

8 DoD 5000 2-M, *Defense Acquisition Management Documentation and Reports*, Office of the Under Secretary of Defense for Acquisition, 23 February 1991

9 *USAF Master Plan for a Chemical Warfare Detection, Identification, and Warning (CDIW) System*, Volume II, US Air Force, Aerospace Medical Division, Brooks Air Force Base, TX, June 1983

10 *Assessment of Chemical and Biological Sensor Technologies*, Board on Army Science and Technologies, National Research Council Commission on Engineering and Technical Systems, National Academy Press, Washington, DC, 1984

11 *Chemical Agent Data Sheets*, Volume I, Special Report EO-SR-74001, Edgewood Arsenal, Aberdeen Proving Ground, MD, December 1974

12 AMC Regulation 385-131, *Safety Regulation for Chemical Agents H, HD HT, GB, and VX*, 9 October 1987

13 HQ Aeronautical Systems Division (AFSC), Letter, AESX, subject *Joint Services Materiel Developers Conference*, Wright-Patterson Air Force Base, OH, 15 January 1986

14 DOD-HDBK-178(ER), *Quantitative Description of Obscuration Factors for Electro-Optical and Millimeter Wave Systems*, 25 July 1986

15 N R Jensen, *Independent Evaluation Plan for the XM20 Simplified Collective Protection Equipment (SCPE) Preplanned Product Improvement*, HQ, US Army Test and Evaluation Command, Aberdeen Proving Ground, MD, 19 August 1986

16 S A Mumford, *Assessment of Detection for Biological Agents*, Unpublished Draft Report, CB Detection and Alarms Division, US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, circa 1983

17 TM 3-216/AFM 355-6, *Technical Aspects of Biological Defense*, Departments of the Army and the Air Force, 12 January 1971

18 *Functional Analysis of Integrated Reconnaissance, Detection, and Identification (RDI) Systems and Battlefield*(U), CRDEC-CR-87091, by EAI Corporation, Abingdon, MD, for US Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, and US Army Chemical School, Fort McClellan, AL, August 1986, (THIS DOCUMENT IS CLASSIFIED SECRET)

19 AR 70-127, *Integrated Logistic Support*, 2 July 1990

20 DA PAM 700-55, *Instructions for Preparing the Integrated Logistic Support Plan*, 21 August 1986

21 MIL-STD-1388-1A, *Logistic Support Analysis*, 11 April 1983

22 MIL-STD-1388-2B, *DoD Requirements for a Logistic Support Analysis Record*, 28 March 1991

23 AR 750-1, *Army Materiel Maintenance Policy and Retail Maintenance Operations*, 30 October 1989

24 AR 700-27, *Level of Repair Analysis (LORA) Program*, 18 December 1987

25 MIL-M-63038B, *Manuals, Technical Organizational or Aviation Unit, Direct Support or Aviation Intermediate, and General Support Maintenance*, 14 January 1981

26 AR 70-38, *Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions*, 1 September 1979

27 NAT-STD-2895, *Extreme Climatic Conditions and Derived Conditions for Use in Defining Design/Test Criteria for NATO Forces Materiel*, 15 February 1990

28 AR 70-47, *Engineering for Transportability*, 19 August 1985

29 AR 702-3, *Army Materiel Systems Reliability, Availability, and Maintainability (RAM)*, 1 May 1982

30 MIL-STD-1629A, *Procedures for Performing a Failure Mode, Effects, and Criticality Analysis*, 28 November 1984

31 MIL-HDBK-791(AM), *Maintainability Design Techniques*, 17 March 1988

32 W O Blackwood and J. W Dice, Eds , *MANPRINT Primer*, Office of the Deputy Chief of Staff for Personnel, MANPRINT, Research and Studies, Washington, DC, 24 June 1988

33 AR 602-2, *Manpower and Personnel Integration (MANPRINT) in the Materiel Acquisition Process*, 19 April 1990

34 AR 385-16, *System Safety Engineering and Management*, 3 May 1990

35 AR 40-10, *Health Hazard Assessment Program in Support of the Army Materiel Acquisition Decision Process*, 15 September 1983

36 MIL-HDBK-764(MI), *System Safety Engineering Design Guide for Army Materiel*, 12 January 1990

37 MIL-STD-882B, *System Safety Program Requirements*, 1 July 1987

38 AR 602-1, *Human Factors Engineering Program*, 15 February 1983

39 *DoD Human Engineering Guide to Equipment Design*, Government Printing Office, Washington, DC, 1972

40 MIL-STD-1472D, *Human Factors Engineering Design Criteria for Military Systems, Equipment, and Facilities*, 14 March 1989

41 MIL-HDBK-761A, *Human Engineering Design Guidelines for Management Information Systems*, 30 September 1989.

42 MIL-HDBK-759A, *Human Factors Engineering Design for Army Materiel*, 30 June 1981

43 D Nowak, J Chalcraft, and J Nickle, *Developmental Test/Initial Operational Test and Evaluation of the Automatic Chemical Agent Alarm Set, A/E 23D-1 (v), (IDS)*, ED-TR-76114, Edgewood Arsenal, Aberdeen Proving Ground, MD, December 1976

44 AR 70-71, *Nuclear, Biological, and Chemical Contamination Survivability of Army Materiel*, 1 April 1984.

45. *NBC (Nuclear, Biological, Chemical) Contamination Survivability A Handbook for Development/Management of Materiel Programs*, by Battelle Columbus Laboratories, Columbus, OH, for US Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD September 1985

46 T E Hill, C V Robinson, J M Tierney, and J H Thompson, *Guidelines—Design to Minimize Contamination and to Facilitate Decontamination of Military Vehicles and Other Equipment. Interiors and Exteriors*, CRDEC-SP-84023, US Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, August 1984

47 *NBC Materials Handbook, Volume 1 Decontaminants*, by Hughes Aircraft Co , Missile Systems Group, Canoga Park, CA, for US Army Tank-Automotive Command, Warren, MI, December 1984

BIBLIOGRAPHY

DoD Directive 1430 13, *Training Simulators and Devices*, 22 August 1986

J van der Laan, J Leonelli, J Rice, *Ground-Mobile Breadboard Upgrade (GMBU) Light Detection and Ranging (LIDAR) System Preliminary Hazard Analysis Report*, by SRI International, Menlo Park, CA, for US Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, August 1987

CHAPTER 7
DESIGN OF DETECTION SYSTEMS

This chapter briefly discusses how the threat and the hazard that evolves from the threat lead to the major requirements of chemical and biological (CB) detection systems, namely, sensitivity, response time, and specificity The operational situation establishes other specific requirements agent identification, automatic operation, unattended operation, agent quantification, environmental requirements, size, weight, power; and reliability, availability, and maintainability (RAM) Other general Army requirements, such as integrated logistic support (ILS), manpower and personnel integration (MANPRINT), and nuclear, biological, and chemical (NBC) contamination survivability, also affect the design of the CB detection system Detection system design is discussed in terms of the three major processes sample acquisition, sample analysis, and response (alarm) As discussed in Chapter 5, the design of equipment is divided between the chemical and biological threat and the point and standoff detectors

7-0 LIST OF SYMBOLS

C = concentration, mg/m^3
CL = concentration path length, mg/m^2
Ct = dosage, $mg \cdot min/m^3$
L = agent cloud path length, m
T = temperature, °C
t = time concentration is present, min
x = distance between moving mirror and beam splitter, m

7-1 INTRODUCTION

The extent of the threat is dependent upon the type of agent used, chemical or biological, the class of agent, persistent or nonpersistent; the operational use of the agent, the physical form, i.e , vapor, aerosol, or liquid droplets, and weather and terrain conditions

The hazards imposed by the threat present different design challenges with respect to sensitivity, response time, and specificity For example, a nonpersistent vapor normally presents a high-concentration, short-duration, inhalant hazard, whereas a liquid droplet persistent agent imposes a low-to-moderate inhalant concentration and a long-term persistent contact hazard Biological agents can be extremely toxic due to their high infectivity rate and small particle sizes (3-5μm) These different hazards result in significantly different design problems in the areas of sample acquisition, sample analysis, and response (alarm)

The intended operational use of the detection system also imposes design problems For example, if a system is intended for use by a combat unit, size, weight, and power must be considered and held to a minimum, whereas a detector system intended for use at a fixed installation is not so constrained

For these reasons, when a new set of requirements is being developed, both the equipment user and the developer should take an active part in formulating realistic requirements The equipment users understand the operational needs and the developers know the state-of-the-art technology The requirements must be as specific as possible so the user understands exactly what he is getting and the developer fully understands the challenges the requirements have established. A set of requirements should not contain generalities If necessary, a requirement may be divided into essential and desired criteria, and whenever possible, requirements should be expressed in quantitative numbers For example, the minimum detectable concentration should be stated in milligrams per cubic meter, response time in seconds or minutes, and weight in kilograms

Once a specific set of requirements has been developed and agreed upon by both the user and the developer, design of a specific detection system must be considered in terms of the detection processes, i.e , sample acquisition, sample analysis, and response (alarm).

Another important requirement comes from the operational use concept, that is, whether a point sampling or a line-of-sight (LOS) detector is needed This decision limits the sample acquisition technologies that can be used and impacts on the detection technologies to be considered The number of detection technologies available for exploitation in line-of-sight instruments, however, is already limited when compared to those that can be used for point sampling devices. Thus design of point sampling detectors and design of line-of-sight detectors are discussed individually.

7-2 CHEMICAL POINT DETECTORS

The various forms of agent can significantly impact component design, particularly in sample acquisition Vapors and fine aerosols can be efficiently sampled from an airstream moving into the detector at relatively low airspeeds and volume Such a slow-moving stream can be accomplished with a relatively low expenditure of energy and a simple design. Low expenditures of energy and simple designs conserve size, weight, and cost, par-

ticularly in automatic sampling systems that require batteries for energy

Large aerosols and liquid droplets, however, present a different problem in sample acquisition The high kinetic energy of these particles is caused by gravitational and wind forces acting on the relatively large mass of the particles Changing the direction of such particles requires much larger expenditures of energy and is not practical for design in most agent detectors A solution to this problem is to allow the particles to impact directly on a relatively large surface This solution presents other problems (See Chapter 5), such as contamination of the impaction surface by dust and rain, lack of control of the environment to be sampled, impact of other contaminants, and temperature of the reacting surface

Ideally, one set of requirements could be generated, which would create a detection system to detect and identify all threat agents in all operational situations. Present technology and any technology in the foreseeable future, however, cannot meet these requirements As a result of the technology shortfalls, the detection problem must be broken down into discrete systems capable of solving portions of the overall need At a minimum, detection technology limitations cause the overall need to be broken down into three system families chemical point sampling detectors, chemical line-of-sight detectors and biological detectors The diversity of the disseminated threat agents and the various physical forms that can occur, i e., vapors, aerosols, and large liquid droplets, create additional complications that must be resolved

7-2.1 THREAT

Because of the different ways various agents act on man, detector sensitivity and response time is required to change as follows

1 *Persistent agents* The primary threat to man is long-term exposure to low concentrations, therefore, the detector should have high sensitivity with a relatively long response time to the contact hazard

2 *Nonpersistent agents* The primary threat to man is short-term exposure to the vapor or fine aerosol, therefore, the detector can have less sensitivity than persistent agent detectors and should have a quick response time (There are few cumulative effects because agents dissipate rapidly)

7-2.2 REQUIREMENTS (CRITERIA)

Different operational situations generate different chemical and biological agent and hazard information requirements In order to characterize this variance as needs, the Reconnaissance, Detection, and Identification Master Plan (RDIMP) identifies four different operational situations. combat and combat support, combat service support (CSS), reconnaissance (RECON), and fixed site installation (FSI) (See Chapter 3 for a detailed discussion of these situations.) Not only will the information needs differ between the battlefield situations, but the characteristics of the devices used by the units can also change significantly.

Various battlefield detection needs can generate point detector criteria For example, in a mobile survey of a battlefield area, a drop-off detector could continue to monitor the area that had been surveyed by a vehicle These drop-off detectors would monitor the area after the initial survey to alert follow-on troops to agent presence that developed after the initial scan Such a drop-off detector would have to be low cost, lightweight, and small A telemetering device could alert troops of its location for possible recovery and of the presence of agent

During development of a set of requirements for a detection system, no single requirement can be addressed in isolation Each requirement must be considered in relation to all other requirements for a system because if considered separately, each requirement may be fully met but could place unrealistic requirements on the rest of the system For example, the sensitivity requirement for the detoxification level for every probable threat agent could be met by using a tandem mass spectrometer, but such an instrument could not meet other requirements, such as size, weight, power, reliability, and cost Establishing requirements therefore becomes a process of fully understanding each requirement and then conducting tradeoffs between the requirements to achieve the best overall device that will meet the need It is in this tradeoff process that a clear delineation of desired and essential requirements must be made Once a complete set of requirements has been established for a detection system, certain essential and desired criteria may be included to guide the developer further in the hardware design

7-2.3 COMPONENT DESIGN

Chemical point detector design involves drawing a sample of the surrounding atmosphere into a detector and processing it to a detector cell (sample acquisition) At the detector cell the sample of atmosphere is analyzed and the output signal is processed (sample analysis) to a network that can provide audible and/or visible alarm at the detector and in many cases at a remote location where audible and visible alarm can also occur (response or alarm) Chemical point detector design differs from chemical standoff detector design primarily in the sample acquisition process The point detector provides response for chemical agent only at a specific point, whereas standoff detectors respond to a chemical agent cloud passing through the line of sight of the detector at some distance

Chemical point detectors have many more operational applications than chemical standoff detectors This can lead to discrete component design Because they have

many applications and to ensure adequate area coverage, point detectors have a large basis of issue (BOI). For example, in the M8A1 chemical agent point detection system, the BOI varies from three to eight systems per using company, whereas the tentative BOI for the XM21 chemical agent standoff detection system would authorize one detector per NBC reconnaissance vehicle The greater distribution of the M8A1 impacts directly on system cost, logistics, and maintenance requirements These factors must be considered in the design and selection of specific components and processes

Another significant aspect in the design of components is the tradeoff in complexity among the various detection processes As discussed in Chapter 5, if the sample analysis process lacks sufficient sensitivity to meet the requirements, sensitivity may be enhanced by increasing the quantity of the sample that is acquired per unit of time Similarly, detection sensitivity may be increased by using more sophisticated signal processing techniques, which in effect lower the signal-to-noise ratio needed for a reliable response On the other hand, the sample acquisition process can be simplified if more sensitive and selective sample analysis techniques are used A good example of this tradeoff is the M256A1 Chemical Agent Detector Kit in which sensitive chemical sample analysis techniques are used in conjunction with silica gel paper to produce a static sampler that does not require an air pump and greatly reduces complexity and cost in the sample acquisition process.

7-2.3.1 Sample Acquisition

The purpose of the sample acquisition process for point detectors is to collect a representative sample of the atmosphere surrounding the detector and to transport it to the sample cell for analysis This process represents the major disadvantage between point detectors and line-of-sight detectors Rather than physically collecting the sampled atmosphere, the LOS detector "looks" at the atmosphere along a line of sight for some distance (up to 5 km), referred to as the field of view (FOV), and uses the information collected to perform the sample analysis Some main advantages and disadvantages of point detector sample acquisition versus line-of-sight sample acquisition are summarized in Table 7-1

The ability to control the collected sample before analysis offers a significant advantage to all point detectors Dust and interfering materials can be screened from the sample, rain and snow can be selectively sampled out, the sample rate can be varied, adverse environmental conditions such as low temperature and high humidity

TABLE 7-1. SAMPLE ACQUISITION: POINT DETECTION VERSUS LINE-OF-SIGHT DETECTION ADVANTAGES AND DISADVANTAGES

	ADVANTAGES	DISADVANTAGES
Point Detectors	1 Control of collected sample before analysis 2 Does not require clear line of sight over a distance 3 Design that results from process is generally small and lightweight 4 Inexpensive to design and simpler than LOS	1 Detects at point only 2 Requires air pump and motor 3 Efficient collecting of all physical forms of agent is difficult 4. Omnidirectional sampling required
Line-of-Sight Detectors	1 Detection of agent at a distance 2 Detection of liquid contamination on ground and equipment possible 3 Agent cloud characterization possible 4 No air pump or motor required 5 Good reliability	1 Clear line of sight over a distance required 2 No control of sampled atmosphere 3 Selection of detection technology is limited 4 Information data signal from sampling is relatively small 5 Collecting optics required 6 Design is relatively large and heavy 7 Cannot function in shelters, bunkers, etc 8. More operator training required

can be controlled, and the collected sample can be concentrated if the detection technology lacks the required sensitivity Because the detector samples only at a given point, a clear line of sight is not required The device is simple and inexpensive to design and can be small and lightweight

The major disadvantage of point detectors is the lack of a capability to detect agents at a distance and provide advance warning of attack or contamination Collecting all of the physical forms of chemical agent (i.e , gas, aerosol, airborne liquid droplets, and deposited liquid) is also more difficult, particularly since the equipment must continuously sample the air from all directions at once (omnidirectional sampling) Finally, automatic point detectors require an air pump and motor for collection that add cost and weight to the design

The sample acquisition process that is selected can aid in meeting the sensitivity requirements for point detectors by concentrating the sample so that the sample analysis cell "sees" a higher concentration of agent for analysis than actually exists in the surrounding atmosphere One of the major design problems in sample acquisition, however, is efficiently collecting all the physical forms of disseminated chemical agents There is a gap in collecting aerosol particles for chemical point detectors in the 50-to 200-μm range that technology has yet to close In addition, the flat collector plates used to acquire droplets above 200 μm and up to 3000 μm in size provide little advance warning to personnel because they only respond after gravity deposition Furthermore, due to the lower frequency of agent particle distribution at the larger droplet size, the collector plates must be large (at least 0 05 m^2) to achieve rapid detection Alternatively, a large number of collector plates of a smaller size can be placed in the same geographic area

One of the advantages of a point detector is the capability of the sample acquisition system to accommodate dust and interference filters, which can greatly improve the specificity of the device For example, the Modular Chemical Agent Detector was designed to be used on tracked and wheeled vehicles where dust loadings could reach very high levels The expected dust loadings were so high that a prefilter tape was devised that slowly and continuously moved through the sampling airstream at the rate of 25 4 mm/h At this speed any given clean point on the dust prefilter was presented to the sampling airstream approximately every 20 min The tape was driven by a simple advancement mechanism that uses a small, low-power motor The tape was sealed to the slightly negative pressure of the airstream by using two O-rings that applied pressure to the top and bottom of the tape The automatic prefilter changer was so effective that it was used in demilitarization of mustard to remove iron particles from the sample stream of a stack monitor (a device used to sample aliquots of gas for analysis to determine the presence of chemical agent)

Point sampling sample acquisition also allows the use of chemical prefilters to remove interferents and to convert agents that are not easily detected by chemical analysis to other detectable compounds An example of the use of a conversion prefilter occurred in the development of the M8 alarm The rate of reaction for the technology used in the M8 alarm is quite rapid at pH 9 3 when the reagents come into contact with G-agents With V-agents, however, the rate of the oxime reaction is too slow for detection unless the pH of the medium approaches 14, which is so high that the G-agents decompose before reaction with oxime can occur To solve this problem, a chemical prefilter consisting of silver nitrate and potassium fluoride impregnated on a paper filter material was developed The prefilter catalytically reacts with V-agents and converts them to G-agents, which are detected in the sample analysis cell The conversion prefilter serves a dual purpose First, it converts the low-volatility V-agent into a volatile G-agent, which easily passes through the following dust filter with little loss from surface adsorption Second, the conversion prefilter can be used as a gas chromatographic, demilitarization agent monitor for the detection of V-agents because a suitable adsorption bed for V-agents has not been found The sample acquisition process can also be used to lower atmospheric humidity and control inlet airstream temperature, as discussed in par 5-2 1 1 1

Caution must be used by the designer in exercising the many options available in designing the sample acquisition system The operational use of most point sampling detectors requires small, lightweight, and low-power detectors They also have a high distribution density As more modifications are added, complexity increases, which generally lowers reliability and increases cost, size, weight, and power

For example, automatic sensors are available to monitor airflow during sample acquisition and can be linked to the response (alarm) system in order to alert troops when the rate of sample collection drops below a preset level The sensors and their associated circuitry, although relatively simple, have their own failure rate and add cost, weight, and power draw to the devices For these reasons, this type of sensor has not been used in point detectors Instead, the operator performs a manual check of airflow at periodic servicing intervals by using a rotometer, which is manually attached to the sample air intake

7-2.3.2 Sample Analysis

The detection technology used in sample analysis is the essential part of the system on which the other detection processes depend Thus when designing a detection system, the designer must consider sample analysis first When various detection technologies for the sample analysis process are evaluated, the three primary reconnaissance, detection, and identification (RDI) require-

ments to be considered are sensitivity, response time, and specificity The RDI requirements for agent identification and quantification also directly depend on the technology selected but, in most cases, are not as essential Other requirements can also impact the sample analysis process but not to the same extent that these three requirements do

The chemical agent sensitivity of the point detector is an inherent characteristic of the detection technology selected for sample analysis It can be improved by proper modification of the sample acquisition or signal processes but only within a limited range of no more than a factor of 10 to 20 If a detection technology is available that fully meets or even exceeds the sensitivity criteria for the device, the design of the sample acquisition and signal processing tasks becomes much simpler and RAM goals much easier to achieve Unfortunately, this scenario is generally not the case, and the system design must include some modification to the sample acquisition design or improvement in the signal processing to achieve the sensitivity requirement Improvement of these processes is limited by the practical constraints of other criteria for point detectors such as response time, reliability, size, weight, and power

