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NBC Protection Considerations for ECS Design

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature. More detailed information is typically classified and not available for publication.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE AC-9 Aircraft Environmental Systems Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

TABLE OF CONTENTS

1. SCOPE 3
2. REFERENCES 3
2.1 Applicable Documents 3
2.1.1 SAE Publications 3
2.1.2 U.S. Government Publications 3
2.2 Other Applicable References 4
2.3 Related Publications 5
2.4 Definitions 5
2.5 Abbreviations 7
3. THREAT 8
3.1 Types of Threat 9
3.2 Detail Threat 9
3.2.1 Nuclear Agents 9
3.2.2 Biological Agents 9
3.2.3 Chemical Agents 12
3.3 Aircrew Vulnerability 15
3.4 Avionics Vulnerability 16
3.5 Simplified Chemical Warfare (CW) Attack Scenario 16
4. DETECTION 18
4.1 Military Detection System Categories 18
4.1.1 Point Detectors 18
4.1.2 Stand-Off Detectors 18
4.2 Relationship to Industrial Applications 18
4.3 Applications to Military Aircraft 19
4.4 Aircraft ECS Applications 19
5. HARDENING 20
5.1 Airframe Hardening Requirements 20
5.2 Avionics 20
5.3 Fuel 21
6. DECONTAMINATION 21
7. SEALING 22
8. INGRESS AND EGRESS: 22
9. PROTECTION 23
9.1 Individual Protection 23
9.1.1 Heat Stress Relief 23
9.1.2 Respiratory System 26

9.2 Collective Protection: ... 27
9.2.1 "Dirty Cockpit" Approach ... 30
9.2.2 "Clean Cockpit" Approach ... 30
9.2.3 "Clean Cockpit and Clean Avionics Bays" Approach ... 30
9.2.4 Closed-Loop ECS ... 31
9.3 Hybrid Protection ... 31
10. NBC FILTRATION ... 32
10.1 Removal of NBC Agents ... 32
10.2 Means of Defining Filter Design Requirements ... 32
10.3 Types of NBC Filters: ... 32
10.3.1 Low and High-pressure Carbon Filters ... 32
10.3.2 Pressure Swing Adsorption ... 34
10.3.3 Temperature Swing Adsorption ... 34
10.3.4 High Temperature Catalytic Reactor ... 34
11. NOTES ... 35

FIGURE 1 TYPICAL, SIMPLIFIED CW THREAT SCENARIO SHOWN AS A CONCENTRATION VERSUS TIME PROFILE ... 17
FIGURE 2 TYPICAL CONCENTRATION DECAY PROFILE OF A CW ATTACK ... 17
FIGURE 3 COMFORT ZONE FOR WATER COOLED GARMENTS (BASED ON NUNNELEY, [1970]) ... 25
FIGURE 4 JET AIRCRAFT RESPIRATORY AIR SUPPLY OPTIONS ... 28
FIGURE 5 HELICOPTER RESPIRATORY AIR SUPPLY OPTIONS ... 29
FIGURE 6 TYPICAL CLEAN COCKPIT APPROACH ... 30
FIGURE 7 TYPICAL CLOSED-LOOP ECS ... 31
FIGURE 8 CARBON FILTER ... 33
FIGURE 9 PRESSURE SWING ADSORPTION ... 34

TABLE 1 BIOLOGICAL WARFARE AGENTS FROM ARMY FM 8-9 [1996] ... 10
TABLE 2 CHEMICAL AGENT PROPERTIES ... 13
TABLE 3 PARAMETERS RELATED TO HUMAN THERMAL COMFORT ... 24
TABLE 4 COMPARISON OF AIR AND LIQUID COOLED GARMENTS ... 26

1. SCOPE

This SAE Aerospace Information Report (AIR) provides Nuclear, Biological and Chemical (NBC) protection considerations for environmental control system (ECS) design. It is intended to familiarize the ECS designer with the subject in order to know what information will be required to do an ECS design where NBC protection is a requirement. This is not intended to be a thorough discussion of NBC protection. Such a document would be large and would be classified. Topics of NBC protection that are more pertinent to the ECS designer are discussed in more detail. Those of peripheral interest, but of which the ECS designer should be aware are briefly discussed. Only radiological aspects of nuclear blast are discussed. The term CBR (Chemical, Biological, and Radiological) has been used to contrast with NBC to indicate that only the radiological aspects of a nuclear blast are being discussed. This is actually a more accurate term to describe the subject of this paper, but NBC has become more widely used in the aircraft industry.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP780 Environmental Systems Schematic Symbols