The response time requirement of chemical point detectors is, in almost all cases, for a fast response, i e , 10 s or less The operational use of chemical point detectors usually requires that the detector be collocated with the using element or placed upwind with a remote alarm to achieve some advance warning Even if the detector is placed upwind, response time must be relatively fast because the distance the agent must travel from the detector to the remote alarm cannot be very far (about 200 to 400 m) due to other point detector requirements (These requirements are discussed in par 7-2 3 3) Chemical agent point detectors respond to dosage Ct Thus if the total dose quantity of agent an individual receives is to be kept below the incapacitating level when high concentrations C of agent are present, the time the concentration is present t for agent detection must be short Modifications to the sample acquisition process can be made that will allow a detection technology to respond to low concentrations of agent by accumulating the sample for a longer time (low C and high t) and also to respond to high concentrations of agent in a short period of time (high C and low t) For example, the M8A1 chemical agent point detector can be modified by using a concentration module in the sample acquisition process The minimum detectable concentration for the device is improved by a factor of 10 while the rapid response of the detector to high concentrations remains the same The concentrator module consists of a tube containing a gas chromatography material (PORAPAK®*) The sampled air passes through the tube in which agent is collected Every 10 min the tube is rapidly heated and the agent is evaporated By collecting the sample for 10 min and allowing it to flow into the detector cell, a concentration of agent 10 times the concentration of the air and agent mixture is achieved Thus a low concentration of the agent can be detected

One of the factors that directly affects the efficiency of a gas chromatography column is the depth of bed of the adsorbent By keeping the bed depth very shallow (about 6 mm), poor adsorption efficiency allows high concentrations of agent to slip rapidly through the adsorption tube and cause a fast response In this manner sensitivity is improved for low agent concentrations without significantly increasing response time

The detection technology that is selected must also have good specificity so that compounds that might occur in a battlefield atmosphere (e g., smoke, burning rubber, petroleum) do not cause false responses and interfering compounds do not mask true agent responses It is important to recognize that specificity is not a part of reliability, availability, and maintainability (RAM)—it is an essential requirement in itself

For example, in the M8A1 alarm the detection technology (use of an oxime that combines with nerve agent to produce cyanide, which was detected electronically) gave false responses to high concentrations of some signaling smokes and to hexachloroethane (HC) screening smoke because traces of cyanide were present. The response of the device to signaling smokes was considered a shortcoming only because signaling smokes are usually disseminated over small areas and away from the detector. The response to high concentrations of HC screening smoke, however, was considered a deficiency HC smoke can occur over large portions of the battlefield for long periods of time and in high concentrations The problem was corrected by introducing a prefilter in the sample acquisition process to remove the HC smoke but through which the agent would pass

When selecting the detection technology for an alarm, as much data as possible must be collected in the areas of sensitivity, response time, and specificity Testing for these requirements in this phase can prevent longer time delays and larger dollar expenditures than if problems arise later in the development process. In general, reasonable projections of the performance of a technology in a detector design can be made for its meeting other RDI requirements Assessment of performance against other criteria should be carefully weighed and total system performance evaluated early in the selection stage and continuously throughout the development cycle Testing must be conducted not only in the laboratory but also under the most adverse field conditions and at environmental extremes to understand fully actual and projected performance Over 100,000 h of testing were conducted

*Use of a trade name does not constitute endorsement by the US Government

during the development of the M8 alarm. Testing can be reduced if many of the requirements for a follow-on detection system are similar to those for an existing item and many of the components in both systems are the same An example is the development of the M8A1 point detector, for which testing was significantly reduced Two factors affected this reduced testing requirement. First, the M43A1 contains the basic flow system of the M8, including the air pump Therefore, no life tests were required on the air pump, and flow system tests for agent absorption and desorption could be kept to a minimum. Second, the detector, the remote alarm circuitry, and hardware from the M8 system were used in the M43A1 system Therefore, component testing again was reduced

During selection of the detection technology to be used in the sample analysis process, how the projected finished design will meet all requirements for the system is important For example, logistic requirements must be considered early in development Point detectors, as previously discussed, generally receive a wide distribution in the field The M8 point sampling system used a wet chemical detection technology, which required chemicals to be replenished every 12 h The chemical resupply kit, the M229, is 0 04 m^3 in size, weighs approximately 6 4 kg, costs $75 dollars, and lasts for 15 days The BOI for the alarm specified overseas issue, which resulted in very high transportation volume and cost Logistic resupply of chemicals for the M8 was among the main problems that initiated the follow-on development of the M8A1, which employs a physical method for detection that requires no resupply of wet chemicals

If adequate testing of the detection technology used in the sample analysis has been done, a number of the parameters, including all critical parameters, should be known This knowledge allows design of the sample cell to be straightforward and the type and design of the signal processing to be well-established Such variables as sample size (whether static or dynamic), sample flow rate, temperature control, and signal-to-noise ratio, should also be known

Component materials must also be evaluated Plastic offers an attractive alternative to metal because it is easy to manufacture at low cost Since the final cell design is likely to be required in high quantities cost is a major consideration Injection molding of a plastic cell is relatively inexpensive, even if auxiliary assembly or secondary machining operations are required. Material costs are also relatively low There are a number of conditions to be considered, however, in designing a cell made of plastic In a sample analysis cell that requires close dimensional tolerances, the cold flow characteristics of the plastic during manufacturing must be considered because dimensions can change and result in problems such as air leakage Also the chemical constituents of many plastics slowly migrate with time (This movement occurs primarily in the activator used in the plastic) and cause chemical compounds to be introduced into the sample that might cause false alarms. The problem is further exacerbated by the unknown nature of some plastic materials since manufacturers will not release the proprietary manufacturing processes for their plastics Manufacturers may change chemicals at their discretion provided the physical performance does not change from that specified

Although the exact design of the signal processing circuitry may not be established at this early stage, particularly if complicated logic is required, an idea of the scope of the design and the type of logic required should be available from the testing accomplished to date Data from the testing must be the basis for the development of signal processing, particularly in the areas of signal enhancement, noise suppression, and the effects of environmental extremes

7-2.3.3 Response (Alarm)

The main function of the alarm process is to alert troops to the presence of chemical agent in sufficient time for them to take protective action By their nature, however, point detectors cannot respond until the agent is at their location therefore, advance warning of a chemical attack cannot be given unless the detector is positioned upwind from the using element. Furthermore, due to the time required to mask and to take other protective actions, no alarm, whether point or line of sight, can alert unprotected soldiers to an on-target agent attack in sufficient time to prevent casualties. Soldiers under attack must follow current doctrine Take protective action as soon as projectiles, aircraft spray, or rockets start to fall. With these limitations the only useful warning application of a chemical point detector is to warn the users of an upwind chemical attack where the agent is being carried by the wind to their location To accomplish this warning, a detector placed upwind from the unit should send an alarm signal (by wire or radio transmission) to an alarm unit at the user's location

In recent years another important application of point detectors has been recognized to locate and warn of liquid chemical hazards on the ground or on equipment This function is important for two reasons First, when a hazard is detected, the user can bypass the area and avoid being contaminated (contamination avoidance). Second, the user can accurately locate the contamination on the ground, vegetation, or equipment This advantage is an important aid in decontamination, which is a time- and labor-intensive process that has serious logistic impact Therefore, any improvement in locating the contaminated area by using a point detector offers significant military payoff

In addition, point detectors make excellent monitors For example, they are used inside collective protective shelters to monitor entry of any agent into the shelter They can also indicate when the concentration level of

agent drops below the design threshold level and aid the commander in deciding when it is safe to reduce the mission-oriented protective posture (MOPP) level

Each of these applications leads to different requirements for the response (alarm) process Response to an agent attack can be accomplished by visible (light) and/or audible (horn) means A remote alarm uses the same means of warning Connection between the remote alarm and the detector is accomplished by transmission of a signal by wire or radio If the detector is used as a monitor for chemical agent contamination, some type of semiquantitative indicator (generally visual) must also be employed The response process will be discussed, in the subparagraphs that follow, in terms of its various warning means

7-2.3.3.1 Visual Response

A visual detector response to chemical agents has two uses an alert warning to take protective action and a readout used primarily for decontamination monitoring that should be at least semiquantitative in output

The visible alert response to warn the user of the presence of chemical agent can be accomplished best by using a light bulb The design is simple, circuitry is straightforward, cost and weight are minimal, reliability is good, and maintenance is relatively easy. A visible alert, however, has several drawbacks The user must be looking in the direction of the alarm, sunlight can mask the light output, it draws considerable power, and depending on size and intensity, it can be a beacon that draws enemy fire at night. A number of light bulbs of different sizes with different light outputs are available for selection, and plastic transparent lens covers of various colors can be used to provide the bulbs protection from the environment Circuitry for both visible and audible alert warnings should contain a mechanism to lock the device in the alarm mode until it is manually reset by the user The alarm locking mechanism ensures that the operator knows an agent attack has occurred even though the agent level may have dropped below the threshold level needed for the device to stay in alarm mode Both visible and audible circuitry should also contain a shutoff switch or a volume control to reduce or eliminate light and sound when needed for security purposes

For warning purposes, an audible alarm is better than a visible alarm because an audible alarm does not require the user to view it for recognition Also it is easier to design an audible alarm that can be heard over battlefield noise than to design a light that can be seen easily from a distance under sunlight conditions For monitoring purposes, however, a visual alarm is better than an audible alarm For example, when monitoring for contamination, an operator must be with the monitor to search for the contamination. The operator can easily watch a meter to pinpoint the contamination and to obtain a semiquantitative estimate of the concentration

Selection of a visual indicator depends to some extent on the operational use of the detector, and a wide variety of visual indicators is available from which to select The most important design features to consider are ruggedness, low power draw, and easy readability under sunlight conditions Consideration of human factors is important when selecting the response indicators so that maximum information can be transferred to the operator as rapidly and simply as possible

7-2.3.3.2 Audible Response

As discussed in par. 7-2.3.3 1, the audible alert is best for warning, whereas the visual indicator is best for monitoring, and the same circuitry can be used for either application For audible response a sound that changes frequency in the 90 to 95 dB range will carry a considerable distance over background battlefield noise The sounder, or horn, must operate under extreme environmental conditions and draw as little power as possible because it may require power from the batteries for a considerable time For example, the M8 horn used in the M43 and M43A1 detectors meets these requirements.

The audible response is also better suited for detectors used in combat vehicles and shelters The warning signal from the detector can be fed into the intercom system of a combat vehicle to alert the occupants The signal should rise above, but not drown out, voice communications Also an audible horn is generally more effective than a visible indicator in a shelter because many of the occupants of shelters, like those in a communications van, have their attention focused on their work rather than an alarm indicator

To provide maximum flexibility, all detectors should contain both an audible and visible alarm and a switch or volume control that can regulate alarm signal output as the operational situation demands The main disadvantage to such a design is the additional power drain that results when both alarms occur simultaneously This drain can be particularly significant in point detectors using batteries as a primary power source A small, lightweight detector loses utility if it requires a heavy battery For example, the operational power draw for the M43 or the M43A1 detector is about 3 W. Each detector weighs 2 7 to 3 6 kg, and the battery, shown in Fig 7-1, to operate these devices for 12 h of continuous operation weighs about 3 6 kg When an agent response occurs in the detector, the detection function must cease while the audible and visible responses are given. When the audible and visible responses have been completed, the detection function can resume The power requirement to sustain both functions simultaneously is too great to meet the requirement of 12 h of continuous operation

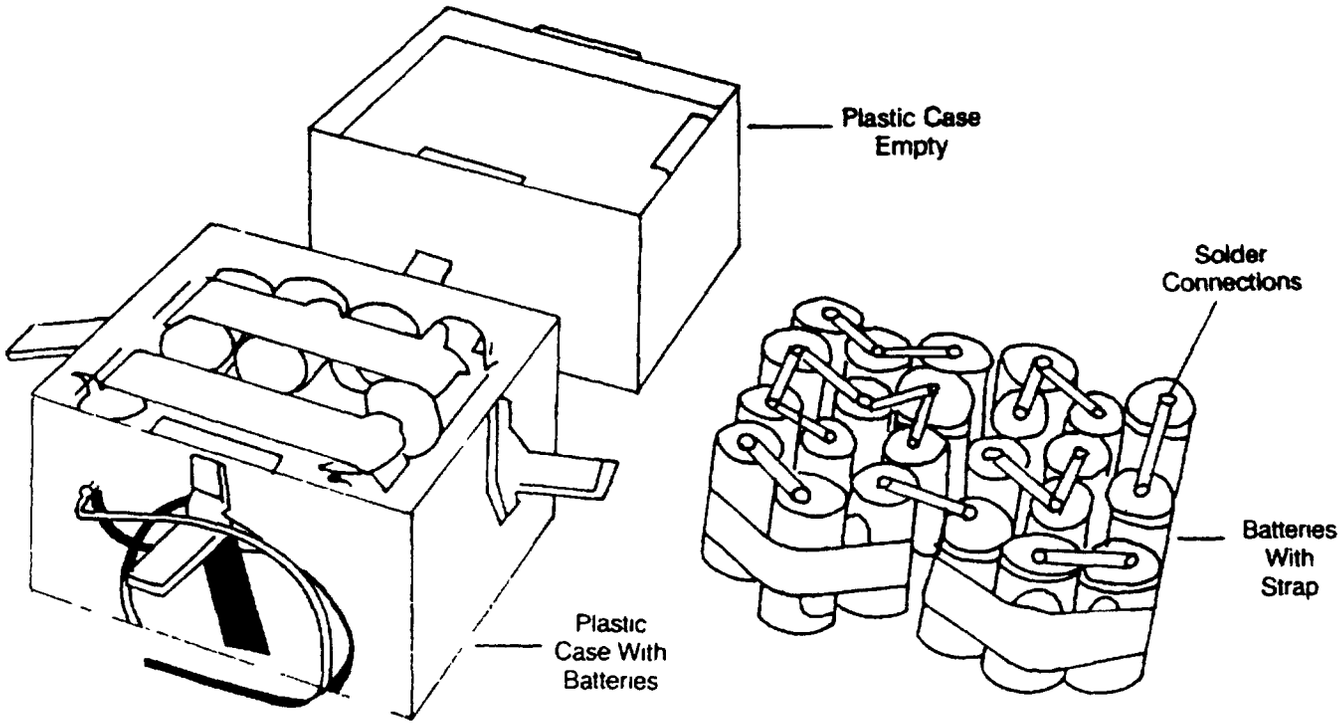


Figure 7-1. Components of the Primary Batteries for the M43 and M43A1 Detectors (Ref. 1)

7-2.3.3.3 Remote Response Indication

Many operational concepts of use require employment of an ancillary alarm that is remote from the detector. The major function of the remote alarm is to provide an advance warning of an upwind chemical hazard by a detector placed upwind that transmits the alarm signal back to the remote alarm Transmission can be accomplished by use of wire or radio signal The remote alarm can also be used at fixed sites and inside shelters to provide a similar warning function

Like the detector, the remote alarm generally contains both a visible (light) and audible (horn) indicator Power for the operation of the remote alarm and its response indicators can be contained in the remote alarm so that the detector is not burdened with the additional weight and size of the remote power supply

7-2.4 OTHER DESIGN CONSIDERATIONS

Other design considerations can be discussed best in terms of the item requirement. In most cases these requirements apply to both standoff and point detectors The design considerations are discussed in terms of and the order of the requirements (criteria) listed in par 6-5 Designing a device for proper sensitivity, response time, and specificity has been discussed in par 7-2 3 2

7-2.4.1 Agent Identification

The designer has little flexibility during the design process concerning agent identification If the detector is required to identify the hazard agent either by class or by individual agent, a sample analysis technique with this capability must be selected Little can be done during the sample acquisition or response process to provide agent identification, therefore, the selected sample analysis technology must possess the capability for agent identification The agent identification criteria, however, can affect the sample acquisition and response processes, particularly in the response process where additional indicators would be necessary to pass the identification on to the operator A quick general agent warning is still the most important initial response criterion so that immediate protective measures can be taken Once the operator is protected, he can determine what agent or class of agent is present Speed of response only for agent identification is not as important, so the response indicator can be simplified by using the operator for interpretation, such as interpreting a meter readout.

7-2.4.2 Automatic Operation

All warning devices for chemical or biological agents have the requirement for fully automatic operation Semiautomatic operation, however, is a very desirable characteristic for monitoring devices If the warning function is to allow the user to take protective action against an agent hazard as rapidly as possible, the detector must not depend on an operator in its response loop because under the stress of combat or even when performing noncombat duties, he/she cannot focus constantly on the operation of the detector

The requirement for automatic operation creates a considerable challenge in the areas of reliability, signal processing, response processing, and overall complexity Fully automatic operation removes the user from the operation of the device, which simplifies training but increases the maintenance burden, and impacts on all three of the detection process designs

Automatic sampling pumps must be designed for sample acquisition The signal processing phase of the sample analysis and response (alarm) processes cannot depend on an operator to make decisions on the signal output of the analysis and to sound the warning when agent attack occurs The automatic pumps and warning indicators also are the main users of power, which affects the size, weight, and cost of the system

Semiautomatic operation for monitoring in the areas of contamination avoidance and decontamination generally require automatic operation up to the signal processing phase of sample analysis. Both of these functions occur after the user has taken protective action, so instantaneous response is not required However, rapid detection of contamination is still necessary For example, using a monitor to detect contamination on equipment involves passing the detector over the equipment If the response time is long, the monitor will not accurately report the actual location of the contamination on the equipment

A comparison of the M43A1 chemical point detector to the M256A1 Detector Kit is an illustration of the added design complexity imposed by the automatic operation requirement (This discussion also includes the unattended operation requirement covered in par 7-2.4 3) The M256A1 kit performs the sample acquisition process by a static sampling technique using silica gel paper, whereas the M43A1 detector requires an air pump with a motor, inlet heater, prefilter, and an omnidirectional inlet capable of operating in the rain or snow (The design of the M256A1 static sampler and associated detector technology is simple, but it was *not* inexpensive or easy to develop Because of size, sensitivity, and time for collection, static sampling had never been done before, and its development represented a significant technological breakthrough Now developed, however, the M256A1 Detector Kit is inexpensive to procure, lightweight, and simple to operate in the field.) The M256A1 requires no specific military occupational specialty (MOS) for operation, and only limited training is necessary In fact, the training time necessary for operating the M256A1 is much shorter than that for the M43A1 due to the simplicity of M256A1 The two major drawbacks of the M256A1 Detector Kit, however, are its labor-intensive operation and its lack of capability to provide immediate warning Therefore, the M256A1 Detector Kit can be used only as a monitoring device, whereas the M43A1 provides immediate warning of the presence of a chemical hazard

7-2.4.3 Unattended Operation

As described in Chapter 6, a system operating in an unattended mode is fully automatic while being remotely monitored. Much of the rationale, advantages, and disadvantages of automatic operation applies to unattended operation Because unattended operation removes the operator from the data gathering and analysis loop, the requirement for this type of operation imposes a more complex design on the signal processing and warning processes of the detector The requirement for unattended operation is more important in a warning than it is in a monitoring application As in automatic operation, unattended operation requires the use of an air pump with a motor to acquire the sample, more complex electronics for signal processing coupled with automatic sample analysis, and a visible and/or audible warning device to alert the user to the presence of a hazard

7-2.4.4 Agent Quantification

Agent quantification is necessary for those devices used to locate contamination, and it is desirable in some monitoring devices that must indicate a range of concentration When necessary, agent quantification limits the selection of the detection technology used in the sample analysis process because a continuous sample analysis process must be used, such as the M8A1 ion mobility detector, rather than a batch-type analysis process, such as the M8 electrochemical detector The agent-detector contact cannot be forecast, thus the time the detector starts to sample an agent cannot be known This unknown time prevents even a semiquantitative indication of agent concentration in a batch process

7-2.4.5 Integrated Logistic Support (ILS) and Logistic Support Analysis (LSA) Considerations

Although logistic considerations are thoroughly discussed in Chapter 6 the designer must also consider ILS and LSA requirements A good example of logistic support analysis inputs into the design of hardware occurred during the development of the M43A1 detector Recommendations or investigations made for LSA were

1 Addition of decals on the cell module, electronics module, and pump module that show part name and number

2 Provision for a plastic cover to protect the electronics module during handling when used as a spare

3 Provision for plastic covers to protect the pneumatic fittings and connectors of the cell module and pump module during handling when used as a spare

4 Addition of a warning label to the cell module that states, "Radiation exposure can occur when cell module is opened Cell should be disassembled only at depot level "

5 Addition of a yellow and red caution label to the cell that states, "Caution! Radioactive Material" and has

a space for entering the name of the isotope, the amount used, and the date placed into the detector

6. The temperature paddle in the XM140 Chemical Agent Automatic Alarm Test Set is reversible to eliminate the problems experienced when breakage occurs due to forced insertion

7. Revisions of the top case assembly drawing for the preproduction units showing absence of the horn, meter, and other easily removed items to allow identification of the top case assembly as a spare item in this configuration

8 A special ball end hex drive wrench to remove the subassembly housing was added as part of the XM140

9 Provision of all floating-type chassis connectors that mate with plug-in floating-type modules to decrease damage due to misalignment caused by tolerance buildup

10 Provision of a raised section adjacent to the hole on the chassis assembly to act as a guide to ensure that the hole in the chassis assembly aligns exactly with the hole in the air inlet housing for proper installation mating with the pneumatic fitting on the cell module

11 Use of screws and nuts (not rivets) to secure all turn-lock receptacles on the detector unit

12 Addition of an instruction plate on the bottom case assembly with the inscription that follows

USUAL RESERVICING INSTRUCTIONS
(Refer to TM-3-6665-312-12 for detailed instructions)

1 Start·

a Unscrew plug and close air inlet

b Install flowmeter

2 Check battery voltage

3 Check airflow

4 Operate for 5 min or until meter reading is in green band.

5 Press bit switch Alarm should sound

6 Use test paddle. (Refer to TM-3-6665-312-12)

a Disconnect power

b Remove air filter and discard if dust laden

c Install test paddle

d Connect power Alarm should sound

e Disconnect power

f Remove test paddle

g Install air filter

h. Connect power

7 Remove and store flowmeter

8 Turn air inlet to "Open" and replace plug.

ILS and LSA considerations are contained in the technical data package (TDP) for the item The TDP is the most important output of the development program Too often, shortcuts in the preparation of the TDP and its verification are taken during the development program in order to meet schedules or to stay within cost constraints The development engineer concerns himself with type classification of the item, which is based upon the performance of the hardware against the requirement However, the only way the item can subsequently be produced in quantity and provide the same level of performance is through the TDP

A good example of the problems caused by poor quality preparation and verification of the TDP occurred during the development of the M43 detector This detector uses a reinforced fiberglass case that consists of both an exterior and an interior shell with Freon-filled fiberglass insulation and an electrical heater filament between the two shells This case was required to a 1 5-m drop test onto a hard surface at each of its corners when loaded with the detector weight During development the cases were fabricated by hand lay-up, a slow and costly fabrication method

During the development phase only enough cases were manufactured for the developmental and operational testing (then termed DT/OT) These cases passed the drop test To save time and money, no additional cases were manufactured and disassembled to verify the wall thickness and insulation uniformity of the case against the TDP requirements Only external case dimensions were checked against the TDP During initial production testing, the cases failed the drop test at the corners Subsequent analysis showed the TDP did not represent the cases used during DT/OT because the corners of the test cases were much thicker than required by the design drawings The analysis and correction of the TDP problem resulted in production downtime of five months and a large expenditure of additional funds It also delayed fielding of the item for five months.