2.1.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-STD-1472F Human Engineering Design Criteria for Military Systems, Equipment, and Facilities, Department of Defense, August 23, 1991

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FM 8-9, NAVMED P-5059, AFJMAN 44-151 NATO Handbook on the Medical Aspects of NBC Defensive Operations, AMedP-6(B), Departments of the Army, the Navy and the Air Force, Washington, DC, February 1, 1996

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Southern Research Institute, [1984], Absorption/Desorption and Permeation Tests of Sealant Materials for Human Engineering Laboratory,” Report Nos. SORI-EAS-84-818, ADD750736, CB-010905, for the U.S. Army Human Engineering Laboratory, Aberdeen, MD.

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2.4 Definitions

ABSORB: To penetrate the surface of a material and intermix with the material.

ADSORB: To adhere to or become attached physically by adhesion forces on a surface.

AIRWASH: Exposure to a flow of air.

ASPHYXIATING TOXIC AGENTS: See CHOKING AGENTS.

BLISTERING TOXIC AGENTS (VESICANTS): These agents include sulfur mustard (H/HD) and nitrogen mustard (HN), arsenicals such as lewsite (L), and, phosgene oxime (CX). Mustard agents are also known by the French name yperite. Characteristic of these agents is their capacity of injuring skin integuments with the formation of abscesses and ulcers. However, they are all cell poisons, and accordingly they also affect the organs of vision, respiration, and all internal organs.

BLOOD AGENTS: Hydrogene cyanide (AC), cyanogen chloride (CK), arsine (SA). These agents affect the body functions preventing the normal transfer of oxygen from the blood to the body tissue.

CHOKING AGENTS: These agents include Phosgene (CG), Diphosgene (DP) and Chlorine (CL). Also known as lung or asphyxiating agents, they injure the respiratory tract, particularly the lungs. Death results from pulmonary edema.

CONTAMINANT: A chemical or biological agent or radioactive material posing a threat to equipment or personnel.

DANC SOLUTION: A decontaminant that consists of the chemical RH 195 dissolved in acetylene tetrachloride (tetrachloroethane); RH 195 is a white to cream-colored powder that decomposes gradually, giving off a chlorine-like odor. This decontaminant is obsolete.

DECONTAMINANT: Anything used to perform decontamination.

DECONTAMINATION: Process of sufficiently reducing the hazard caused by NBC contamination in order to allow the mission to be accomplished. Hazard may be reduced by chemical neutralization or by removing, destroying, or covering the contamination.

DETOXIFICATION: To remove a poison or toxin or the effect of such from the body.

EDEMA: An abnormal accumulation of fluid in tissue or a body cavity.

G-AGENTS: A family of neuroparalytic toxic (nerve) agents that includes sarin (GB), soman (GD) and tabun (GA).

IMPERMEABLE: Not allowing passage, as of a liquid, through its substance; pertaining to materials-through which penetration of chemical agents is not possible.

INCAPACITATING AGENTS: Agents intended for disorganizing enemy forces by physical (nausea, vision impact) or mental (behavioral disturbances) impairment. This group includes the psychochemical agents.

IRRITANT TOXIC AGENTS (STERNITES): These agents include dipheaylchlorarsine, didhenyl-eyanarsine, adamsite. They irritate the mucous membranes of the upper respiratory tract and cause irrepressible sneezing, pains of chest, vomiting, and other morbid phenomena. Irritant toxic agents are intended to weaken the fighting capacity of troops and produce their physical exhaustion. These chemicals are also used by the police and for training purposes.

LACRIMATORY (LACRIMATION): The secretion of tears especially when abnormal or excessive.

LUNG AGENTS: See CHOKING AGENTS.

MISSION-ORIENTED PROTECTIVE POSTURE (MOPP): A flexible system of command calling for chemical agent protection during chemical warfare to facilitate mission accomplishment. The system gives the commander and staff a range of choices as dictated by the situation.