7-2.4.6 Environmental Requirements

The need to operate an agent detector under a complete range of temperature conditions, i e , in rain, fog, or snow, creates significant additional design problems for the developer For example, the M43 and M43A1 detectors use an aqueous detection solution that freezes at approximately −1°C In addition, the sample acquisition airstream should be heated to approximately 35°C for

proper conversion prefilter reaction The heating required to maintain these operating temperatures is accomplished by using electrical energy from the battery power supply Fig 7-2 shows the increase in power consumption as a function of decreasing temperature for the M43 detector The increases in power drawn from the primary battery supply reduce battery life from seven days of continuous operation at 21°C to only 12 h at −40°C Although the reduction in battery life is very large, the power draw of 18 W at −40°C was improved after substantial design effort on the case, the sample acquisition insulation, and the heater

The requirement for a detector that must operate unattended for periods of up to 12 h and must function under rain or snow conditions presents another challenge to the designer The rain and snow cap developed for the M43A1 detector and shown in Fig 7-3 offers a solution to this problem

The screw-on cap comes with an umbrella plastic cap A that fastens to the standpipe B by a snap ring held to the umbrella cap by four supports The distance from the inside of the umbrella cap to the outside of the standpipe C is large enough to prevent large raindrops from being drawn into the detector, but it will allow agent particles to flow in freely The umbrella cap A can be snapped off of standpipe B in snow conditions to prevent snow from building up and clogging the air inlet

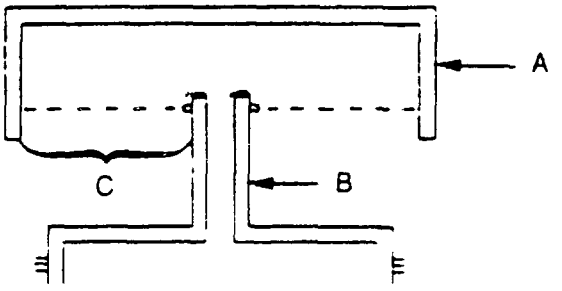


Figure 7-3. Rain or Snow Cap (Ref. 1)

Operation under sunlight conditions in a hot environment also can affect detector performance with respect to detection technology and/or the detector electronics The best protection available currently is to use a field-expedient, natural or artificial sunshade for the equipment The sunshade should not influence the natural flow of air over the detector, disruption of the flow could degrade sample acquisition

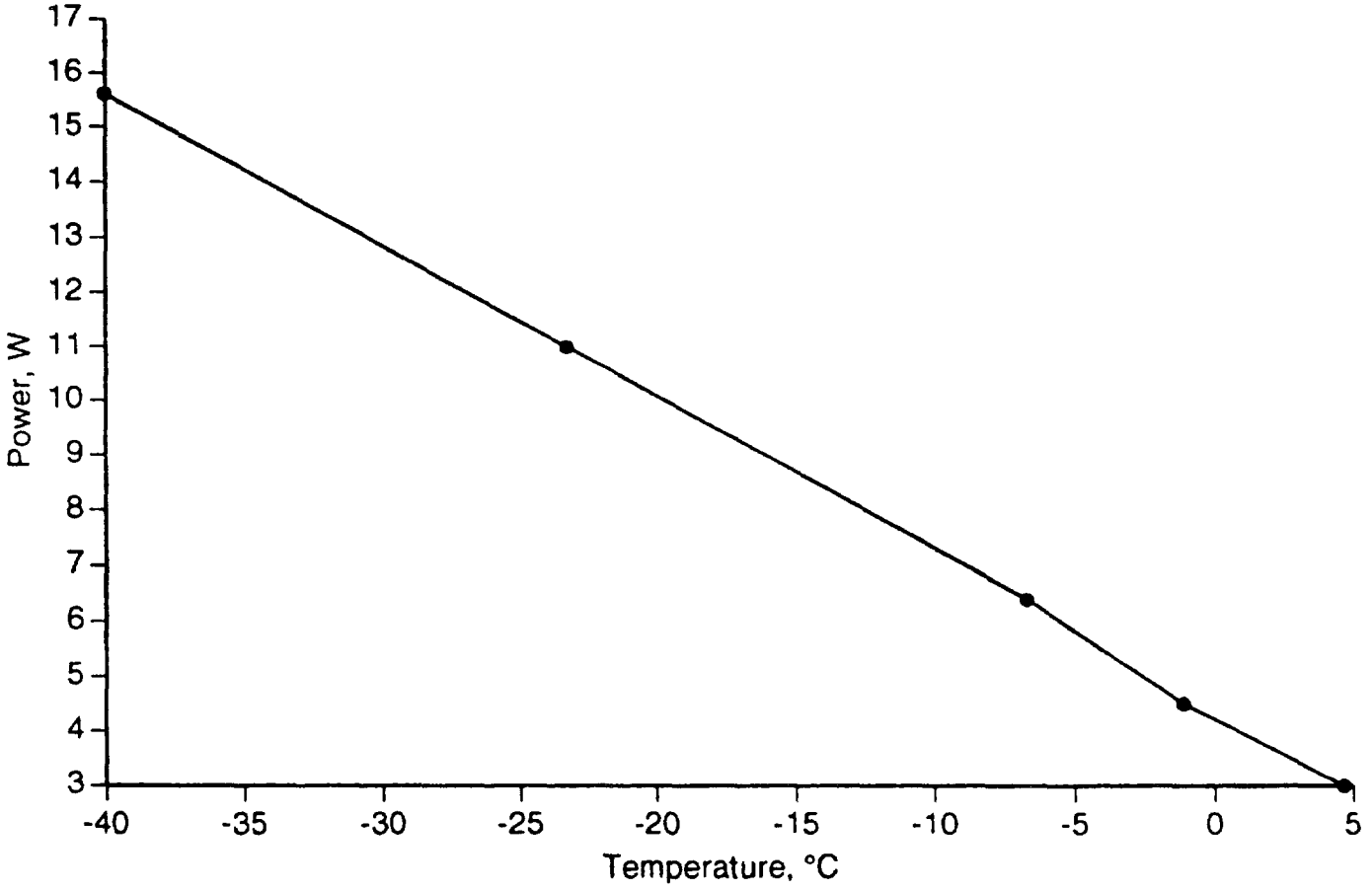


Figure 7-2. M43 Detector Power Consumption at Low Temperature (Ref. 2)

7-2.4.7 Size, Weight, and Power Requirements

The criteria for size, weight, and power are discussed in Chapters 5 and 6 as are the constraints these requirements place on the design of agent detectors

7-2.4.8 Reliability, Availability, and Maintainability

Reliability, availability, and maintainability (RAM) characteristics are defined in Chapter 6 Common terms for reliability must be agreed to among the user, the developer, and the tester as early as possible in the program Such terms as mean-time-between-failure (MTBF), mean-time-between-false-alarm (MTBFA), mean-time-between-mission-stoppage (MTBS)* must have common terms of reference and quantitative numbers assigned to each factor The type of event that constitutes a failure must also be assigned. Wherever possible, components should be modular for quick and easy replacement and should allow fault isolation to determine the cause of the failure

7-2.4.9 Manpower and Personnel Integration (MANPRINT) and NBC Contamination Survivability

These important requirements apply to all Army equipment and are not unique to detection equipment The appropriate Army regulations and pamphlets for these criteria thoroughly cover the need for, and ways of, designing them These requirements are discussed in more detail in par 6-6 3

7-3 CHEMICAL STANDOFF DETECTORS

7-3.1 THREAT

Chemical standoff detectors can provide detection of and warning against the same threat agents and physical forms as chemical point detectors The standoff detection systems detect vapors and fine aerosols very efficiently In a passive standoff detector such as the XM21, as the particle size of the aerosol or liquid droplet increases, the sensitivity decreases until at larger particle sizes the detector has very poor sensitivity or none at all The laser standoff detection system that uses backscatter radiation can detect larger particle sizes (See pars 7-3 3 1 4 and 7-3 3 2 1)

Infrared (IR) standoff detectors offer unique potential for direct detection of liquid chemical agent on the ground or on equipment, one of the major hazards anticipated on the chemical battlefield. The main advantage of standoff detectors is their ability to detect the hazard produced from the threat at distances of up to five km from the detector hardware Similarly, the standoff detectors need a line of sight of considerable length (at least 100 m) for detection, but conversely, they cannot operate when the line of sight is obscured, interrupted, or in closed environments, such as vehicles, vans, or shelters Because of the principal advantages and disadvantages of standoff and point detectors, their best use is as complementary devices

7-3.2 REQUIREMENTS (CRITERIA)

Different operational situations generate different agent and hazard information needs, which can vary across the battlefield according to operational situations Not only will the information needs differ between the battlefield units, but the characteristics of the point and standoff detectors used by the units can also vary significantly The same rationale discussed in par 7-2 2 should be used to establish a set of requirements for a standoff detection system for the combat user

In the context of the four battlefield situations, the need for remote detection focuses on each unit's ability to receive and process information concerning battlefield hazards in time to warn troops to take protective action Remote detection has a lesser role in the combat and combat support (CS) and RECON battlefield situations than it does in the CSS and fixed site environments

The highly mobile combat and CS units require real time detection, and their detectors must be capable of operating while on the move In this situation, response time is more critical than detector sensitivity Similarly, the mission of NBC reconnaissance is to identify and map contamination of battlefield positions, movement routes, and other contaminated sites Because of the rapid pace of reconnaissance operations, remote detection becomes impractical

In situations that are less mobile, such as the CSS unit environment and fixed sites remote detection can provide advance warning of attacks conducted against targets upwind of the operational area Such operations as airfields, ports, rear supply trains, and other units that are in fixed or semifixed positions, e g , supply trains and field hospitals, can effectively use remote detectors to provide advance warning of an attack

Table 7-2 summarizes detector performance criteria across all four battlefield situations

*MTBS is the time interval in which any failures or false alarms occur that prevent successful completion of a 12-h mission

TABLE 7-2. BATTLEFIELD NEEDS VERSUS DETECTOR PERFORMANCE CRITERIA (Ref. 3)

REQUIREMENTS	COMBAT AND CS	CSS	RECON	FSI
Agent detection	all known and unknown agents in all physical states			
Response time	real time on demand			
Sensitivity	detox level			
Accuracy	very high per 72-h mission			
Size	man-portable		must fit in vehicle	adjustable
Data transmission	automatic and must interface with warning system		compatible with Division/Corps nets	compatible with Corps/ organization, automatic
Transmit service/set up-take down time	instantaneously usable			
Consumables	for 72-h mission		for 24-h mission	
Alarm	trigger automatic			
Environmental conditions	hot, basic, and cold (AR 70-38)			
Power	internal with size constraints			unrestricted
RAM	reliability—500 h MTBF			
	availability—23 of 24 h			
	maintainability—90% correctable			
Conventional attack	high probability of survival			
NBC attack	AR 70-71 for NBC			
	AR 70-60 for nuclear			
Identification	identify all known, adaptable to unknown			
Operator requirements	turnkey, common skills			
Ruggedness	MIL-STD-810			
Range	immediate operational area	3 km^2	3-12 km	3 km^2
Capability to operate mobile	high			
Quantification	quantify all known, adaptable to unknown			
Reset time	continuous			

7-3.3 COMPONENT DESIGN

Standoff detection design differs from point detection design primarily in the sample acquisition process because it measures the average agent concentration along a line-of-sight of considerable distance from the detector (up to five km) The point detector measures the agent concentration only at the location of the detector

Unlike chemical point detectors, standoff detectors can cover large areas of the battlefield from a fixed position in a relatively short period of time This feature significantly reduces the number of detectors required by the operational unit to provide adequate warning Standoff detectors, however, placed inside cannot provide warning of agents entering enclosures for personnel in vehicles, vans, and shelters because these detectors require a long path for sensitive operations As indicated previously, the tentative BOI for the XM21 standoff detector is one per NBC reconnaissance vehicle This relatively low distribution means that the component cost factor, although always important, is not as important as it is with point detectors

Standoff detectors are generally more complex in design and operation than point detectors It is, therefore, very important that the system developed be as modular as possible and have built-in fault isolation for maintainability and simplicity Also equipment operation must be designed to be as simple as possible in order to conform with MANPRINT requirements

7-3.3.1 Sample Acquisition

The operational use differences between sample acquisition in point and standoff detectors were discussed in Chapter 5 If the requirements dictate the need for standoff detection, the sample acquisition device requires substantial engineering design to achieve adequate signal information for input into the signal processor The XM21 standoff detector best illustrates the complex engineering design of a passive sample acquisition device The discussion of each component in the sample acquisition and analysis for standoff chemical agent detectors is extracted in part from Ref 4

Fig 7-4 shows the functional block diagram for the XM21 Remote Sensing Chemical Agent Alarm The sample acquisition device includes the entrance window, spatial scanner, spectrometer (containing the reference source, interferometer, and IR detector), and cryogenic cooler Each of these functional parts is discussed in the paragraphs that follow

7-3.3.1.1 Entrance Window

The entrance window is a germanium window with antireflective coatings on both sides to improve transmission The front coating is durable because it must be exposed to the atmosphere and the elements, whereas the inner surface has a high-efficiency coating The window maintains the pressure barrier of the detector, and it permits transmission of the IR energy in the 8-12-μm region The window is specially taped to increase its conductivity to less than 0 03 μm, which allows it to be an integral part of the electromagnetic interference (EMI) and electromagnetic pulse (EMP) shielding of the XM21

7-3.3.1.2 Spatial Scanner

Standoff detectors view the area of detection interest along a single line of sight or instantaneous field of view (IFOV) To monitor an upwind area for an agent cloud, three options are available (1) to use a large number of detectors (not cost-effective), (2) to rotate the entire detector mechanically and automatically across the sample area, or (3) to install a spatial scanner within the detector head that performs the same function as option (2) The XM21 Remote Sensing Chemical Agent Alarm uses option (3), which is the simplest and most cost-effective method The spatial scanner directs the IFOV of the interferometer to seven discrete azimuth positions

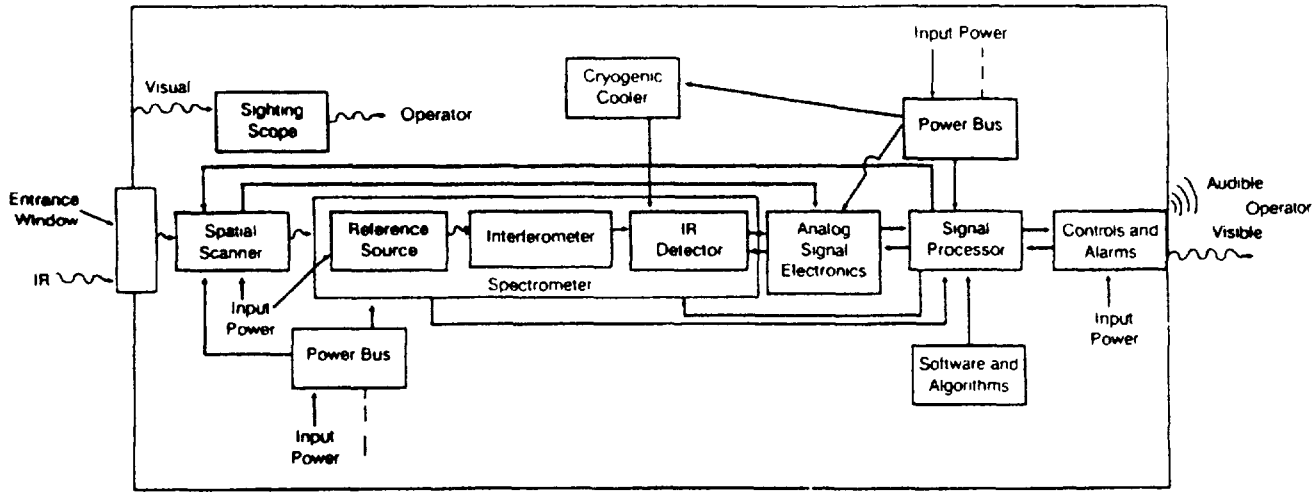


Figure 7-4. XM21 Detector Functional Block Diagram (Ref. 4)

along a 60-deg, horizontal angle

Positioning the scanner to each of the seven discrete azimuth positions is controlled by the signal processor during the collection and data processing function A potentiometer is connected to the spatial scanner and can be read by the signal processor, this feedback is used to verify the movement and location of the scanner A normal scan cycle includes a data-gathering rotation and a return rotation The data-gathering rotation consists of a 30-deg mirror rotation to yield a 60-deg field of regard (The field of regard is the field of view the detector is scanning at a given point in time) The seven scanning positions are spaced along the 30 deg of mirror rotation, consequently, the mirror must travel 5 deg between each step to yield 10 deg between each IFOV After processing at the seventh scan position, the scanner returns to position 1 by reversing direction and backtracking over the data-gathering path. A complete scan cycle requires less than one min to complete

7-3.3.1.3 Spectrometer

The spectrometer receives the IR radiation from the scanner and generates the electronic signal that is processed to produce the alarm The components of the spectrometer are the reference source, the interferometer, and the IR detector

7-3.3.1.3.1 Reference Source Assembly

The reference source assembly is used during the normal and the system test modes of operation and contains a polystyrene filter assembly, blackbody plate, and associated electronics

During the normal mode of operation, the blackbody plate is a constant source of radiation used to test signal levels and signal-to-noise ratios

During the system test mode, the reference assembly is used to flip a polystyrene test filter into the optical path of the IR detector The polystyrene test filter must be detected during the confidence test function

7-3.3.1.3.2 Interferometer

The XM21 interferometer is based on a single-cube Michelson design, shown in Fig 7-5, that is a fixed plane mirror in one axis, a moving mirror in a perpendicular arm, and a Ge-coated ZnSe beam splitter It is the heart of the XM21 sample acquisition and sample analysis Interferometers are characterized as high-throughput devices because they do not require slits to achieve resolution performance The device converts the incoming radiant energy into an interferogram

The incident radiation is divided into two beams, as shown on Fig 7-5(A), using a 50% reflective and 50% transmissive beam splitter Each beam is then redirected by mirrors back to the beam splitter where they combine constructively or destructively depending on the relative path differences traveled by each beam and the frequency content of the incident radiation The combined radiation is directed to an IR-sensitive detector. Variation in path length in one arm of the interferometer (which accomplishes the IR frequency sweep) is done by moving the physical position of its mirror As the moving mirror moves back and forth, the distance x between the fixed mirror and the beam splitter varies with respect to the distance between the beam splitter and the moving mirror and causes phase differences due to the different path length in each "leg" of the interferometer Therefore, each input frequency yields a cosine wave with a unique period and amplitude The corresponding alternating current (ac) signal generated by the detector is called an interferogram and is shown in Fig 7-5(C) This interferogram can be mathematically transformed to produce an IR spectrum

To meet the users' stability and ruggedness (shock and vibration) requirements, the XM21 includes a flex pivot design for all points of rotation of the moving mirror, as shown in Fig 7-6 A flex pivot allows rotation in one plane while allowing very slight deflection in the perpendicular direction Due to the short physical retardation of the moving mirror (approximately 1 25 mm), no significant vertical displacement of the moving mirror in relation to the fixed mirror occurs