NEUROPARALYTIC TOXIC AGENTS (NERVE POISONS): G-agents, V-agents, and other organic derivatives of phosphoric and alkyl phosphoric acids. These toxic agents cause disturbances of functions of the nervous system, muscular convulsions and paralysis.

NEUTRALIZATION: The chemical process by which a decontaminant reacts with a chemical agent to produce less hazardous products.

NONPERSISTENT AGENTS: These agents may include nonpersistent nerve agents, choking agents or various combinations, which are usually disseminated in a vapor or aerosol state. They are quickly diffused or dissipated in the atmosphere and primarily intended to cause casualties by entry through the respiratory tract.

OFF GASSING RATE: The rate at which agent that has been adsorbed by a material is vaporized and released due to changes in conditions surrounding the material such as temperature and pressure.

OVERPRESSURE (POSITIVE PRESSURE): Pressure that is greater than that of the prevailing outside atmosphere.

PANTOTOXIC AGENTS: These agents include hydrocyanic acid, cyanogen chloride, arsenic hydride, phosphorus hydride, carbon monoxide, and organo-fluorine compounds. They cause general poisoning of the organism, although the mechanism of their action and character of affection are completely different.

PERCUTANEOUS: Effected or performed through the skin.

PERMEABLE: Having pores or small openings that allow liquids or gases to penetrate.

PERSISTENT AGENTS: These agents may include persistent nerve agents, blister agents, or a combination of both. They have a more permanent lingering effect and are used to contaminate equipment and terrain and to cause casualties through the skin absorption route.

PSYCHOCHEMICAL AGENTS: These agents include diethylamide of lysergic acid, mescaline, pailocine, benzilic acid derivatives, and others. They cause disturbances in the action of the central nervous system with the symptoms of psychic affections.

SLURRY: Suspension of a solid in a liquid; in general, it is a mixture of a decontaminating agent with water for use as a decontaminating solution.

SORB: To absorb or adsorb.

TACTICAL CLASSIFICATION: A classification that subdivides toxic agents according to their effect on the organism. The following three groups are usually distinguished: lethal, incapacitating, herbicides.

TEAR-PRODUCING TOXIC AGENTS (LACHRYMATORS): These toxic agents include chloracetophenone, bromobenzyl cyanide, and chloropicrin. They irritate the mucous membrane of eyes and upper respiratory pathways, causing a profuse flow of tears and intense smarting of eyes and nose. They are and primarily used for mob and riot control and not for NBC warfare.

V-AGENTS: A family of neuroparalytic toxic (nerve) agents that includes O-ethyl S-diisopropylaminomethyl methylphosphonothiolate (VX).

VOICEMITTER: Device enabling voice transmission outside of a mask.

VOMITING AGENTS: These agents include Diphenylchloroarsine (DA), Adamsite (DM), Dyphenylcyanoarsine (DC). They are disseminated as an aerosol and primarily used for mob and riot control and not for NBC warfare.

2.5 Abbreviations

AC: Hydrogen cyanide

CB: Chemical and biological

NBC: Chemical, biological, and radiological. This is used to contrast with NBC to indicate only that the radiological aspects of a nuclear blast are being discussed.

CG: Phosgene

CK: Cyanogen chloride

CL: Chlorine

CT: Cumulative concentration multiplied by time (actually the time integral of concentration)

CW: Chemical warfare

CX: Phosgene oxime

DA: Diphenylchloroarsine

DC: Dyphenylcyanoarsine

DM: Adamsite

DP: Diphosgene

ECS: Environmental control system

GA: Tabun

GB: Sarin

GD: Soman

H/HD: Sulfur Mustard

HEPA: High efficiency particulate air (usually in reference to a filter)

HN: Nitrogen Mustard

L: Lewsite

MOPP: Mission-oriented protective posture

MMD: Mass mean diameter

NBC: Nuclear, biological, and chemical

PSA: Pressure Swing Adsorption

SA: Arsine

TSA: Temperature Swing Adsorption

VX: O-ethyl S-diisopropylaminomethyl methylphosphonothiolate

WCG: Water cooled garment.

3. THREAT

As with other military weapon systems, NBC weapons have as their goal harming the opponent. The wide range of threats and effects, both offensive and defensive, of these weapons is what sets NBC weapons apart from others. Effects can vary from the destruction associated with nuclear weapons to a famine associated with biological agents. The examples show that the time required for NBC weapons to affect their intended targets can vary from immediate to months. Some of these weapons can be tailored to be non-lethal, but still cause intensive casualties, thus decreasing overall combat effectiveness. The threat and the effects of these weapons will be discussed in aircraft operational terms, in flight, as on a mission, or on the ground where the aircraft would be serviced.

3.1 Types of Threat

a. NUCLEAR - A nuclear device produces immediate blast, heat and radiation effects. The ECS is not capable of dealing with the blast, heat effects or the radiation that can penetrate the aircraft structure. Following a nuclear detonation, radioactive residue forms a cloud that moves with the wind, creating both an atmospheric and ground hazard. If the aircraft encountered a radioactive cloud, radiation in the form of alpha and beta particles and gamma radiation would be encountered. This radiation results from the decay of radioactive particles making up the cloud. Crew and equipment exposure would result from the ingestion of radioactive materials into the vehicle through the bleed system and ECS. While the radiation levels would be lower than that of the blast area, the crew effects from prolonged exposure, particularly if the particles are inhaled or ingested, could be severe. Avionics equipment could also be affected. The vehicle, its crew and its subsystems would require detection of the radiation and decontamination after recovery to protect the crew and allow for normal maintenance activities.

b. BIOLOGICAL - The means of dispensing various agents is provided in Table 1. In flight, the biological agents would be ingested into the pressurized zones of the aircraft through the bleed system and ECS. The high temperature encountered in the engine and bleed system would provide some destruction of the agents in flight, but due to short dwell times in the bleed air system, some contamination must be assumed to pass through to the ECS. Bleed air temperatures of most aircraft on the ground are generally not high enough to destroy any agent. There would be no immediate effect on the crew because of the time required for the biological agent to act. Table 1 provides the exposure time and lethality of the various agents. Again, exposure of the vehicle to biological agents must be detected. The crew would require medical attention, and the vehicle must be decontaminated prior to servicing and reuse.

c. CHEMICAL - Like biological agents, chemical materials can be dispensed as aerosols and would be ingested into the bleed air system. Again, some of the agents would be destroyed by oxidation with the bleed air at high temperature in flight; however, the remaining agent would go through the ECS to the pressurized zone. The effects on an unprotected crew could be immediate or take up to days to be observed, depending on agent type. Air-cooled equipment would also be contaminated, requiring care in servicing. As with biological agents, any contamination of the vehicle would have to be decontaminated prior to ground service and reuse.

3.2 Detail Threat

The various military services have established detailed threat information for various operational areas. This information, which is generally classified for specific threats, provides the expected concentration levels for various agents. This information is required prior to starting a detail design of an NBC protection system. For each of the threats defined in 3.1, properties are examined in general terms, and the relative difficulty of protecting aircraft from each is discussed.

3.2.1 Nuclear Agents

The radioactive particles of most concern are dust particles thrown or sucked up by surface or near-surface bursts and contaminated with radioactive fission fragments. These particles range in diameter from less than 1 μm to more than 100 μm. Inhalation of radioactive particles can be more serious. Although the nose effectively filters particles with diameters greater than 5 μm, particles with diameters on the order of 1 μm are deposited in the alveolar (air) cells. Radioactive dust must be excluded from the crew compartment.

3.2.2 Biological Agents

Potential biological warfare agents are shown in Table 1, along with their type, incubation period, and approximate human mortality rate. Biological agents and toxins are generally solids and are disseminated as aerosols of particles having a mass mean diameter (MM D) smaller than 10 μm. They can also be disseminated in liquid solutions or slurries. Solid agents dispersed in this manner remain as solid residue after the liquid carrier evaporates.