Another important feature of this design is the use of a single-cube interferometer Both the laser and white light beams pass through the same beam splitter and reflect from the same mirrors as the primary IR signal The interferograms from these two sources are used to start the sample acquisition process and determine the sample interval of the signal interferogram, therefore, a significant gain in resistance to the relative drift between components is achieved This resistance to component drift results in a device that is very insensitive to thermal expansion problems

7-3.3.1.3.3 IR Detector Assembly

The IR detector assembly has two detector elements, the germanium detection lens and the field stop, all housed in a dewar (a thermos-like device) that is cooled to −191°C, which lowers background noise due to thermal emission Lowering the background noise increases the signal-to-noise ratio and significantly increases sensitivity The detector element is a photoconductive mercury-cadmium-tellurium crystal that is very sensitive to radiant energy The field lens uniformly distributes the image across the face of the detector crystal, as shown in Fig 7-7 This distribution averages out areas of nonuniform responsiveness across the face of the detector effectively and ensures a uniform response across the field of view of the sensor The field stop ensures that the detector views only the highly transmissive and highly reflective optics of the system that are at ambient temperature

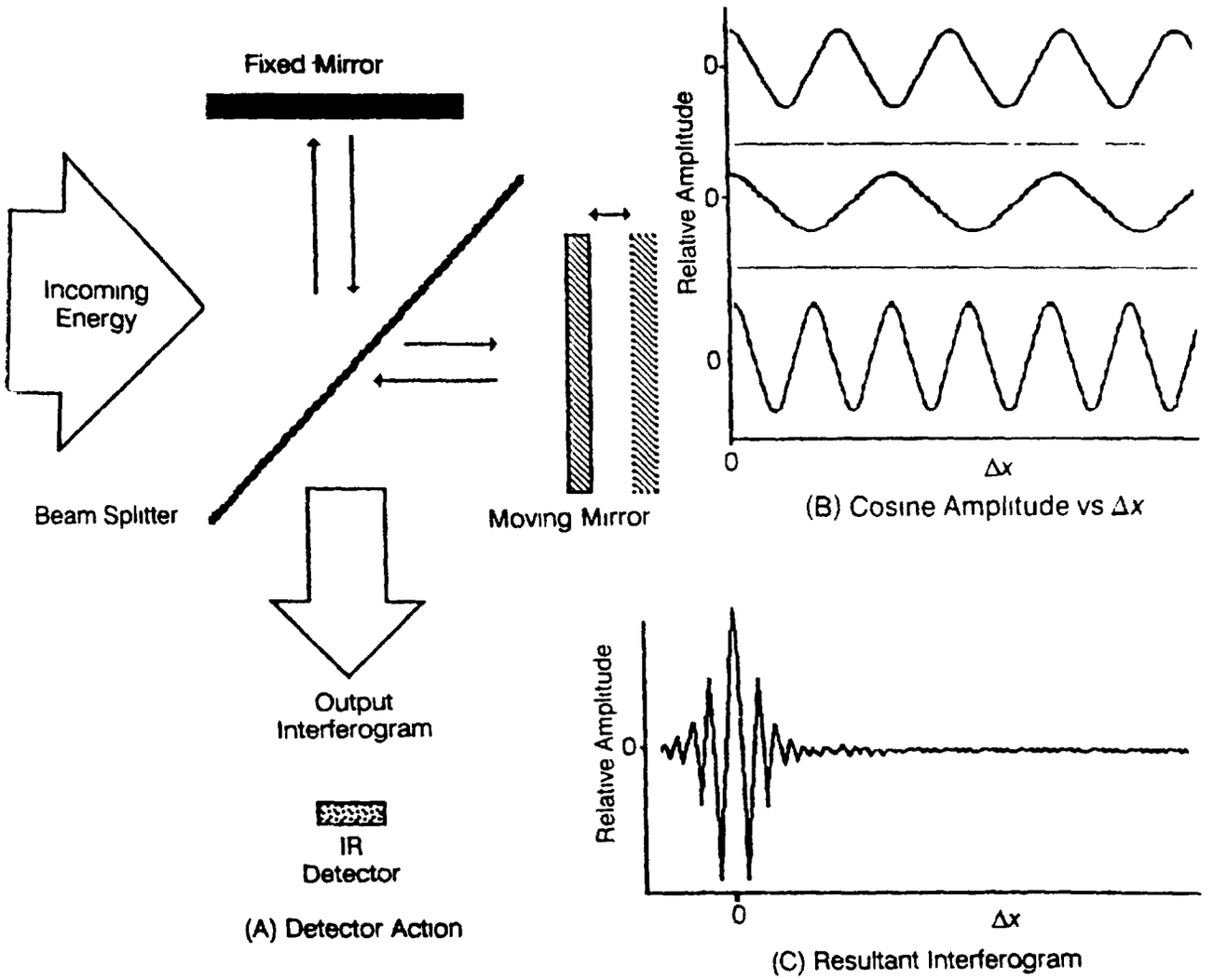


Figure 7-5. Michelson Interferometer (Ref. 4)

/-3.3.1.4 Laser Standoff Detector

An alternate method to passive sample acquisition using infrared standoff detection is to use an active laser as the energy source rather than background emissivity The laser is collocated with the detector, and its energy output is focused along the field of view of interest in relatively intense pulsed wavelengths in the IR region of the spectrum Part of this energy is backscattered to the detector by dust and other particles in the atmosphere, the backscattering provides the analytical energy for the detection This technique of differential adsorption/ differential scatter offers several distinct advantages over a passive IR system By timing the pulses of the laser against its return signal, the discrete average concentration of agents along portions of the path length (for example, 100-m segments) can be measured rather than integrating the concentration along the entire path length as in passive detection In this way, a true picture of the concentration cloud profile of the agent can be obtained and mapped electronically

The most important feature of a laser system is its potential to measure directly liquid agent in the air or deposited on surfaces, such as terrain or equipment, due to the IR scattering properties of the liquid agent Most other methods of detecting deposited liquid depend upon sampling the agent vapors above the deposited liquid agent These methods can have particular difficulty when detecting the low-volatility, persistent agents, especially at low temperatures where the agent volatility is reduced

The engineering technology associated with laser standoff detectors is not as advanced as that of passive systems The two main problems associated with laser standoff detectors are (1) obtaining a lower power laser that emits in the proper spectral region and possesses sufficient operating life and (2) the development of signal-processing interferograms and algorithms capable of handling the complex signals from the detector for sensitivity and specificity

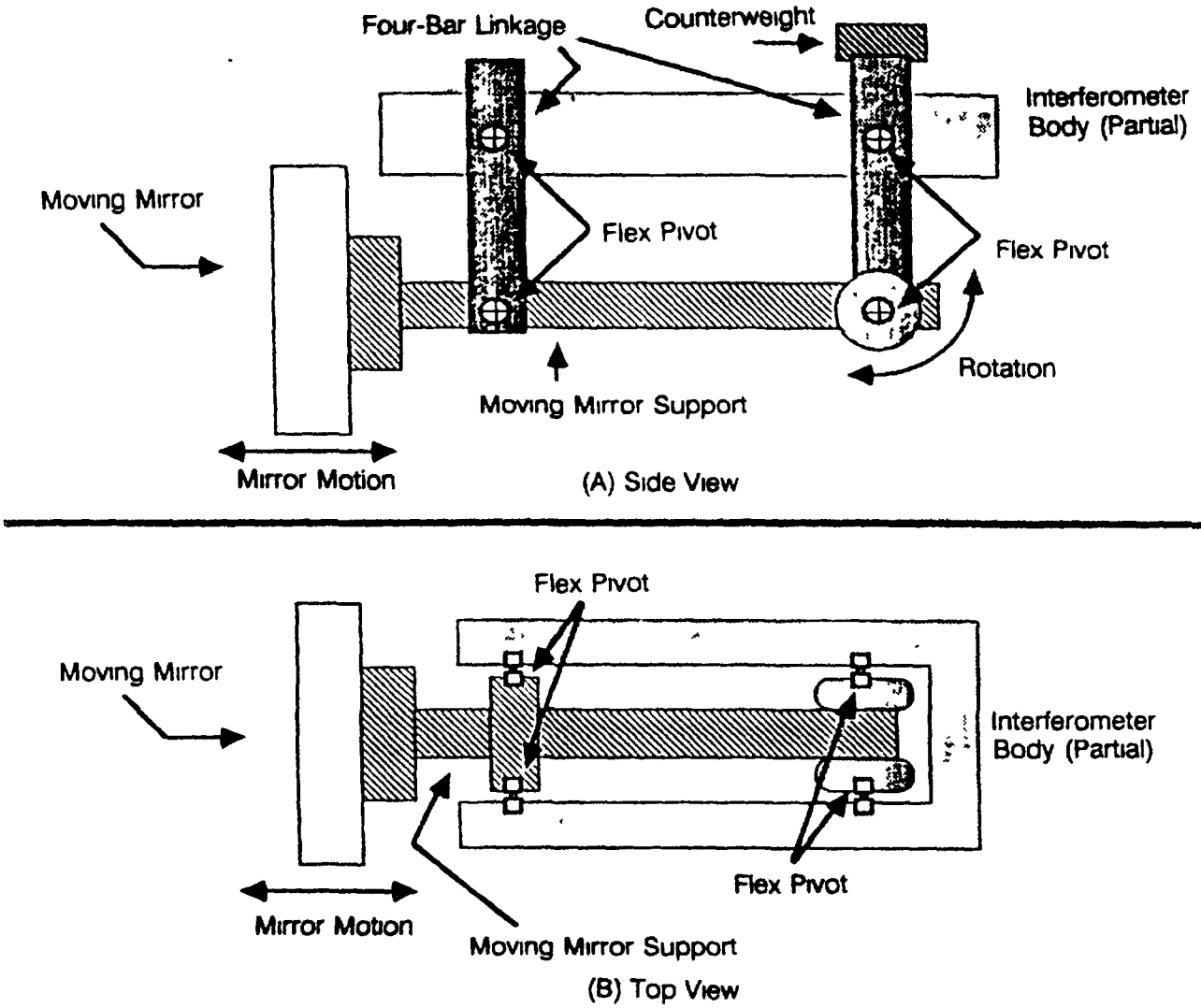


Figure 7-6. Flex Pivot or Porch Swing Mechanism (Ref. 4)

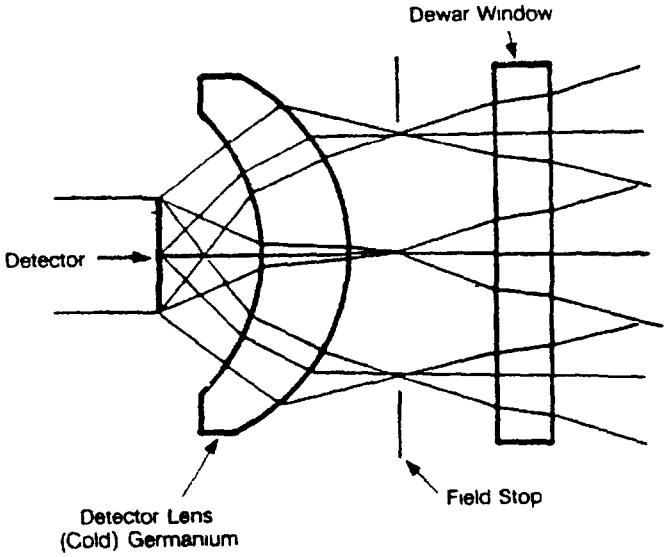


Figure 7-7. Optical Diagram of the Field Lens Assembly (Ref. 4)

7-3.3.2 Sample Analysis

7-3.3.2.1 Detection Technology

For standoff detection, selection of a detection technology is very limited Detection technology that senses changes in the IR energy of an agent cloud is the only technology presently available The technology can be further broken down into active or passive detection A passive standoff chemical agent detector, such as the XM21 alarm, analyzes the spectral characteristics of an atmosphere by using the radiance differences between the vapor cloud and the radiation source behind the cloud relative to the position of the detector For a uniform blackbody radiation source (Natural and man-made objects are essentially blackbodies at 10 μm in the IR spectrum), these radiance differences can be expressed in terms of temperature differences without regard to spectral frequency An active standoff chemical agent detector operates on the same radiance differences but obtains its

energy from the backscatter of a larger IR source from a laser within the detector

An example of how passive IR detectors can possess sufficient sensitivity to meet the users' requirements can be shown by comparing the XM21 noise equivalent temperature change ΔT with typical real-world values of ΔT The XM21 noise equivalent ΔT is approximately 0 01 deg C for a pure blackbody source (emissivity = 1) temperature difference If an expected target cloud emissivity is approximately 0 1 and there is a 2 to 5 signal-to-noise ratio, for accurate detection the effective ΔT is 0 2 to 0 5 deg C Typical real-world values of ΔT based on analysis of XM21 field trials are substantially higher, as shown in Fig 7-8

A point sampling detection sensitivity is measured in terms of Ct A standoff detector integrates the energy difference from agent along the line of sight, therefore, it cannot directly measure concentration An IR detector detects a signal based on average concentration C within a cloud multiplied by the cloud path length L and yields the concentration path length CL For example, a cloud with an average concentration of 10 mg/m^3 and a path length (along the line of sight) of 15 m yields the same signal as a cloud having a concentration of 1 mg/m^3 and a 150-m path length The CL for either case is 150 mg/m^2

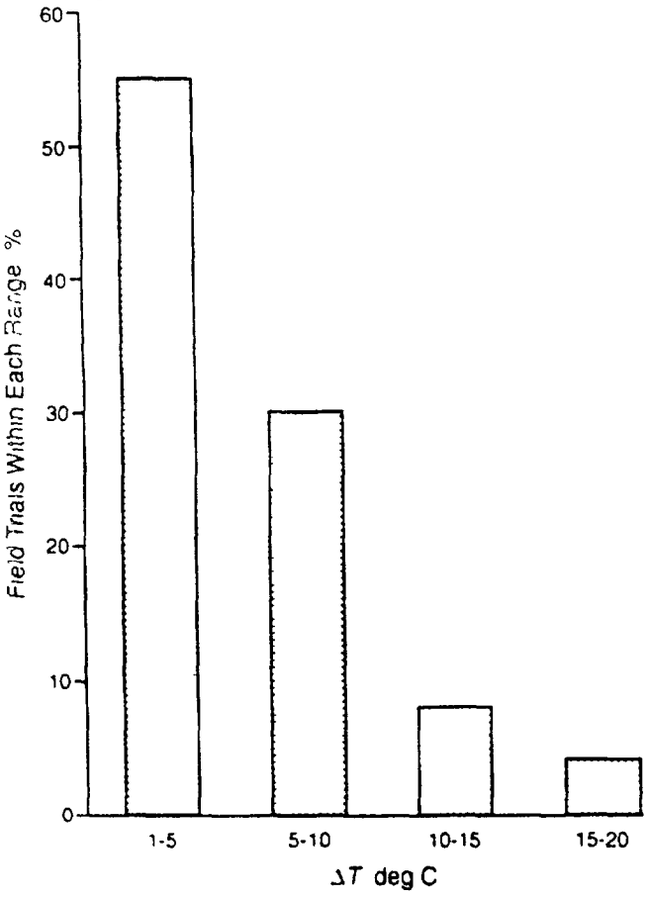


Figure 7-8. Typical Real-World ΔT Ranges Based on XM21 Field Trials (Ref. 4)

Standoff IR detection is based upon the spectral features in the 8- to 12-μm region. This region is a relatively clear atmospheric "window" under various weather conditions There are a number of battlefield compounds that possess strong IR absorption features in this region that are similar to chemical agent absorption dust, phosphorous smoke, other military smokes, explosives, and other hot sources The spectral characteristics of an agent and an interferent are shown in Fig 7-9 The basic spectral features of chemical agents are the key to detection, whereas the spectral differences the interferents exhibit provide a means to discriminate

7-3.3.2.2 Signal Processing

The difficult nature of the detection problem requires that both the optical sensor and the signal processing be optimized A good example of how optimization can be accomplished occurred during the development of the XM21 alarm The signal processing steps, i e , detection and discrimination algorithm development, are discussed in the final report on that program (Ref 4) This discussion is Appendix A

7.3.3.2.3 Detection on the Move (Autonomous Background Compensation)

The XM21 detection and discrimination algorithms are dependent on their ability to perform a background subtraction step that removes unwanted features from the spectrum This allows the agent or no-agent decision to be made without the complications introduced by spectral constituents of the background scene Interest has increased in using the XM21 on a moving vehicle, however, detection from a moving vehicle prevents the use of background subtraction because the background is constantly changing

To solve this problem, autonomous background compensation (ABC) algorithms were developed to eliminate the need for background averaging and subtracting Each scene spectrum is processed autonomously, or without reference to the previous spectral history of that portion of the scene, to compensate for the rapidly changing scenes The ABC algorithm processes the data and compares them to a set of numbers that represents the agent of interest The output of this process is a number that represents the level of agreement of the unknown data set to the neat agent The size of the quantifier (positive direction) indicates the strength of this agreement, a greater positive direction equates to a higher confidence in the decision power

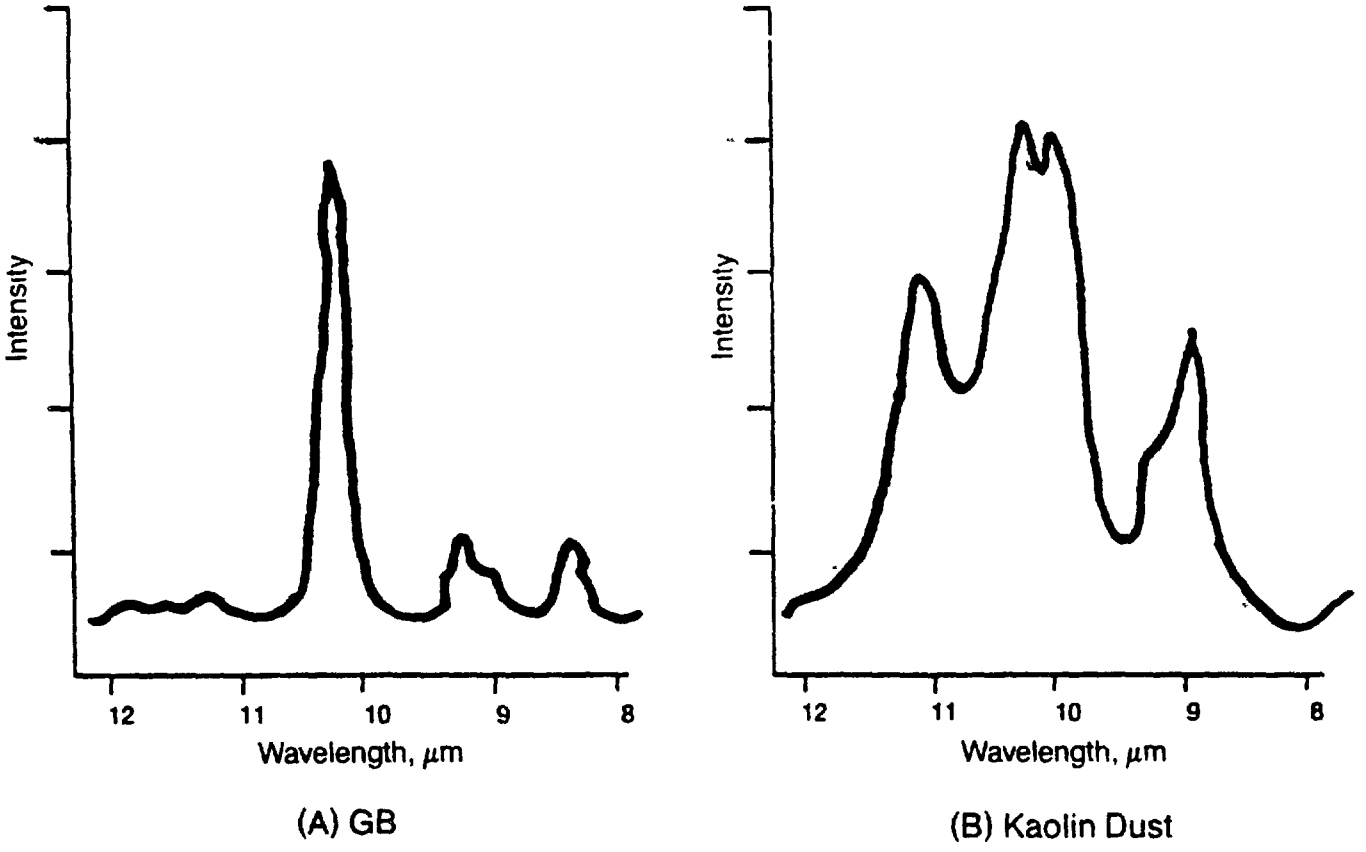


Figure 7-9. Spectral Features of Agent and Interferent (Ref. 4)

7-3.3.3 Response (Alarm)

The operational requirements for response to the chemical threat are the same as those discussed for point sampling detectors except the need for a remote alarm is limited primarily to fixed site applications. The alarm-operating circuitry and hardware for standoff detectors are very similar to those used in point sampling detectors The only significant additional need for standoff detectors is a series of lights or a position meter that shows which field of view the detector is scanning and that an agent was detected in that field of view The status of the lights or position meter can be controlled by the signal processor of the device by an input/output (I/O) board. The use of an indicator that shows which fields of view contain an agent allows the operator to determine cloud position and the distance traveled over time

The operational need of troops operating under combat conditions may govern design of the audio and visual signals chosen for agent response For example, in some cases it is desirable to have the audible and visible responses as loud and bright as possible to warn troops over a large area In other cases, such as an advance outpost, both sound and brightness must be held to a minimum. In addition, if detector response is linked with other communication nets, the response should not interfere with other tactical communications For example, if the detector is mounted on a tank and the detector response is linked with the tank communication system, any alarm should not interfere with vital voice communications under combat conditions

7-4 BIOLOGICAL DETECTORS

The biological agent threat, which includes both pathogens and toxins, and its impact on detection requirements are discussed in Chapters 2 and 3 The major design impact for detection of biological agents compared to the impact for detection of chemical agents is the vastly increased sensitivity required This requirement is based on the fact that a given mass of biological agents is more toxic than the same mass of chemical agents (Biological agents, excluding toxins, are not usually described in mass units, i.e., organisms per cubic meter, not kilograms per cubic meter.) As explained in Chapter 5, the requirements to increase sensitivity also impact the rejection of interfering materials (specificity) and the fact that a number of nontoxic, proteinaceous materials are present in the atmosphere in much greater concentrations than the agents

At the present time there are no biological detection technologies that approach meeting the requirements for agent sensitivity and specificity (See Chapter 4 for more discussion) This fact is true for both point sampling and standoff detector technologies The approach to date and in the foreseeable future uses the principle of collecting

large quantities of the atmosphere and concentrating it into a small amount of liquid or air (sample acquisition) The larger particles of interfering materials that are naturally present in the sample are selectively rejected by physical means and thus improve the specificity If this technique can be successfully and reliably employed, then various biological detection technologies can be considered for exploitation

7-4.1 THREAT

Much of the information on biological agent threats is not available in open literature. Generally, biological agents are solid and may be dispensed in solid or aerosol form As discussed in Chapter 2, biological agents present an inhalation and ingestion threat Dispersed as fine aerosols, biological agents with particle sizes of less than 10 μm can be inhaled by unprotected troops Biological agents also may be used to contaminate food or water supplies and thus create an ingestion threat

Biological agents are living organisms that die rapidly after dissemination They do not survive well outside their natural environment and are prone to decay from such environmental conditions as sunlight Because of the fine aerosols that can be achieved with some dissemination systems (3 to 5 μm), biological weapons can contaminate large areas

Because biological agents can build up in the body over time, the detector is required to have have very high sensitivity, response time, however, can be slow Detector requirements are similar to those for nonpersistent chemical agents but require much greater sensitivity and slower response time

7-4.2 REQUIREMENTS (CRITERIA)

The requirement to detect biological agents is bounded by two major difficulties (1) the ability to differentiate between agent and other battlefield or environmental interferents and (2) the ability to detect small aerosols across large areas In the Reconnaissance, Detection, and Identification Master Plan (RDIMP), requirements for detection of biological and chemical agents are similar Detection systems are required to detect all known and unknown agents in real time (<5 s) prior to incapacitation wherein 5% of the target population is infected (Ref 3)

7-4.3 COMPONENT DESIGN

Sample acquisition, sample analysis, and response time for biological agents must be more specific than processes for chemical agents Biological particles are disseminated in particle sizes of less than 10 μm Therefore, the volume of samples collected tends to be larger than that of chemical agents

The analysis process is complicated by the life span of biological agents Biological agents are living organisms that die over time, especially when exposed to certain environmental conditions, such as sunlight If they survive and infect personnel, symptoms are delayed for as much as 1 to 3 days This delay affects both sample analysis and the resultant response time

The following paragraphs discuss sample acquisition, sample analysis, and response time as they relate to biological detection and warning Specific design requirements are highlighted

7-4.3.1 Sample Acquisition

Because biological agents are generally employed in a sabotage role against rear area fixed installations, sampling techniques are less stringent in terms of size, power, and weight of instrumentation Therefore, sampling techniques using high volumes of sampled air over extended periods of time can be used This method offers higher detection probabilities and increases sensitivity by differentiating between particle size and background interferents

The best example of a high-volume sampler with particle size selection is the sample acquisition process used in the XM19 alarm Fig 7-10 shows the XM19 functional block diagram The sampled atmosphere is drawn into the unit at a rate of approximately 1100 L/min over a preimpactor The preimpactor removes extremely large particles through a two-stage impactor, which in turn selectively eliminates larger particles into the postimpactor where only particles in the 2 5- to 10-μm range are collected Air is drawn from the postimpactor concentrator at a rate of 15 L/min into an air impaction nozzle, which impacts these small particles onto a slowly moving tape where they are chemically treated and analyzed (Ref 6) Fig 7-11 shows an improved design concept of the collector concentrator that is easy to operate and clean in the field This type of collector concentrator can efficiently collect all of the small particles (2 to 10-μm region) in 1100L of air and concentrate them on a small spot of moving paper tape while it selectively rejects those particles above 10 μm in size even though there are many more particles in the larger size range

The main drawbacks to this type of sampler are its size, weight, and power requirement To operate efficiently, the unit must operate at a pressure of approximately 2 49 kPa To move 1100 L/min of sampled air against this partial vacuum, a Rotron blower was used This blower is large and required 220 W of power, but it was very reliable and demonstrated the tradeoff opportunities in design

7-4.3.2 Sample Analysis

Over the past 40 years, many biological detection concepts have been investigated Biological materials disseminated in particle sizes of 1 to 5 μm are sufficient for introduction into and retention by the human respiratory tract The continued viability of an aerosol cloud of such particle size is subject to turbulent environmental factors

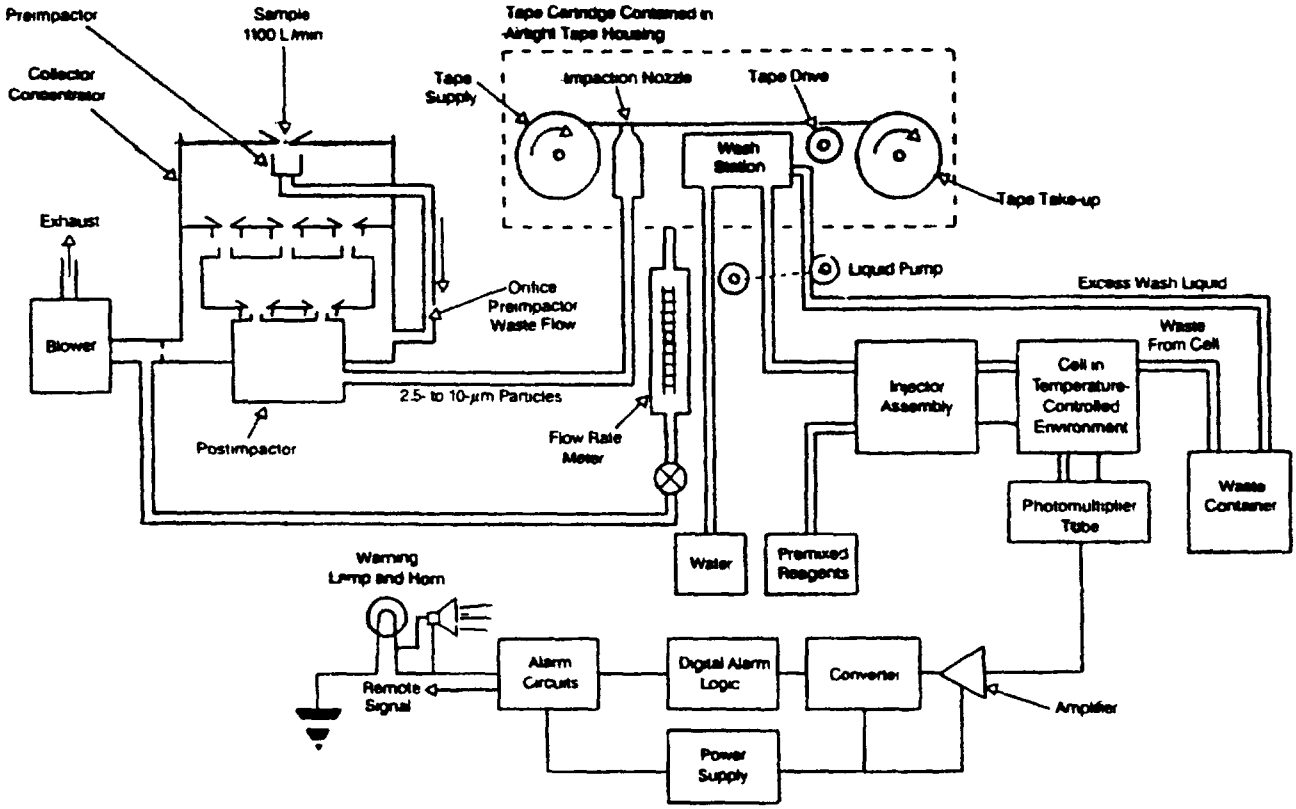


Figure 7-10. XM19 Functional Block Diagram (Ref. 5)

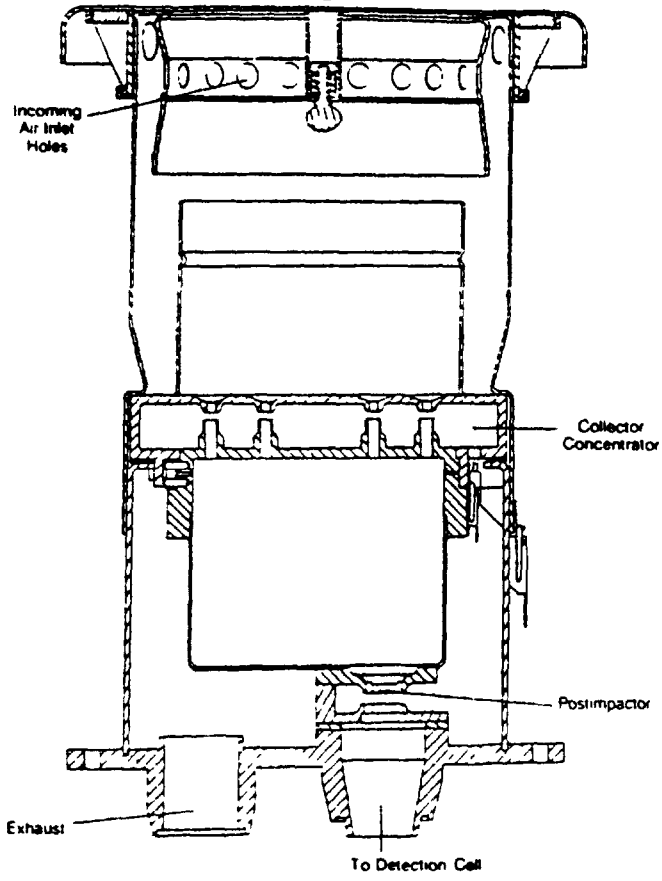


Figure 7-11. Collector-Concentrator Concept Design (Ref. 7)

such as humidity, wind speed, and solar radiation, during cloud travel and eventual residence in the host organism A primary concern in biological agent sampling is the ability of the detector to discriminate between living and dead agent organisms as well as among other biological materials that may exist in the environment

A recent development effort, the Biological Detection and Warning System (BDWS), incorporated a sample collection device to gather and store a sufficient volume of material to enable detection of the agent The sample was maintained in a transport medium for laboratory analysis at a later time Because biological agents have incubation periods of 1 to 3 days, the analysis was more effective when delayed This effort, however, was abandoned in 1983 because operational requirements were not met

Past research and development efforts have used both point and standoff technologies for biological agent detection Techniques common to chemical detection, such as light detection and ranging (LIDAR), chemiluminescence, and mass spectrometry, have been evaluated for biological agent detection applications Each technology addresses the ability to separate agent materials from other battlefield interferents LIDAR assumes the presence of tryptophan, a compound common to most biological materials, to sample fluorescent materials The LIDAR technology requires a high concentration of material present at the sampling locations Chemiluminescence was terminated due to the size and

complexity of the instrumentation required as well as to insufficient background specification (Ref 3).

The remaining technology, mass spectrometry, is one of three selected by the RDIMP for future research and development (R&D) Microsensors and DISC/DIAL, the other two technologies selected for standoff detection, are also considered the best available technologies to pursue for future applications Current development efforts are using a combination of mass spectrometry and microsensors The CB minidetector, that is currently under development, is modular and uses antibodies for specific agents including some toxins, bacteria, viruses, and rickettsias Through identification algorithms, the CB mini-mass spectrometer uses pattern recognition techniques to provide specific information on types of chemical and biological agents

A combination of technologies has also been evaluated for sampling unknown agents One such combination, receptor sites and microsensor technology, will allow rapid detection of generic agents

7-4.3.3 Response (Alarm)

The response requirements for biological detection are identical to those for chemical agents The RDIMP requires real-time (<5 s) response for incapacitation of 5% of infected personnel and 2 min for detoxification and threshold response for 5% of affected personnel

Detector design challenges for biological detectors include discrimination of biological agent materials to provide rapid warning and analysis of the sample to provide real-time information to the user

REFERENCES

1 *Detector Unit, Chemical Agent Automatic Alarm M43A1 Engineering Design Report*, Contractor Report, by Honeywell Inc., St Petersburg, FL, for US Army Armament Research and Development Command, Chemical Systems Laboratory, Aberdeen Proving Ground, MD, June 1979

2 J. F Wroten, Jr , and F K Davey, *Development of a Spontaneous Electrolysis Portable Chemical Agent Alarm*, Defense Development Engineering Laboratories, Edgewood Arsenal, MD, December 1969

3 *Reconnaissance, Detection, and Identification (RDI) Master Plan (MP)*(U), CRDC-CR-85032, US Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, and US Army Chemical School, Fort McClellan, AL, August 1985, (THIS DOCUMENT IS CLASSIFIED SECRET)

4 J R Bryson, S Moschetto, R I Weissberg, and W Thielhart, *XM21 Remote Sensing Chemical Agent Alarm Final Report*, CDRL Sequence No A014, by Honeywell, Inc., Clearwater, FL, for Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, 27 March 1987

5 *Design Studies of XM19 Alarm Components*, Report No ED-CR-77018, US Army Armament Research and Development Command, Chemical Systems Laboratory, Aberdeen Proving Ground, MD, June 1977

6 T R Herndon and H S Wells, Jr , *Development of a Chemiluminescence Detector* Report No ED-CR-73003, EIR-964, by Environmental Science Division, Bendix Corporation, Baltimore, MD, for Edgewood Arsenal, Aberdeen Proving Ground, MD, September 1973

7 *Engineering Development of the Biological Detector and Warning System*, ARCSL-CR-78032, Chemical Systems Laboratory, US Army Armament Research and Development Command, Aberdeen Proving Ground, MD, February 1978

APPENDIX A
SAMPLE SIGNAL PROCESSING DESIGN

Signal processing is required to condition the output signal of the sensor and process it into a form (in this case agent or nonagent decisions) useful to the user. Each of these processing steps is discussed in this appendix. This appendix is taken entirely from Ref. 1.

A-0 LIST OF SYMBOLS

f = a negative power of 2
R_1 = unflipped dot product response
R_2 = flipped dot product response
S = spectrum vector
W = discriminant vector

A-1 DETECTION AND DISCRIMINATION ALGORITHMS PROCESSING STEPS

A number of well-known signal processing and pattern recognition algorithms have been combined to produce the desired results. Fig. A-1 shows the steps in the XM21 signal processing chain.

A-1.1 SIGNAL AVERAGING

The inherent signal-to-noise ratio of the output signal of a sensor can be improved by the square root of the number of measurements averaged if that signal is constant and the noise is random. Both of these conditions are true for the short time durations over which XM21 signals are averaged. Because subsequent steps in the signal processing chain, most notably the fast Fourier transform (FFT), require considerable calculation time, it has been possible to overlap signal averaging for one measurement with the remainder of the processing for the previous measurement in real time using multitasking software. Thus after the first measurement in a sequence, succeeding measurements are signal averaged without incurring any time penalty. Currently, the XM21 averages eight interferograms for a signal-to-noise improvement of approximately 2.8. The interferometer operates at about five scans per second; this is approximately 1.5 s of data.

A-1.2 FAST FOURIER TRANSFORM (FFT)

The output signal of the sensor is an interferogram, the Fourier transform of the infrared spectrum it is sensing. This spectrum is traditionally recovered by performing an inverse Fourier transform. However, because the final output of an XM21 detector is not a spectrum and all of the information is in the interferogram, it should be possible to apply pattern recognition procedures directly on the interferogram in order to make the required decisions. This approach could eliminate the need for an FFT and greatly speed the calculations required by the XM21. Considerable work in this area has been stimulated by the use of commercial Fourier spectrometer systems in analytical chemistry and the need for automatic spectral search software to identify samples from their measured spectra (Refs. 2 and 3). Unfortunately, the time

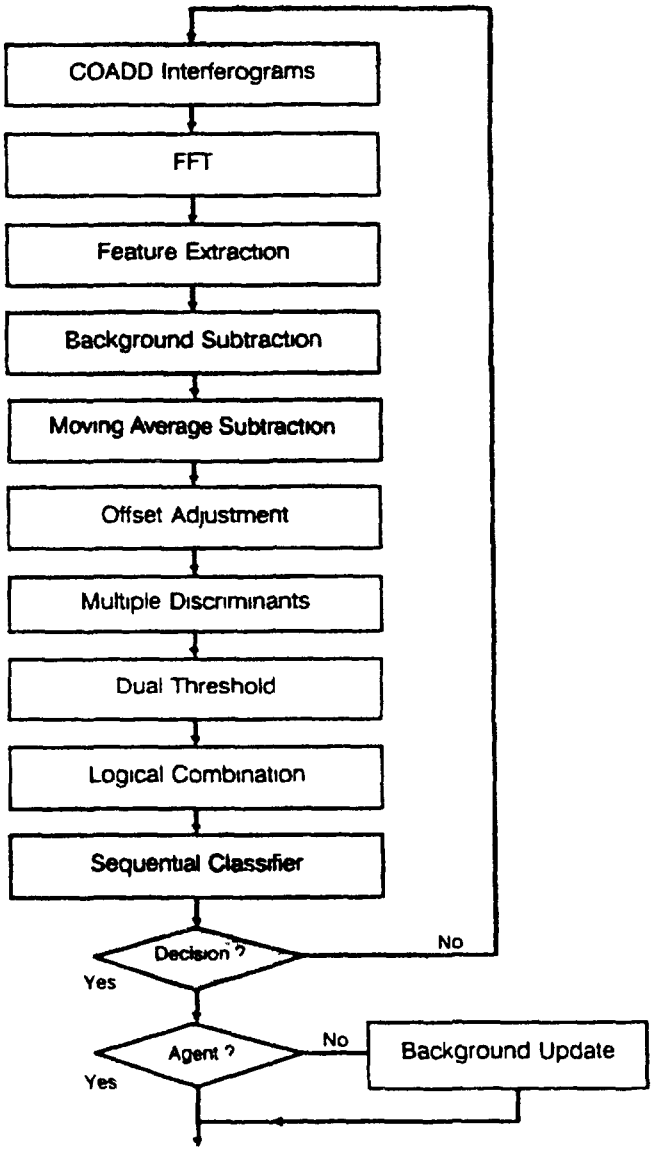


Figure A-1. XM21 Real-Time Signal Processing (Ref. 1)

domain techniques have all proven to be either less robust or no more computationally efficient than an FFT followed by frequency domain processing Thus the XM21 uses the traditional approach.

The algorithm for the FFT of real input data (Ref 4) was coded in assembly language for speed By using tabulated complex exponentials, the double precision (32-bit) integer 1024-point FFT requires about one second to calculate using the 8-MHz M68000 processor in the XM21 Prior to the FFT a triangular weighting function is applied to the interferogram to reduce the side lobes in the resulting instrument function.