TABLE 1 - BIOLOGICAL WARFARE AGENTS FROM ARMY FM 8-9 [1996]

Group	Disease	Likely Methods of Dissemination	Incubation* Time	Duration of Illness	Lethality
Bacteria	(Inhalation) Anthrax	Spores in aerosols	1-6 days	3-5 days	High
	Brucellosis	1. Aerosol 2. Sabotage	Days to months	Weeks to years	Low
	Cholera	1. Sabotage 2. Aerosol	1-5 days	1 or more weeks	Moderate to high
	Melioidosis	Aerosol	Days to years	4-20 days	Variable
	(Pneumonic) Plague	1. Aerosol 2. Infected vectors	2-3 days	1-2 days	Very high
	Tularemia	Aerosol	2- 10 days	2 or more weeks	Moderate if untreated
	Typhoid Fever	1. Sabotage 2. Aerosol	7-21 days	Several weeks	Moderate if untreated
Rickettsiae	Epidemic Typhus	1. Aerosol 2. Infected vectors	6-16 days	Weeks to months	High
	Q-Fever	1. Aerosol 2. Sabotage	10-20 days	2 days to 2 weeks	Very low
	Rocky Mountain Spotted Fever	1. Aerosol 2. Infected vectors	3-10 days	2 weeks to months	High
	Scrub Typhus	1. Aerosol 2. Infected vectors	4-15 days	Up to 16 days	Low
Chlamydia	Psittacosis	Aerosol	4-15 days	Weeks to months	Very low
	Coccidioidomycosis	Aerosol	1-2 weeks	Weeks to months	Low
	Histoplasmosis	Aerosol	1-2 weeks	Weeks to months	Low
Viruses	Chikun-Gunya Fever	Aerosol	2-6 days	2 weeks	Very low
	Crimean-Congo Hemorrhagic Fever	Aerosol	3-12 days	Days to weeks	High
	Dengue Fever	Aerosol	3-6 days	Days to weeks	Low
	Eastern Equine Encephalitis	Aerosol	5-15 days	1-3 weeks	High

* Incubation applies to infectious disease. With toxins, its application refers to the period between exposure and appearance of the symptoms and signs of poisoning.

TABLE 1 - BIOLOGICAL WARFARE AGENTS FROM ARMY FM 8-9 [1996] (CONTINUED)

Group	Disease	Likely Methods of Dissemination	Incubation* Time	Duration of Illness	Lethality
Viruses (cont.)	Ebola Fever	Aerosol	7-9 days	7-9 days	High
	Korean Hemorrhagic Fever (Hantaan)	Aerosol	4-42 days	Days to weeks	Moderate
	Lassa Fever	Aerosol	10-14 days	1-4 weeks	Unknown
	Omsk Hemorrhagic Fever	1. Aerosol 2. Water	3-7 days	7-10 days	Low
	Rift Valley Fever	1. Aerosol 2. Infected vectors	2-5 days	Days to weeks	Low
	Russian Spring-Summer Encephalitis	1. Aerosol 2. Milk	8-14 days	Days to months	Moderate
	Smallpox	Aerosol	10-17 days	1-2 weeks	High
	Western Equine Encephalitis	Aerosol	1-20 days	1-3 weeks	Low
	Venezuelan Equine Encephalitis	1. Aerosol 2. Infected vectors	1-5 days	Days to weeks	Low
	Yellow Fever	Aerosol	3-6 days	1-2 weeks weeks	High
Toxins	Botulinum Toxin	1. Sabotage 2. Aerosol supply)	Variable (hours to days)	24-72 hours Months if lethal	High
	Clostridium Perfringens Toxins	1. Sabotage 2. Aerosol	8-12 hours	24 hours	Low
	Trichothecene Mycotoxins	1. Aerosol 2. Sabotage	Hours	Hours	High
	Palytoxin	1. Aerosol 2. Sabotage	Minutes	Minutes	High
	Ricin	Aerosol	Hours	Days	High
	Saxitoxin	1. Sabotage 2. Aerosol	Minutes to hours	Minutes to days	High
	Staphylococcal enterotoxin B	1. Aerosol 2. Sabotage	1-6 hours	Days to weeks	Low
	Tetrodotoxin	1. Sabotage 2. Aerosol	Minutes to hours	Minutes to days	High

* Incubation applies to infectious disease. With toxins, its application refers to the period between exposure and appearance of the symptoms and signs of poisoning.