A-1.3 PHASE CORRECTION AND FEATURE EXTRACTION

The output of the FFT is a 512-point complex shuffled spectrum The spectrum is unshuffled and phase corrected using the Mertz technique (Ref 5) If the complete spectrum were to be unshuffled and phase corrected, the resulting 512 ordered (in frequency) data points would extend from 0 wave numbers to 1970 89 wave numbers Since data outside the nominal 10-μm atmospheric spectral window of 833 to 1200 wave numbers do not contribute any remote sensing information, they need not be processed Thus a very efficient one-step combined, unshuffled, phase correction and feature extraction process was developed for the XM21 By using tabulated indices into the 512-point complex, shuffled spectrum, only the 98 data frequencies between 833 and 1200 wave numbers are phase corrected and stored in a 98-point real integer array for subsequent processing

A-1.4 AVERAGE BACKGROUND SUBTRACTION

As indicated in par A-1 3, the signal of interest is a small fraction of the total observed signal The pattern recognition process is greatly facilitated if the signal can be refined so that the signal of interest is a higher percentage of the total signal Toward this end, the average background spectrum for the current azimuth position is subtracted from the scene spectrum This process rejects most of the unwanted signal The method used to determine the average background spectrum for each azimuth position is discussed in par A-1 11

A-1.5 MOVING AVERAGE SUBTRACTION

The residual from background subtraction is not necessarily a pure target spectrum Other effects, such as slight changes in the background temperature or composition, can leave a broadband signal in the difference spectrum Because the agent features are well-defined spectral bands the difference spectrum can be further purified with a high-pass filter This filter rejects all broadband components of the difference spectrum and passes only the relatively narrow band features characteristic of agents Although there are a number of more sophisticated ways to implement this process, a simple moving average subtraction was chosen as being easy to implement, relatively efficient to compute, and adequate in performance The combined effects of background subtraction and moving average subtraction have proven very effective in purifying the input so that the pattern recognition process reliably separates agents from nonagents

A-1.6 OFFSET ADJUSTMENT

The last step prior to the actual pattern recognition process is a signal offset adjustment by which the maximum value in the spectrum is subtracted from each point in the spectrum This adjustment allows the use of zero thresholds during the linear discrimination process without increasing the dimensionality of the input spectrum vector See the discussion on algorithm training in par A-2 for more information

A-1.7 MULTIPLE LINEAR DISCRIMINANTS

Pattern recognition is achieved through the use of a series of linear discriminants Each discriminant vector is a set of coefficients equal in length to the spectrum vector There is a separate discriminant stored in the read-only memory (ROM) of the XM21 for each agent or simulant to be detected The dot product of the input spectrum with each coefficient set is calculated and compared to a threshold established to form a set of preliminary agent or nonagent decisions

The coefficients in the ROM of the XM21 are the key element of its ability to discriminate agents from nonagents They are calculated off-line as described in par A-2

A-1.8 DUAL THRESHOLD

As indicated previously, the agent spectral features may appear in either absorption or emission. Because the discriminant coefficients are trained for absorption, the emission case will not be detected It is difficult to tell which case is present in a given unknown spectrum One case may be effectively converted to the other, however, by negating the moving average subtracted spectrum prior to the offset adjustment It would be possible to process each spectrum both ways and be assured that one way was the absorption case This result may also be achieved with a considerable savings in computation by adding a second data dependent threshold, as shown in Table A-1

Combining the dot product responses R_1 and R_2 as defined in Table A-1 results in a quantity that is more efficient to evaluate than R_2 This combination yields

$$R_1 + R_2 = [\min(S) - \max(S)] \cdot W \quad \text{(A-1)}$$

TABLE A-1. DUAL THRESHOLD JUSTIFICATION (Ref. 1)

	UNFLIPPED	FLIPPED
Spectrum	S	–S
Offset Adjustment	S – max(S)	–S + min(S)
Dot Product	R_1 = W[S – max (S)]	R_2 = W[–S + min(S)]
Agent Detection Threshold	$R_1 > 0$	$R_2 > 0$ or $R_1 + R_2 > R_1$

where

S = spectrum vector
W = discriminant vector
R_1 = unflipped dot product response
R_2 = flipped dot product response

and min (S) and max (S) represent the minimum and maximum values in the test spectrum, respectively Because the sum of the W coefficients is a constant, it can be computed once at the start of a run and saved Thus for each discriminant only R_1 is computed If it is greater than zero or less than $R_1 + R_2$, then that discriminant is said to have made an agent decision

A-1.9 LOGICAL COMBINATION OF MULTIPLE LINEAR DISCRIMINANTS

The XM21 must signal a warning or give an alarm of any agent for which it is programmed. Thus the decisions from each of the discriminants are all combined by the use of "or" statements to form a single scan decision

A-1.10 SEQUENTIAL CLASSIFIER

To further minimize false alarms, the single scan decisions are not used directly to make alarm or no-alarm decisions Instead, the single scan decisions are fed into a sequential classifier Wald (Ref 6) presents the theory and design methodology for sequential classifiers Fig A-2 shows the one implemented for the XM21 Whenever a plot of the agent decisions versus the total number of decisions touches a boundary, as shown in Fig A-2, the sequential classifier makes a decision If the plot remains within the no-decision central area, a decision is deferred pending more data Note that if the first decision is no agent, the sequential classifier immediately decides no agent The fastest agent decision is reached with three initial single scan agent decisions In no case will the sequential classifier require more than nine single scan decisions

When the sequential classifer reaches a decision, all counts are set to zero in preparation for the next decision.

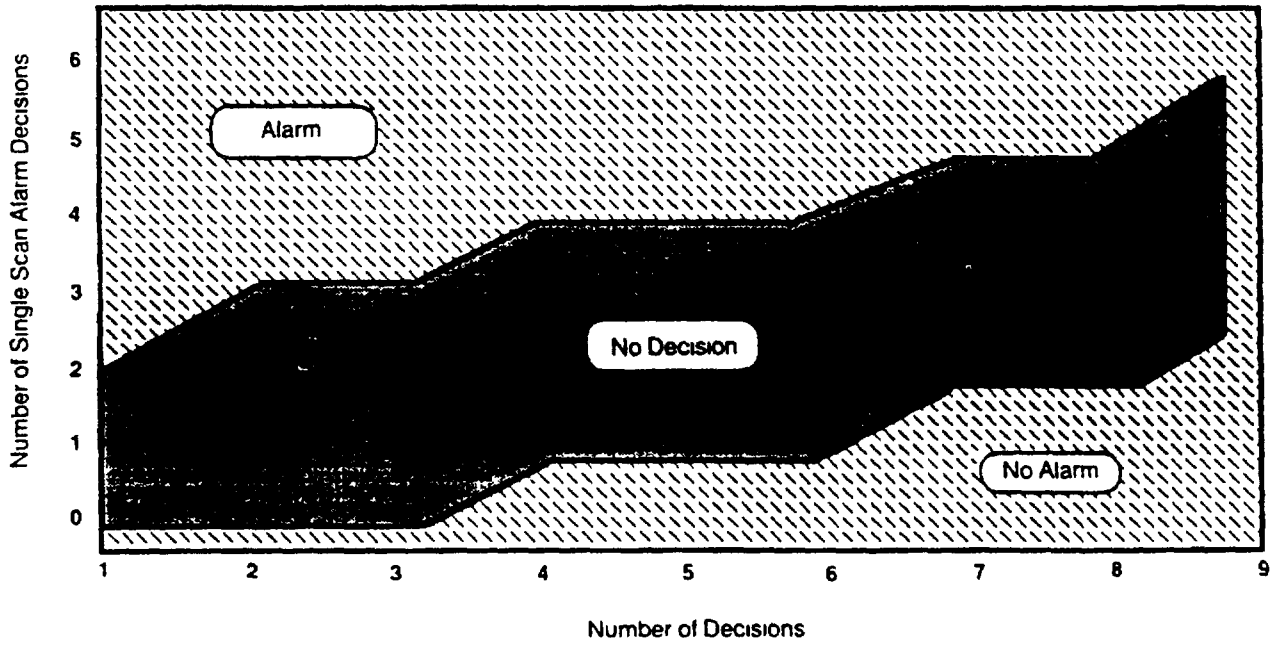


Figure A-2. Sequential Classifier Decision Space (Ref. 1)

A-1.11 AVERAGE BACKGROUND UPDATE

If no agent decision is reached by the sequential classifier, the original scene spectrum prior to background subtraction is averaged into the background spectrum for the current azimuth position A recursive exponential averaging technique used to approximate a five-minute time constant is that the updated average background is equal to the previous average background multiplied by f plus the original scene spectrum multiplied by one minus f, where f is a negative power of 2, so that the process can be implemented with shifts instead of multiplications

If an agent decision is reached by the sequential classifier, the background spectrum for the current azimuth position is not updated

A-2 XM21 ALGORITHM TRAINING

A-2.1 APPROACH

The approach used in XM21 algorithm training is to collect sensor data that are representative of the nonagent class in one set and sensor data representative of an agent class in another set These two data sets are then used in an automated linear discriminant training procedure to develop the coefficients for that agent The procedure is repeated for each agent discriminant to be included in the XM21

XM21 algorithm training is based on the large data base of recorded background measurements accumulated over the six years during XM21 field tests. Data from a variety of background types have been collected under all weather conditions, times of year, and times of day for several locations across the United States For most of these, data containing various battlefield interferents, such as signal and screening smokes, dusts, explosives, and vehicle exhausts, have also been recorded Selected data representative of all measurement types have been assembled into a standardized nonagent training set

It is not possible to build an agent class training set from field data because open-air field testing of chemical agents is not conducted During the early stages of the XM21 program, agent simulant coefficients were in fact trained with actual field data since field testing with non-lethal chemical simulants having spectral features similar to those of the agents is practical

Currently, the XM21 radiometric scene simulation computer model is used to introduce the effects of an agent, or agent simulant, cloud into existing measured background spectra and thus produce an agent training set This scene simulation model has also been used to simulate agent simulant training data The simulation has been validated in that the agent simulant coefficients trained from the simulated data have proven as effective in field tests and off-line algorithm evaluation studies as those trained using field data

A-2.2 IMPLEMENTATION

The automated XM21 training process is shown in Fig A-3 After the agent training spectra are simulated, all spectra are processed with essentially the same pre-processing as that used in real time in the XM21 First, the background spectrum is subtracted and then the moving average is subtracted All target spectra are then contrast corrected if necessary to produce the absorption case Therefore, if the peaks of the spectral bands point up, the spectrum is flipped, i e , multiplied by -1 The decision as to whether each target spectrum must be flipped or not is determined by visual inspection of the data and encoded into the data base This procedure assures that the algorithm training will not be confused by the natural occur-

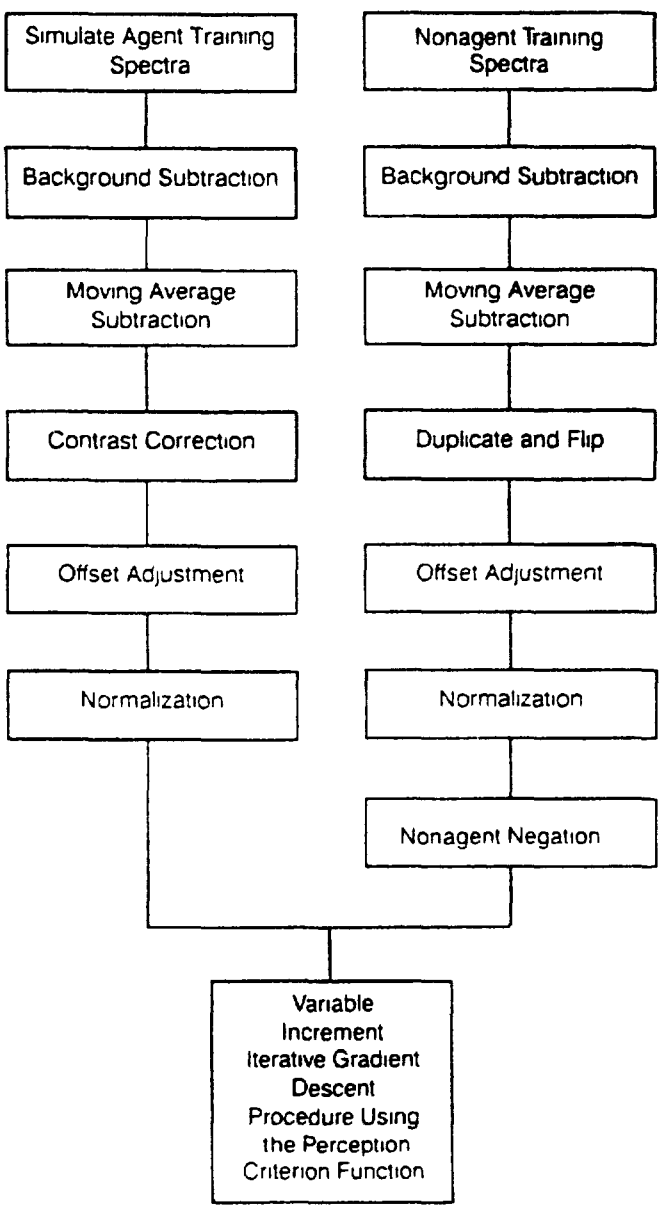


Figure A-3. Automated XM21 Training (Ref. 1)

rence of both absorption and emission agent data Because both absorption and emission nonagent data must be discriminated against, however, each nonagent spectrum is duplicated and flipped to generate both cases

Next, each spectrum is offset adjusted as described previously This operation transforms the data and enables a hyperplane through the origin of the *n*-dimensional spectrum space to separate the agent and nonagent classes Following this separation, each spectrum is normalized to a unit area so that each one will have comparable weight in the training process to come

The last step prior to the actual determination of the discriminant is to negate all of the nonagent spectra This step, as suggested by Duda (Ref 7), automatically self-labels the two classes to be separated with the linear classifier A discriminant vector **W** is sought so that its dot product with any spectrum vector **S** is positive if **S** is in the agent class and negative if **S** is in the nonagent class. The nonagent training spectra have all been negated, therefore, the problem is reduced to finding a **W** that produces a positive dot product for all training spectra

The actual training process, which finds a **W** vector that discriminates agents from nonagents, is a variably incremental, iterative, gradient descent procedure using the perception criterion function Duda (Ref 7) presents the theory of this procedure, and Fig A-4 shows a somewhat simplified diagram of how this procedure has been implemented for XM21 algorithm training This iterative approach has proven very practical for XM21 training, which requires a large number of training spectra, over

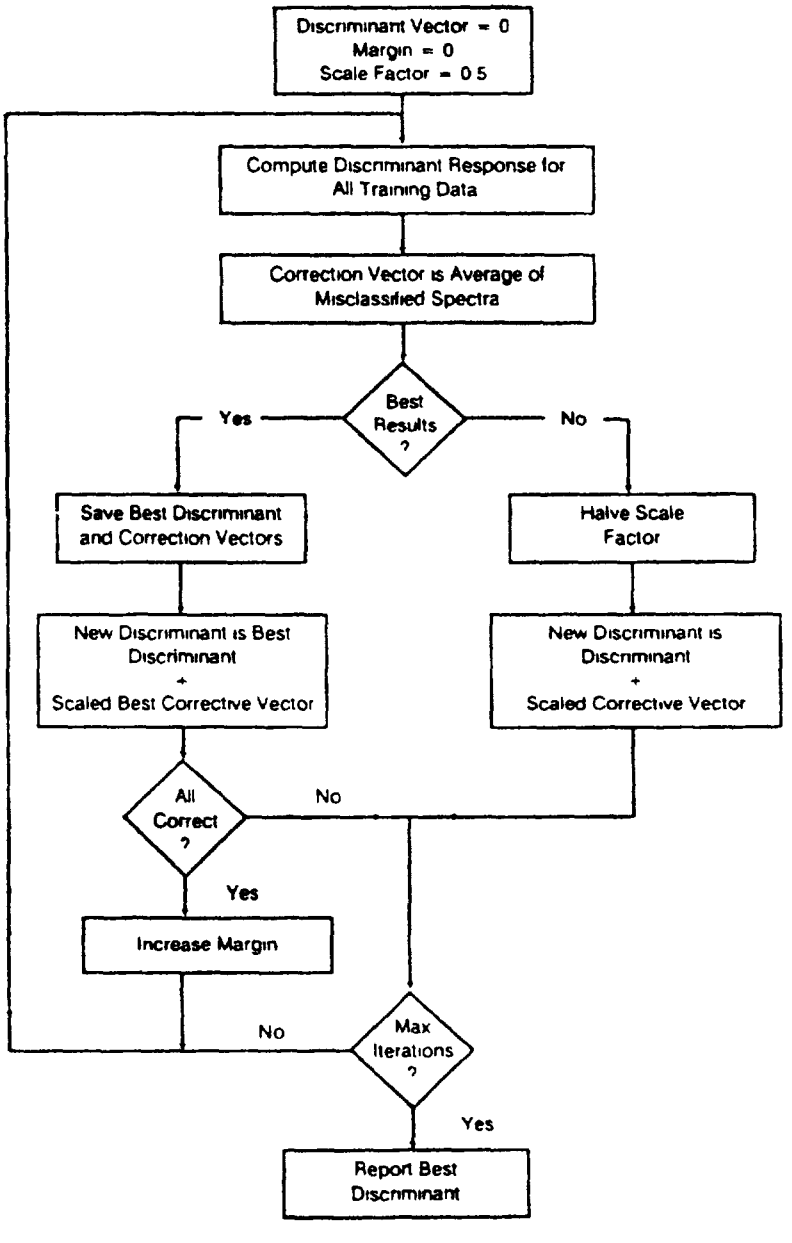


Figure A-4. Simplified Variably Incremental, Alternative Gradient Descent Procedure

2000, and a high vector dimensionality, 98

Starting with an initial guess of a null W vector, the response, i.e , dot product, with each training spectrum is computed and a correction vector consisting of the average misclassified spectrum is constructed If this iteration is the best so far, i e , has the fewest misclassified spectra or is equal to the fewest misclassified spectra and has a better worst-case response, the next trial discriminant is formed by adding a scaled down correction vector to the old discriminant If this iteration is not the best, the scale factor is halved and the new discriminant is formed by adding a scaled down best previous correction vector to the best previous discriminant If the training data prove to be separable, i e , no misclassifications, the process is repeated, this time a constant, or margin, is subtracted from each calculated response If the training data are still separable, the margin is increased and the process is repeated until separation is no longer possible The use of a margin forces the decision surface toward the center of the hyperspace gap between the agent and nonagent classes and thus reduces the probability of misclassifying a spectrum during real-time operation of the XM21

A-2.3 EVALUATION

Due to experimental difficulties, it was not possible to evaluate the performance of the XM21 algorithms completely with field testing, and there is the previously mentioned problem of open-air testing with chemical agents Although open-air testing using simulants is possible, accurate independent ground truth information is difficult, if not impossible, to obtain and the actual agent coefficients are not tested To overcome these difficulties a multifaceted approach to algorithm performance evaluation is used

A large standard data set (SDS) of well-characterized nonagent field measurement data and agent data simulated on measured background spectra has been assembled The SDS is totally independent of the algorithm training data and contains a wide variety of background types, weather conditions, seasonal variations and interferents The first step in algorithm evaluation is to process the SDS The results provide an objective, repeatable standard of comparision Actual field testing also plays an important role Extensive field testing against various backgrounds and interferents can and does directly test the susceptibility of the agent coefficients to false alarms In addition, agent simulant coefficients developed with the same methodology as the agent coefficients are challenged under realistic field test conditions to verify the basic detection capability of the XM21 Finally, the XM21 is tested against actual agents and simulants in controlled chamber tests, which prevent any chemical agent from being released into the atmosphere These tests provide a logical link between agent and simulant test results

The results of the ongoing performance evaluation effort have been very positive The XM21 has met or exceeded its detection sensitivity requirements, and thousands of hours of field testing including intensive exposure to battlefield interferents have also demonstrated a very low false alarm rate

REFERENCES

1 J R Bryson, S Moschetto, R I Weisberg, and W Thielhart, *XM21 Remote Sensing Chemical Agent Alarm Final Report*, CDRL Sequence No A014, by Honeywell, Inc , Clearwater, FL, for US Army Chemical Research, Development, and Engineering Center, Aberdeen Proving Ground, MD, 27 March 1987

2 T L Isenhour, G W Small, and G T Rasmussen, "An Infrared Search System Based on Direct Comparison of Interferograms", Applied Spectroscopy 33, 444-9 (1979)

3 L V Azarraga, R R Williams, and J A de Haseth, "Initial Results From an Interferogram-Based Search System", *Proceedings of 1981 International Conference on Fourier Transform Spectroscopy*, H Sakai, Ed., SPIE Volume 289, Bellingham, WA, 1981 232-4

4 G D Bergland, "A Fast Fourier Transform for Real Valued Series", Communications of the ACM 11, 703-10 (1968)

5 L Mertz, *Transformations in Optics*, John Wiley and Sons, Inc , New York, NY, 1965

6 A Wald, *Sequential Analysis*, John Wiley and Sons, Inc New York, NY, 1959

7 R Duda and P Hart, *Pattern Recognition and Scene Analysis*, John Wiley and Sons, Inc , New York, NY 1973

GLOSSARY

A

Absorption Spectroscopy A study of the energies and wavelengths of radiation absorbed by atoms and molecules of materials under various physical conditions (This technique can be used to identify agents and measure their concentration Lasers are used because their narrow range of wavelengths permits high-resolution measurements)

Accuracy The measure of a detector or sensor system to detect, identify, or quantify agents correctly Correspondingly, the extent to which a false positive or false negative can be tolerated

a False positive An alarm response from the detector or sensor system when no agent is present

b False negative No alarm response from the detector or sensor system when agent is present

Acetylcholine (ACh) A choline derivative found in many parts of the body that plays an important role in the transmission of an impulse from one nerve fiber to another

Acetylcholinesterase (AChE) An enzyme that hydrolyzes acetylcholine into acetic acid and choline and thereby prevents excess buildup of the neurotransmitter and regulates the transmission of nerve impulses

Acquisition The process consisting of planning, designing, producing and distributing a weapon system or equipment

Acquisition Plan (AP) Derived from the Acquisition Strategy (AS) Summarizes acquisition background and need, objectives, conditions, strategy and related functional planning (with emphasis on contractual aspects) Provides detailed planning for contracts and milestone charting

Acquisition Strategy (AS) Conceptual framework for conducting materiel acquisition that encompasses broad concepts and objectives which direct and control overall development, production, and deployment of a materiel system

Active System Artificially stimulates the agent cloud by employing its own radiation source The most common active radiation source for detection systems is the laser, which can produce coherent radiation in wavelengths ranging from the ultraviolet (UV) to the infrared (IR)

Aerosol. A liquid or solid composed of finely divided particles and suspended in a gaseous medium

Agent Threat warfare material referring to a chemical, biological, or toxin (CBT) substance.

Agent Quantification Determination of chemical or biological agent concentration or amount of concentration

AirLand Battle Approach to military operations that realizes the full potential of United States (US) forces It does this by extending the depth of the battlefield and integrating conventional, nuclear, chemical, and electronic means to describe the battlefield on which the enemy is attacked to the full depth of its formations The AirLand battle seeks, through early initiation of offensive action by air and land forces, to conclude the battle on US terms

Air Stability Condition of the atmosphere as affected by the gradient of air temperature in the vertical direction which determines the extent of mixing or exchange between air layers at different altitudes

Alarm Detector or sensor system response to presence of agent, an audible or visible electronic signal that provides warning of a chemical or biological attack

Algorithm. A mathematical rule or procedure used to solve a problem, a recursive mathematical procedure used in computers

Algorithmic Language A computer language presenting numerical procedures in standard form

Ambient A term meaning surrounding or encompassing, as in ambient air, ambient temperature, or ambient wind speed

Antibody One of a class of substances (proteins) produced by an animal in response to the introduction of an antigen

Antigen A substance that, when introduced into an animal body, stimulates the production of antibodies that react or unite with the substance introduced (antigen).

Army in the Field All types of military personnel and units used in, or intended for use in, a theater of operations

Array A group of detecting elements usually arranged in a straight line (a linear array) or in a two-dimensional matrix (an imaging array)

Assay. Analysis to determine the presence or absence of specific desired components

Atropine Alkaloid substance used to relieve symptoms of

nerve agent poisoning by inhibiting the action of acetylcholine

Automated Operation The capability of a system to operate and regulate itself, system may be fully automated or semiautomated (man in the loop) (Personnel are generally needed to set up, monitor, and replenish consumable supplies in the semiautomatic mode)

B

Backscattering The scattering of light in a direction opposite to the original one in which it was traveling

BG *Bacillus globigii* (now *bacillus globisporus*), a simulant for biological agents such as anthrax

Binary Chemical Ammunition A chemical projectile that uses two separate intermediary chemical compounds that, when loaded in the projectile and mixed enroute to the target, will react to a form nerve agent, e g , GB2 Binary chemical ammunition includes separately packaged canisters containing the binary chemical compounds, which are much less hazardous than chemical agents

Biological Agents Substances consisting of microorganisms with disease-producing properties or toxins intended for military use that through their properties produce lethal, incapacitating, or damaging effects to humans, livestock, or plant life

Biological Warfare (BW) Employment of biological agents to produce casualties in humans or animals and damage to plants or material, BW also includes defense against such employment

Biological Weapon An item of materiel that projects, disperses, or disseminates a biological agent, which includes arthropod vectors

Bliss Slope Change in relationship between a dose and a toxicological response when an animal is exposed to a toxic chemical agent

Blister Agents Chemical agents that affect the eyes, lungs, and skin In liquid, aerosol, or vapor form, these agents can burn or blister any part of the body they may contact either internally or externally They are effective in small quantities and produce delayed casualties

Blood Agents Chemical agents that are usually disseminated as vapors or gases and are taken into the body by breathing They affect the circulatory and respiratory systems by preventing the use by cells of the oxygen carried by the blood They can act very quickly and cause symptoms ranging from convulsions to coma and death

Breadboard An experimental device used to determine feasibility and to develop technical data, normally configured only for laboratory use to demonstrate the technical principles of immediate interest

Built-in Test (BIT) The capability of the detection or monitoring system to test itself for system failures and to indicate the subcomponents that require attention

C

Casualty Agent An agent capable of producing serious injury or death when used in field concentrations

Chemical Agent Chemical substance intended for use in military operations to kill, injure seriously, or incapacitate humans through its physiological effects Excluded from consideration are riot control agents, herbicides, smoke, and flame

Chemical Casualty A person who has been sufficiently affected by a chemical agent to be incapable of performing his duties or continuing his mission

Chemical Mine A mine containing a chemical agent designed to kill or disable personnel or to contaminate materiel or terrain

Chemical Operations Employment of chemical agents to kill or incapacitate humans or animals for a significant period of time and to deny or hinder the use of areas, facilities, or materiel Chemical operations also include defense against such employment

Chemical Projectile Bomb, grenade, rocket, or shell containing a chemical agent, riot control agent, incendiary agent or screening or signaling smoke

Chemical Weapon An item of materiel that disseminates a chemical agent

Chemiluminescence Emission of light from a chemical reaction at ordinary temperatures

Choking Agents Agents that are usually disseminated as gases and are taken into the body by inhalation They affect the respiratory system by damaging the nose, throat, and lungs. In extreme cases membranes swell, lungs become filled with liquid, and death results from lack of oxygen

Cholinesterase (ChE) An enzyme that is necessary to maintain orderly passage of nerve impulses from the nerve endings to the muscles of the body Chemicals that inhibit this enzyme are often referred to as "anticholinesterase" agents

Chromatography * The chemical method used to separate

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compounds dissolved in one phase (usually mobile) through its equilibration with a second phase (usually stationary) The mechanism of separation may involve partition, adsorption, permeation or exclusion, or ion exchange

Circular Intensity Differential Scattering (CIDS) A technique by which circularly polarized light is scattered A sample is illuminated by left and right circularly polarized light of equal intensity The difference between the intensity of the left and right circularly polarized light scattered divided by the sum of the intensities of left and right circularly polarized light scattered is the CIDS signal

Coherent Light Source* A light source capable of producing radiation with waves vibrating in phase The laser is an example of a coherent light source

Collective Protection A shelter with filtered air and positive internal pressure that provides a contamination-free working environment for selected personnel and allows relief from continuous wearing of mission-oriented protective posture (MOPP) gear

Colorimetric Reaction Color change brought about by reaction of an agent with a substrate solution and detected by a colorimeter For chemical detectors that use this principle, the colorimeter or photocell responds to the change in reflectance of a wetted spot on a paper tape through which air is passed

Combat Developer Command or agency that formulates doctrine, concepts, organization, materiel requirements, and objectives, represents the user community in the materiel acquisition process

Communication Transmission of a signal, method of interface with the alarm or other detection and monitoring systems, and type of format of signal

Compatibility The capability of a system to be operated, maintained, and resupplied by persons wearing the full nuclear, biological, and chemical (NBC) protective ensemble Also the capability of a given material to exist unchanged under certain conditions of temperature and moisture when in the presence of some other material

Component. The individual elements of equipment that comprise a module, e g , the receiving module is comprised of a telescope and a detector, each of which is termed a component

Concentration The quantity of a chemical or biological agent present in a unit volume of air Concentrations of airborne chemical agents are usually expressed in milligrams per cubic meter (mg/m^3)

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Consumables All supply items needed to keep the detector or sensor system fully operational over a specific period of time, i.e , mission duration. The specific identity of the items is "consumed" during system operation, e.g , fuel, paper tape, or chemical reagents used to recharge a system

Contamination The deposit and/or absorption of radioactive material or of biological or chemical agents on and near structures, specific areas, personnel, or objects Contamination density for liquid chemical agents is usually expressed in mg/m^2, kg/km^2, or pounds per hectare

Contamination Avoidance Individual and/or unit active or passive measures taken to avoid or minimize NBC attacks and reduce the effects of NBC hazards Passive contamination avoidance measures are concealment, dispersion, deception, and use of cover Active contamination avoidance measures are contamination control; detection, identification, and marking of contaminated areas, issuance of contamination warnings, and relocation or rerouting to an uncontaminated area

Cost Unit cost per system for production type runs

Cyanogen Chloride (CK) A nonpersistent blood agent

D

Data Transmission The transmission of data or information acquired directly from the detector or sensor system to the appropriate commanders and/or decision makers

Decontaminability The capability of materiel to be rapidly decontaminated to reduce the residual hazard to a negligible risk level for unprotected persons who operate, maintain and resupply the materiel

Decontamination The process of making any person, object, or area safe by absorbing, destroying, neutralizing, making harmless or removing chemical or biological agents or by removing radioactive material around or clinging to the person, object, or area

Defensive Measures Measures intended to enable troops to survive and operate in an NBC environment They include detection, protection, decontamination, and medical prophylaxes and antidotes

Deoxyribonucleic Acid (DNA) A type of nucleic acid occurring in the nuclei of plant and animal cells, contains phosphoric acid, D-2-deoxyribose, adenine guanine, cytosine, and thymine

Detection The determination of the presence or absence of a chemical or biological agent at a specific point in time

Detector Crayon Chalklike crayon composed of material that changes color on contact with a liquid blister agent or concentrated blister agent vapors

Detector Paper Paper treated on one side with a chemical compound that turns dark blue, yellow, or red when in contact with V-agent, G-agent, or H, respectively, in liquid form

Detector or Sensor System A device or instrument, which may consist of more than one component, used to accomplish agent detection, identification, or quantification

Detoxification Level The concentration or level of agent that can be counteracted or destroyed by the human body itself within a short period of time without harmful effects

Detoxification Rate. The rate at which the body is able to counteract the effects of a chemical agent This is an important factor in determining the hazard of repeated exposure to low concentrations of chemical agents Some chemical agents are not detoxified at any detectable rate by the human body Sarin (GB) is cumulative to a large degree

Development Test (DT) The engineering test that provides data on safety, the achievability of critical system technical characteristics, refinement and ruggedization of hardware configurations, and determination of technical risks. This testing is performed on components, subsystems, materiel improvements, nondevelopmental items (NDI), hardware-software integration, and related software DT includes the testing of compatibility and interoperability with existing or planned equipment and systems and the system effects caused by natural and induced environmental conditions during the development phases of the materiel acquisition process

Differential Absorption The wavelengths of light absorbed by materials and the relative intensities at which different wavelengths are absorbed This technique can be used to identify materials and measure their abundances Lasers are used because their narrow range of wavelengths permits high-resolution measurements

Discrimination The capability of a detector to distinguish between chemical, biological, and toxin agents or between the classes of an agent, e.g , nerve, blister, blood, vomiting, or choking chemical agent

Discrimination * In electro-optic terms, the degree to which a vision system is capable of sensing differences in light intensity between two regions

Display. Presentation of information in a form readily understandable by the user

Distilled Mustard (HD) A persistent blister agent whose chemical name is bis-(2-chloroethyl)sulfide, injures the eyes and lungs and blisters the skin upon contact

Dosage A measure of the amount of chemical agent in a given volume of air or on a given area of land to which troops are exposed for a period of time

Dose The amount of agent taken into or absorbed by the body A chemical dose is measured in milligrams, whereas a biological dose is measured in number of organisms

E

E. Coli *Escherichia coli* is a gram negative, facultatively anaerobic bacillus that usually causes transient stomach or intestinal disorders It is a biological agent simulant

Electrochemical The interaction or interconversion of electric and chemical phenomena in a cell, a chemical reaction that results in development of a potential in a cell or alters the conductivity of the solution in the cell and thus causes a change in potential

Electromagnetic Radiation * Radiation emitted from vibrating charged particles Electromagnetic radiation is a combination of oscillating electric and magnetic fields that propagates through otherwise empty space with the velocity of light This constant velocity equals the frequency multiplied by the wavelength, hence the frequency and wavelength are inversely proportional to each other The spectrum of electromagnetic radiation is continuous over all frequencies

Electro-Optical Detector * A device that detects radiation by utilizing influence of light in forming an electrical signal It may be a phototube, a photoconductive, photovoltaic, or photojunction cell, a phototransistor, or a thermal detector, such as a thermocouple or bolometer

Electromagnetic Spectrum The range of frequencies of electromagnetic radiation from zero to infinity The spectrum is divided into 26 alphabetically designated bands and extends from gamma rays through visible light, infrared, and radio waves

Embedded Computer Resources Computer resources integral to or required in direct support of Army materiel systems, included are resources required from a design, procurement, and operations viewpoint when separate selection, acquisition, or management is not feasible

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Environmental Extremes The range of environmental conditions and temperatures in which the detector/sensor system can operate

Enzyme A protein produced by a living organism, which catalyzes or accelerates one or more chemical reactions Usually enzymes are easily destroyed or denatured by changes in pH, temperature, and other environmental factors The human body has many enzyme systems cholinesterase is one

Equipment A general term including apparatus, appliances, devices, wiring, fixtures, fittings, material, etc

Esterase One of a group of enzymes that hydrolyze esters

F

False Alarm An indication (alarm) when agent is not present (false positive) *See also* Accuracy

Failure Mode, Effects, and Criticality Analysis (FMECA) Narrative description of probable effects of failure for each failure mode Criticality of the failure is included, e g , completely inoperable in some modes or operable at a degraded level of performance

Field of View (FOV) The maximum angle of view that can be seen through an optical instrument

Fixed Site Installation (FSI) Critical theater command facilities and/or installations These FSIs include air bases, depot storage areas, ammunition supply points, maintenance facilities, signal sites, and some medical installations that are usually located far to the rear of the battlefield

Forward Line of Own Troops (FLOT) A line that indicates the most forward positions of friendly forces in any kind of military operation at a specific time (Reconnaissance elements may operate forward of the FLOT)

Fluorometric The use of a fluorometer to detect and measure fluorescence

Fluorescence Emission of radiation (light) by a substance that has absorbed radiation from another source

Fluorescence Microscopy Microscopy in which microorganisms are stained with a fluorescent dye and observed by illumination with ultraviolet light

Fluorescence Spectroscopy * The spectroscopic study of radiation emitted by the process of fluorescence (The intensity and wavelengths of the emitted light can be used to identify the material and its concentration)

Fourier Transform * The conversion of information from the frequency domain to the spatial domain and vice versa Consists of any of the various methods of decomposing a signal into a set of coefficients or orthogonal waveforms (trigonometric functions). (A laser system that employs a Fourier transform interferometer is classified as a passive infrared system)

Frequency * With reference to electromagnetic radiation, the number of crests or waves that pass a fixed point in a given unit of time in light or other wave motion

Frequency Agile The ability to transfer radiation wavelengths from one frequency band to another *See also* Tunable Laser

G

Gain * Also known as amplification The increase in a signal that is transmitted from one point to another through an amplifier A material that exhibits gain rather than absorption at certain frequencies for a signal passing through it is known as an active medium

Gas Chromatograph The process of converting a liquid or vapor into a gas usually by applying heat and using the chromatograph, e g , ion exchange, to identify the materials

Gaussian Distribution A statistical normal distribution that can be plotted as a bell-shaped curve

G-Series Nerve Agent Nonpersistent nerve agent, e g , tabun (GA), sarin (GB), and soman (GD)

H

Hardness The capability of a system to withstand the damaging effects of NBC contamination and any decontamination procedures and chemicals required to decontaminate the item

Hazard The environment produced by a chemical and biological (CB) attack Hazard is measured in terms of concentration, deposition, or effects on humans

Hydrogen Cyanide (AC) A nonpersistent blood agent

I

Identification Determination of the specific identities of agents that are present, can be subdivided into two levels of identification as follows

a Definitive identification is the determination of the exact identity of a compound through the establishment of a group of unique characteristics

b Classification is the determination that the com-

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pound is a member of a class of substances without knowledge of the exact identity of the compound

Impermeable Protective Clothing Clothing made of material that prevents passage of toxic chemical agents in any physical form

Incapacitating Agent An agent that produces temporary physiological and/or mental effects that will render individuals incapable of concerted effort in the performance of their assigned duties.

Incapacitation, 5% (ICt_5) The agent concentration or level that prevents, through disablement or serious degradation of the abilities of 5% of all exposed and unprotected troops from performing their mission

Individual Protection That protection provided to the individual soldier in an NBC environment by protective clothing and/or personal equipment, such as protective masks

Infection Invasion of body tissues by microorganisms, with their subsequent growth and reproduction, usually spoken of in relation to the disease or injury that is caused

Infectious, 5% Concentration of biological agent that will infect 5% of all unprotected troops exposed to the agent

Infrared (IR) Thermal electromagnetic radiation lying outside the visible spectrum at the red end with wavelengths longer than those of visible light

Initial Operational Capability The first attainment of the capability to employ effectively a weapon, item of equipment, or system of approved specific characteristics, which is manned or operated by an adequately trained, equipped, and supported military unit or force

Integrated Battlefield A combat zone in which either or both combatants have used, are using, or have the capability to use conventional, nuclear, chemical, biological, or electronic weapons singly or in any combination to achieve military objectives

Integrated Logistic Support (ILS) Composite of elements necessary to assure effective and economical support of a system or equipment at all levels of maintenance for its programmed life cycle ILS is a unified and iterative approach to the management and technical activities needed to

a Influence operational and materiel requirements and design specifications

b Define the support requirements best related to materiel system design and to each other

c Develop and acquire the required support.

d Provide required operational phase support at the lowest cost

e Seek readiness and life cycle cost improvements in the materiel and support systems during the operational phase

f Repeatedly examine manpower and logistics requirements throughout the service life of the system

Integrated Logistic Support Plan (ILSP) Provides a composite of all support considerations necessary to assure the effective and economical support of a system for its programmed life cycle and functions as the source document for summary and consolidated information required in other documents of the program management documentation

Interferent Material in the environment that obstructs agent detection or provides input to detectors that is similar to agent input, input may cause false positive responses by the detector

Interferometer A device that divides a single beam of light into two (or sometimes more) components and then recombines them to produce interference In general, the path lengths light travels along the different arms will differ, the difference in distance is proportional to the wavelength of the light times the number of interference fringes Typically, interferometers are used for precise measurements of distance

Interferometry* The study and use of interference phenomena based on the wave properties of light

Ion* An atom that has gained or lost one or more electrons and as a result carries a negative or positive charge

Ion Laser* A laser in which the transition involved in stimulated emission of radiation takes place between two levels of an ion

Ionization Potential* For a particular kind of atom, the amount of energy required to remove an electron from the atom to infinite distance The ionization potential is usually expressed in volts

Inversion. *See* Temperature Gradient

L

Lapse *See* Temperature Gradient

Laser An acronym for "light amplification by the stimulated emission of radiation" applied to a wide range of devices that produce light by that principle Compared to other light sources, laser light covers a narrow range of wavelengths, tends to be coherent, and is emitted in a directional beam

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Laserhead * A laser tube packaged in a housing ready for use, generally requires an external source of the voltage needed to drive the laser

Laser-Induced Fluorescence Spectroscopy * A diagnostic technique in which gas is illuminated with a high-power, monochromatic light source and the reemitted radiation is observed Because the higher energy levels are sparsely populated, virtually all reemitted radiation is due to molecules that were originally in the lower energy levels Therefore, lower level number density can be related to the emission signal

Laser Tube. A tube of glass (or other material) filled with laser gas that often contains integral optics, requires external packaging and a voltage supply.

Lethal Chemical Agent. Chemical agent that may be used effectively in field concentrations to produce death *See also* Toxic Chemical Agent.

Lewisite A persistent blister agent classified as an arsenical

LIDAR An acronym for "light detection and ranging", analogous to radar. Like radar, LIDAR systems can be used to measure distance by measuring the round-trip time of a light pulse Many LIDAR systems also observe the wavelengths of light returned and use the spectroscopic information collected to detect air pollutants and other materials. The term is often interchangeable with laser radar, or LADAR.

Life Cycle Cost (LCC). Approach to costing that considers all costs incurred during the projected life of the system, subsystem, or component being evaluated, includes cost to develop, procure, operate, and maintain and support the system over its useful life

Line of Sight (LOS) The line of vision, the optical axis of a telescope or other observation system, the straight line connecting the object and the objective lens of the viewing device.

Liquid Contamination. The amount of liquid agent received by a person on his skin is usually expressed as median lethal dose (LD_{50}) in milligrams of contaminant per kilogram of body weight (mg/kg)

Logistic Control Code (LCC) When an item is approved for production and use, it is assigned an LCC. An LCC of A designates items that are acceptable for the intended mission and will receive full maintenance support. An LCC of B is applicable to items that are used in lieu of LCC-A items or that can no longer be procured but must still be supported

Logistic Support Analysis (LSA) Analytical technique used by ILS management to provide a continuous dialogue between designer and logistician; provides a system to identify, define, analyze, quantify, and process logistic support requirements for the materiel acquisition programs.

Logistic Supportability The degree to which planned logistics support (including test, measurement and diagnostic equipment, spares and repair parts, technical data, support facilities, transportation requirements, training and manpower) allows meeting system availability and wartime usage requirements

M

Maintainability The capability to repair and keep the detector or sensor system operating properly *See also* Reliability, Availability, and Maintainability

Manpower and Personnel Integration (MANPRINT) The entire process of integrating the full range of human factors engineering, manpower, personnel, training, health hazard assessment, safety assessment, and system safety throughout the materiel development and acquisition process

Map To plot the location of an agent cloud, aerosol, large droplets (toxic rain), or ground contamination as a function of area and time.

*Mass Spectrometer.** A mass spectroscope that incorporates an electric detector to record the relative quantity of ionic species that have been differentiated by their mass/charge ratios.

*Mass Spectrometry.** An instrumental technique used to identify the makeup of a sample through analysis of its ionic composition and distribution as derived from a mass spectrometer

*Mass Spectroscope.** An instrument designed to separate molecular and atomic masses by applying a combination of electric and magnetic fields to deflect ions passing in a beam through the instrument.

Materiel Acquisition Life Cycle. A period that includes the development, production, fielding, maintenance, and disposal of materiel.

Materiel Developer (MATDEV). Command or agency responsible for research, development, and production of a system in response to approved requirements

Materiel Requirements Document. Document that states concisely the minimum essential operational, technical, logistical, and cost information necessary to initiate development or procurement of a materiel system.