3.2.3 Chemical Agents

The properties of many chemical agents are presented in Table 2. The chemical agents are arranged in groups according to the physiological effects they produce in the human body. Some information on the more common agents follows. More information on these agents as well as other agents is available on the Internet at Centers for Disease Control and Prevention web site and in FM 4-02.7.

a. Nerve Agents

Nerve agents attack the body's nervous system. They are similar to insecticides and have pale or no color. Most are essentially odorless; however, some may have a faint fruity odor. In toxic amounts, liquid solutions of nerve agents are tasteless. They are all liquids, varying in volatility in the range between gasoline and heavy lubricating oil. Their freezing points are -40 °C (-40 °F) or lower. Nerve agents may be absorbed through any body surface - including skin, eyes, and respiratory tract. Exposure will result in sudden loss of consciousness, convulsions, edema, flaccid paralysis, copious secretions, loss of body functions and miosis. Severe exposures will eventually cause victim to become comatose and suffocate as a result of convulsive spasms.

- Tabun (GA), O-Ethyl, N,N-dimethyl phosphoramidocyanidate
  - Formula: $C_2H_5OP(O)(CN)N(CH_3)_2$
  - Material Impact: Slightly corrosive to steel.
  - Comments: This nerve agent is the easiest to manufacture. Consequently, it is more likely that developing countries start their CW arsenal with this nerve agent whereas industrialized countries consider tabun to be out-of-date and of limited use.
- Sarin (GB), Isopropyl methylphosponofluoridate
  - Formula: $CH_3P(O)(F)OCH(CH_3)_2$
  - Material Impact: Attacks tin, magnesium, cadmium plated steel, and some aluminum. Slightly attacks copper, brass, and lead; practically no attack on 1020 steels, Inconel, and K-monel.
  - Comments: Sarin is a highly volatile liquid. Since vapor concentrations will immediately penetrate the skin, absorption through the skin is as great a threat as inhalation. Death may follow in one minute after direct ingestion of extremely low concentrations (0.01 mg per kg of body weight or higher). Permanent neurological damage may result in people who are not exposed to a lethal dose, but do not receive immediate appropriate medical treatment.
- Soman (GD), Pinacolyl methylphosphonofluoridate
  - Formula: $CH_3P(O)(F)OCH(CH_3)C(CH_3)_3$
  - Material Impact: Slightly corrosive to metals.
  - Comments: Soman is extremely toxic by absorption through the skin and death will follow about 15 minutes after a lethal dose has been absorbed. With the lethal inhalation dose half that of sarin, death will occur between 1 and 10 minutes. Oxime-based drugs, which try to give the body time to destroy and excrete the toxic substances, are useless against soman. A far more persistent agent than sarin, it can easily remain in a particular area for a day or longer, depending on the atmospheric conditions.

TABLE 2 - CHEMICAL AGENT PROPERTIES

Type of Agent	Symbol	Summer Persistence	Winter Persistence	Rate of Action	Vapor/Aerosol Entrance	Liquid Entrance
Nerve	GA GB, GD	10 min-24 hours	2 hours-3 days	Very Quick	Eyes, Lungs	Eyes, Skin, Mouth
	VX	2 days-1 week	2 days-weeks	Quick	Eyes, Lungs	Eyes, Skin, Mouth
Choking	CG, DP, CL	1 to 10 min	10 min-1 hour	Immediate	Lungs	Eyes
Blister	HD, HN	3 days-1 week	Weeks	Slow	Eyes, Skin, Lungs	Eyes, Skin
	L, HL	1-3 days	Weeks	Quick	Eyes, Skin, Lungs	Eyes, Skin, Mouth
	CX	Days	Days	Very Quick	Eyes, Skin, Lungs,	Eyes, Skin, Mouth
Blood	AC, CK	1-10 min	10 min-1 hour	Very Quick	Eyes, Lungs	Eyes, Mouth, Injury