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Median Incapacitating Dosage. The incapacitating dosage of an agent is generally expressed as the median incapacitating dosage, i.e., the amount of inhaled vapor or liquid agent on the skin that is sufficient to disable 50% of exposed, unprotected personnel For inhalation effect the median incapacitating dosage is expressed as the ICt_{50} and for liquid effect as the ID_{50}

Median Lethal Dosage. The median lethal dosage of an agent employed for inhalation as a vapor or aerosol is generally expressed as the LCt_{50}. The LCt_{50} of a chemical agent is the dosage, i.e., vapor concentration of the agent multiplied by the time of exposure, that is lethal to 50% of exposed, unprotected personnel It varies with the degree of protection furnished by masks and clothing worn by personnel. The unit used to express the LCt_{50} is milligram-minutes per cubic meter ($mg \cdot min/m^3$)

Median Lethal Dose. For liquid contamination the amount of liquid agent received by a person on his skin is usually expressed as median lethal dose LD_{50} in milligrams of contaminant per kilogram of body weight (mg/kg)

Meteorological. Any of a number of atmospheric conditions in an environment, generally limited to surface air

Mie Scattering.* Scattering exhibited by particles (including most pigments) approximately the same size as the wavelength of the radiation under consideration and with a refractive index significantly different from that of the surrounding medium

Miosis Prolonged or excessive contraction of the pupil of the eye, usually the first noticeable symptom in mammals of the effects of nerve agents

Mission Area Analysis (MAA). Assessment of ability of a force to perform within a particular battlefield or functional area. Designed to discover deficiencies in doctrine, organization, training, and materiel and to identify means of correcting these deficiencies Provides a basis for applying advanced technology to future Army operations.

Mission-Essential Materiel. Materiel that is authorized and available to combat, combat support, combat service support, and combat readiness training forces to accomplish their assigned missions.

Mission-Oriented Protective Posture (MOPP) A flexible system of chemical and biological protection for the individual that considers the mission, threat, work rate, and temperature.

Mobility. Refers to the capability of the detection and monitoring system to operate properly, i.e., to detect, identify, or quantify agent, when it is moving, e.g., in a vehicle

Modularity. A design criterion requiring that the equipment be made of replaceable modules and be expandable in design

Module. An assemblage of components comprising instrumentation that performs a separately identifiable function, e.g , the transmitter, receiver, and control and data acquisition equipment may be termed "modules"

Monitoring The continued or periodic act of seeking or determining whether a chemical agent or a biological agent is present

MOPP Gear Individual protective clothing and equipment used to enable troops to operate in an NBC environment MOPP gear includes the chemical overgarment, rubber gloves, chemical protective overboots, protective mask and hood, chemical detection paper, skin decontamination kit, and nerve agent antidote kit *See also* Mission-Oriented Protective Posture.

Mopp Level Degree of mission-oriented protective posture (MOPP) protective clothing and equipment required to be worn

a. MOPP Zero. Mask will be carried with load-bearing equipment; all other MOPP gear will be readily available to the individual.

b MOPP1 Overgarment will be worn, all other MOPP gear will be carried by the individual.

c MOPP2. Overgarment and overboots will be worn, all other MOPP gear will be carried by the individual

d MOPP3 Overgarment, overboots, mask, and hood will be worn; all other MOPP gear will be carried by the individual

e MOPP4. All MOPP gear (overgarment, overboots, mask with hood, and gloves) will be worn by the individual.

f. Mask Only Wearing of only the protective mask when individuals are protected from a transfer hazard or direct skin exposure to liquid or solid contamination.

N

NBC Attack. An attack during which nuclear, biological, and/or chemical (NBC) weapons or weapon systems are used individually or in conjunction with conventional weapons

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NBC Contamination. A term that includes both the individual and collective effects of residual radiological, biological, and chemical contamination. The elements of the acronym "NBC" are defined as follows

a Nuclear (N) Residual radiological contamination consisting of fallout, rainout, and neutron-induced gamma activity

b Biological (B) All the general classes of microorganisms and toxins that can be used as biological warfare agents These classes include bacteria, rickettsia, viruses, fungi, and microbial toxins

c Chemical (C) All known chemical warfare agents These include blood agents, such as AC, nerve agents, such as VX, GB, or thickened GD, and blister agents, such as HD.

NBC Contamination Survivability The capability of a system and its crew to withstand an NBC-contaminated environment, including decontamination, without losing the ability to accomplish the assigned mission

Negligible Risk Level The level of radiological, biological, or chemical contamination that will cause mild incapacitation among no more than 5% of the exposed, unprotected soldiers who must operate, maintain, or resupply a system during the normal mission profile of the system for not more than 12 continuous hours within 1 m of, on, or inside a contaminated surface of the item.

Nerve Agents. Chemical agents that directly affect the nervous system of humans and are highly toxic in both liquid and vapor forms These agents can be absorbed through the skin or inhaled and quickly act to cause casualties and death. Essentially, these agents cause an increase of the chemical acetylcholine in the body by their interference with the enzyme acetylcholinesterase (AChE) and thus affect the transmission of nerve impulses Nerve agents are organophosphorous compounds

Nitrogen Mustards. Persistent blister agents in which nitrogen is the central atom A group of related chemical compounds that may be considered derivatives of ammonia (NH_3) because the hydrogen atoms are replaced by various organic radicals.

Nondevelopmental Item (NDI). A generic term describing either a commercial product or an item that has been developed and used by another service, country, or Government agency

Nonpersistent Agent. A chemical agent that, when released, dissipates and/or loses its capability to cause casualties after passage of 10 to 15 min

Nucleic Acid One of a class of molecules composed of joined nucleotide complexes; the principal types are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)

O

Obsolete Item Item no longer acceptable for military use

Operational Availability (Ao). Percentage of mission time the detector or sensor system is actually in use Also a measure of the degree to which an item is in such a state of repair as to be immediately usable for a mission at an unknown (random) time

Operational and Organizational Plan (O&O Plan). Materiel requirements document that describes how a system will be integrated into the force structure, deployed, operated, and supported in peacetime and wartime *

Operational Characteristics The basic functions a system is required to perform in response to its stated mission

Operator. The soldier or person who will be using the detector or sensor system.

a Operator Input. The steps or specific tasks the operator must perform to place the detector/sensor system into operation

b. Operator Qualification. Any special skills or training the operator must receive in order to operate and use the detector/sensor system.

*Optical Waveguide (OWG).*** Any structure having the capability to guide the flow of radiant energy along a path parallel to its axis while simultaneously containing the energy within or adjacent to its surface.

Oxime A drug used in the therapy of nerve agent poisoning

P

Package The packaging and its contents of explosives or other dangerous articles, as presented for transportation.

Particlrome Detection of airborne biological agents based on light scattering of particulates.

Particulate Refers to the fact that biological organisms are small particles of matter. All known dissemination methods result in an airborne particle cloud, which

*This document is being replaced by the Mission Needs Statement (MNS) and the Operational Requirements Document (ORD) as part of a program by the Department of Defense to standardize requirements documents

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consists of clusters containing varying numbers of organisms.

Passive System. System that does not use an illuminator as a signal source Passive systems detect energy emitted by the target and background or reflected ambient illumination

Percutaneous Effect Toxic effects when the skin is exposed to agent vapor, aerosol, or liquid

Permeable Protective Clothing. Clothing (usually special issue clothing) that has been impregnated with certain chemicals and/or activated charcoal to protect against the vapors and fine spray of chemical agents by neutralization and/or adsorption

Persistent Agent. A chemical agent that remains in the environment for extended periods of time and retains its potency on the battlefield for hours up to weeks

Persistency Duration of effectiveness of a chemical agent that is dependent on the physical and chemical properties of the agent, weather, methods of dissemination, and conditions of terrain

Phosgene Oxime (CX) A blister agent that causes immediate pain as well as blisters to the skin.

Photoacoustic Spectroscopy (PAS).* A method used to obtain the optical absorption spectra of solids, semisolids, liquids and gases PAS is inherently insensitive to reflection or scattering from the sample, analyzes opaque samples, and can measure spectra below the sample surface.

Point Samplers. Detection and monitoring systems that require contact with the agent to achieve detection

Point Source *See* Single Point Source.

Polarization An (optical) condition in a ray of light during which vibrations occur in one plane

Power Measurement of the electrical energy required to make a detection and monitoring system fully operational

Preplanned Product Improvement (P^3I). Planned future evolutionary improvement to a system that is effected by design considerations during development or upgrade to accommodate future applications of projected technology.

Process Manipulation of data or information inputs with preestablished procedures or software in order to generate specific information to be used by designated users for planning or operational purposes

Producibility. The manufacturing methods and technology necessary to fabricate and assemble the detector or monitoring system.

Program Management Documents (PMD). A collection of documents depicting how a need or requirement is to be satisfied through the acquisition process The PMD contain all the necessary information for a particular program

Protective Clothing Specially constructed or chemically treated clothing used to protect individuals against percutaneous attack by a field concentration of toxic or normal chemical and/or biological agents for a time sufficient to complete a mission

Protective Mask. Individual protective equipment consisting of facepiece with integral filter elements or attached canister and carrier The mask protects the wearer against inhaling toxic chemical agents, screening smokes, biological agents, and radioactive dust particles

Q

Quantification. Determination of the concentration or amount of agent present. Full quantification provides numerical approximations of the amount of agent present, whereas semiquantitative measure indicates concentration ranges such as low, medium, or high

Quantify To measure the concentration and/or amount of agent present.

R

Raman Absorption * The absorption of part of the photon energy by a molecule through which there is a slight energy change and the energy balance continues

Raman Effect.* When light is transmitted through matter, part of the light is scattered in random directions A small part of the scattered light has frequencies apart from the frequency of the incident beam by quantities equal to vibration frequencies of the material scattering system. This small part is called Raman scattering. If the initial beam is sufficiently intense and monochromatic, a threshold can be reached beyond which light at the Raman frequencies is amplified, builds up strongly, and generally exhibits the characteristics of stimulated emission. This is called the stimulated or coherent Raman effect A device illustrating the stimulated Raman effect is sometimes called a Raman laser

Raman Spectroscopy The study of the Raman shift (scattering) in light, which is caused by molecules absorbing light and then reemitting the light after

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changing their vibrational quantum state. The result is a shift in wavelength, which is a characteristic of the molecule involved. Raman shifts are changes in photon energy that occur when molecules scatter photons and are caused by the transfer of vibrational energy to or from the molecule

Range The area of coverage required of the detector or monitoring system(s) to provide unit, i e , troop, squad, or platoon, warning and detection of chemical and/or biological agents.

Ranging. Measurement of distance by timing how long it takes a laser pulse to make a round-trip from the laser to a distant object or agent cloud

Rayleigh Scattering.* Scattering by particles very small compared to the wavelength of the radiation being considered. A feature of Rayleigh scattering is that the scattered flux is inversely proportional to the fourth power of the wavelength Thus in the visible region blue light is scattered more strongly by the molecules of the air than are longer wavelengths; this scattering accounts for the blue color of the sky

Real Time Immediate response (warning) upon detection of a hazardous concentration of an agent.

Real-Time Processing.* The capability of a vision system to interpret an image quickly enough to keep pace with most warning network operations.

Receiver. A device that detects an optical signal, converts it into an electronic form, then processes it further for use by electronic equipment From the standpoint of components, it can be viewed as a combination of detector and signal-processing electronics

Reconnaissance (RECON). As pertains to CB defense, RECON is the application of CB agent detection and monitoring systems to search for, detect, identify, quantify, track, and map agent contamination on the battlefield

Reliability The operational dependability of the detector and monitoring system expressed as a mean time between failures (MTBF). *See also* Reliability, Availability, and Maintainability.

Reliability, Availability, and Maintainability (RAM). Capability of ensuring that materiel systems are ready for use when needed, will perform their assigned functions, and can be operated and maintained within the scope of logistic concepts and policies

a. Reliability is the probability that an item will perform its intended function for a specific time under stated conditions.

b. Availability is a measure of the degree to which an item is in a working and committable state at the start of a mission.

c. Maintainability is a characteristic of design which provides that the item can be retained in or restored to a specified condition within a given time.

Remote Detector. An active and/or passive detector system that can detect the presence of agents some distance from the system *See also* Standoff Detector

Required Technical Characteristic. Quantitative system parameters approved by the user that are primary indicators of technical achievement of engineering thresholds. These might not be direct measures of, but should always relate to, the capability of a system to perform its required mission function and to be supported

Reset Time. The time required for the detector system to clear, flush, or readjust itself for repeated agent sampling, i.e., cycle time between samples

Response Time. The amount of time needed for the detector system to detect and process the raw information on the agent encountered and to respond by displaying in some form the required information (such as detection, identification, or quantification), which is to be used for operational and decision-making purposes.

Ribonucleic Acid (RNA). Nucleic acid occurring in cell cytoplasm and the nucleolus; contains phosphoric acid, D-ribose, adenine, guanine, cytosine, and uracil

Riot Control Agent A chemical that produces temporary irritating or disabling effects when in contact with the eyes or when inhaled. The effect usually disappears in minutes when personnel are no longer exposed, and exposed persons rarely require medical treatment. Riot control agents are normally used by governments for domestic law enforcement purposes and are classified as "tear agents" or "lachrymators"

Ruggedness The capability to withstand rough handling and the conditions likely to be encountered on the battlefield.

S

Schoenemann Reaction A test for G-series nerve agents using detector tickets, tubes, or spots impregnated with an enzyme and wetted with a substrate solution. When the wetted enzyme is exposed to the agent, the detector ticket, tube, or spot changes to a characteristic color, which indicates the presence of the agent. Various enzymes have been used for this test; the most recent of which is eel enzyme.

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Screening Smoke A chemical agent that, when burned, hydrolyzed, or atomized, produces an obscuring smoke, which is used to limit observation and reduce the effectiveness of aimed fire Screening smoke is not normally used for toxic effect against personnel

Search To seek CB agents by systematic movement of detection and monitoring systems through preset sectors on the battlefield

Sensitivity The concentration of agent that the detection or monitoring system will detect within its characteristic response time

Sensor The sensor is the overall device that detects, identifies, alarms, and maps the presence of NBC contamination, synonymous with detector, monitor, or system when used in this context

Service or Setup Time The time necessary to place the detector and/or sensor system into operation in the field

Significant Variances. Those differences between planned and actual performance that require further review, analysis, or action. Appropriate thresholds are established as to the magnitude of variances through variance analysis

Signal-to-Noise Ratio (SNR) The ratio of the power of a signal to the power of background noise; usually measured in decibels This is a common measure of the quality of analog electronics or transmission systems

Single Point Source Any single munition or device that produces an agent cloud from a fixed position on the ground

Size Refers to the physical dimensions of a system and its components including the volume occupied by the configuration of the system

Specificity Characteristic of being specific, especially catalyzing or participating in only one chemical reaction Also expressed as the capability of a detector to distinguish a particular agent from other agents, chemicals, or materials in a naturally occuring medium, e.g., ambient air, water, and food.

Spectra Optical frequency or frequencies, either emission or absorption, characteristic of special material

Spectrometer * A detector used to measure the distribution of radiation in a particular wavelength region

Spectrometry.* The study and measurement of spectra and their components.

Spectroscopic Analysis Analysis of a spectrum to determine characteristics of its source, such as the analysis of the optical spectrum of an incandescent body to determine its composition or motion.

Spectrum.* Generally, the visible portion of all electromagnetic radiation The apparent colors are red, orange, yellow, green, blue, and violet, and the corresponding wavelengths range from 750 to 400 nm

Spectrum Analyzer.* A scanning device used to tune through a given frequency range cyclically to determine the amplitude-frequency distribution of the signals present usually by displaying output on a chart or cathode-ray tube

Spore A resistant body formed by certain microorganisms, a resistant resting cell; a primitive unicellular reproductive body

Standard Item Adopted as suitable for use and authorized for inclusion in equipment authorization documents

Standoff Detector Active and/or passive detector systems that can detect the presence of agents some distance from the system *See also* Remote Detector

Substrate The substance acted upon by an enzyme.

Surface Acoustic Wave (SAW)* A sound wave that propagates along the surface of a solid. Also called a Rayleigh wave, it has both longitudinal and transverse (shear) components Such surface waves are used in hybrid electroacoustic devices to signal amplification and recognition, scan visual information, and to delay fast electrical signals

Survey Directed effort to determine the location and nature of the chemical agent in an area

Survivability The capability of a system to avoid or withstand man-made hostile environments without suffering abortive impairment of its capability to accomplish its designated mission

System The overall device that detects, identifies, alarms, and maps NBC contamination. Synonymous with sensor, monitor, or detector when used in this context

T

Tagged Antibodies. Antibodies marked with fluorescent dyes or radioactive isotopes to detect biological agents

Technical Data Package (TDP) That set of information that provides a technical description of an item adequate for the intended use of that data. This description completely defines the required design configuration and assures adequacy of item performance It consists of all applicable technical data,

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such as plans and drawings and associated lists, specifications, standards, models, performance requirements, quality assurance provisions, and packaging data, and may range from a single line in a contract to several hundreds or thousands of pages of documents

Temperature Gradient As applied to chemical operations, the change in air temperature with change in altitude It is normally expressed as the difference obtained by subtracting the air temperature 0.5 m above the ground surface from the air temperature 4 m above the ground surface Examples are

a. Inversion. Condition of maximum air stability in which the air in contact with the ground is cooler than that immediately above, there is no convection

b Neutral. Little or no change in temperature with increase in altitude; results in a moderately stable atmospheric condition

c Lapse Decrease in temperature with an increase in altitude, results in unstable atmospheric conditions

Test, Measurement, and Diagnostic Equipment (TMDE) System or device used to evaluate the operational condition of a system or equipment in order to identify or isolate an actual or potential malfunction

Thickened Soman (TGD) A thickened form of GD used to control drop size and distribution.

Threshold Effect Level The amount of radiological, biological, or chemical dosage that causes the first appearance of symptoms in exposed, unprotected personnel

Toxic Poisonous, pertaining to, due to, or of the nature of a poison

Toxic Chemical Agent A chemical, irrespective of physical state, that may be used effectively in field concentrations to produce injury or death Toxic chemical agents are classified according to their use as casualty agents

Toxicity The property possessed by a material that enables it to injure the physiological mechanism of an organism by chemical means; the maximum effect is death.

Toxins Nonliving, poisonous chemical substances produced by living organisms that, when inhaled, swallowed, or injected into humans or animals, will cause injury or death. Toxins can also be produced synthetically by genetic engineering and are classified as biological agents by the U.S

Track To follow the path of an incoming munition or chemical or biological agent, may provide data for mapping contaminated or threatened areas.

Training Device Item designed, developed, and procured solely to simulate or demonstrate the function of equipment or systems in order to meet training support requirements.

Transmitter A light source, e.g , laser, that is combined with electronic circuitry to operate the source A transmitter operates directly from the signal generated by other electronic equipment to produce the drive current needed for a laser

Tunable Laser A laser that can have its output wavelength changed by a tuning process

Type Classification Identifies the life cycle status of a materiel system after a production decision by assignment of designations, records status of a materiel system in relation to its overall life history as a guide to procurement, authorization, logistical support, asset, and readiness reporting

U

Ultraviolet (UV) Invisible rays of light that are beyond the violet end of the spectrum and are at the opposite end of the spectrum from the infrared, electromagnetic radiation wavelengths of less than 400 nm.

Unattended Operation The capability of a system to operate by itself without intervention by an operator

Unprotected Persons Persons not wearing any special NBC protective clothing or equipment

V

Vapor The gaseous form of a liquid chemical agent

Vector In biology, any organism that is the carrier of a disease-producing virus, such as one of the many insect hosts of microorganisms parasitic to man

Virulent Agents Agents that produce rapid, severe, and malignant results in victims

Virus An obligate intracellular parasitic microorganism smaller than bacteria; most can pass through filters that retain bacteria

Visible. Capability of an alarm always to be in full view of or readily seen by an operator

Visual Capability of an alarm or readout to be recognized by the operator by sight

Volatile. A readily vaporized liquid that evaporates at a relatively low ambient temperature.

Volatility. A measure of the capability of a chemical substance to go from the liquid or solid state directly to

the vapor state. Volatility is expressed as milligrams of vapor per cubic meter (mg/m^3) at a specific temperature and pressure

V-Series Nerve Agent. US persistent nerve agent, e.g., VX and VR-55.

W

Warhead That part of a missile, projectile, torpedo, rocket, or other munition containing either the payload, the nuclear or thermonuclear system, the high-explosive system, the chemical or biological agents, or the inert materials intended to inflict damage on the target.

Warning The timely dissemination of the information that a chemical or biological agent is present or anticipated in an area

Weapons of Mass Destruction. In arms control usage weapons that are capable of a high order of destruction and/or of being used to destroy large numbers of people These can be nuclear, biological, or chemical weapons but exclude the means of transporting or propelling the weapons if such means are a separable and divisible part of the weapons

Weathering. Natural process that gradually accomplishes decontamination by evaporating or decomposing the chemical agent

Weight The physical weight of the system or its discrete (stand alone) components if more than one discrete component is required.

Whetlerization Special treatment of activated charcoal by impregnating it with a mixture of metal salts to increase its adsorption of blood agents

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Review Activity
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Preparing activity.
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(Project 6665-A639)

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3. DOCUMENT TITLE
Chemical and Biological (CB) Agents Detection and Monitoring Systems

4 NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5 REASON FOR RECOMMENDATION

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