Agent	Boiling Point °C	Melting Point °C	Vapor Density (Air=1)	Volatility mg/m^3 @ 25 °C	Median Lethal Dose Percutaneous mg[mg/kg]	Median Lethal Dose Respiratory (2-10 min) mg-min/m^3	Median Incapacitation Dose mg-min/m^3
Nerve							
GA	240	-50	5.63	610	1000	400 [200]	300
GB	147	-57	4.86	22 000	1700	70-100	50
GD	198	-42	6.33	3900	50	70	50
VX	298	-51	9.2	10.5	10	100 [30]	50
Choking							
CG	7.6	-128	3.4	N/A	N/A	3200	
Blister							
H/HD	217	15	5.4	920	100	1500	200
HN-3	138	-4	6.9		10	1500	200
L	190	-18	7.1	121	2800	1200	300
Blood							
AC	26	-13	0.93	1 080 000	1.1	200 [2500-5000]	2000
CK	13	-7	2.1	6 132 000	200	11 000	7000

- VX, O-ethyl S-diisopropylaminomethyl methylphosphonothiolate
    - Formula: $CH_3P(O)(SCH_2CH_2N[CH(CH_3)_2]_2)(OC2H_5)$
    - Material Impact: Negligible on brass, steel and aluminum.
    - Comments: VX, which has no common name, is a persistent substance that can remain on material, equipment and terrain for long periods. It is mainly absorbed through the skin, but it also may be inhaled as a gas or aerosol.

b. Choking Agents

Choking agents attack lung tissue, primarily causing pulmonary edema. They include phosgene (CG), diphosgene (DP), chlorine (Cl) and chloropicrin (PS). Phosgene is the most dangerous member of the choking agents and is the only one considered likely to be used in the future.

- Phosgene (CG), Carbonyl Chloride
    - Formula: $COCl_2$
    - Material Impact: Reaction with metals - None when dry, acidic and corrosive when moist.

- Comments: Phosgene is a colorless gas under ordinary conditions of temperature and pressure. It is an extremely volatile with boiling point of 8.2 °C (46.8 °F), making it a non-persistent agent. Thus, it is transported as a liquid, but after dissemination it rapidly evaporates and forms a white cloud due to its slight solubility in an aqueous environment. The white cloud will then convert to a colorless, low-lying gas. With a vapor density of 3.4 times that of air, this gas will remain for long periods of time in trenches and other low-lying areas. In low concentrations it has a smell resembling new mown hay. Phosgene is readily soluble in organic solvents and fatty oils. In water, phosgene is rapidly hydrolyzed with the formation of hydrochloric acid and carbon dioxide.

c. Blister agents

Blister agents, also known as vesicants, interfere with personnel capabilities by damaging the lung, eyes and skin; therefore, they are likely to be used both to produce casualties and to force opposing troops to wear full protective equipment thus degrading fighting efficiency. Although not designed to kill, exposure to these agents can be fatal. Blister agents can be thickened in order to contaminate terrain, ships, aircraft, vehicles or equipment with a persistent hazard. These agents include sulphur mustard (H/HD), nitrogen mustard (HN), the arsenical vesicants such as lewisite (L) (this may well be used in a mixture with HD), and the halogenated oximes whose properties and effects are very different from those of the other blister agents. There are three varieties of nitrogen mustard (HN1, HN2 and HN3). From a military standpoint, HN3 is the principal representative of the group of nitrogen mustards and is the only nitrogen mustard likely to be used in war.

- Sulfur Mustard (H/HD), Bis(2-chloroethyl)sulfide
  - Formula: (ClC2H4)2S
  - Material Impact: Rapidly corrosive to brass. It will corrode steel at a rate of .0001 inch/month. Pure, undiluted calcium hypochlorite will burn on contact with liquid HD. The mustards are able to penetrate a great number of materials, including wood, leather and rubber.
  - Comments: Sulfur Mustard, yperite in French, is normally amber to black colored liquid with garlic or a horseradish odor, but is clear if pure. Besides being a blister agent, HD is an alkylating agent that acts on blood-forming tissues, which are especially sensitive. The rate of detoxification of HD in the body is very slow and repeated exposures produce a cumulative effect. HD has been found to be a human carcinogen. Depending on the exposure level symptoms may appear within 2 minutes of contact time with a drop of mustard on the skin, or have a latency period of 2 to 24 hours following mild exposure. After exposure to a high dose of mustard vapor, symptoms include nausea, vomiting and symptoms of collapse.
- Nitrogen Mustard-3 (HN3), 2,2,2 tri(chloroethyl)amine
  - Formula: $Cl(C_2H_4)NC_2\ H_5$
  - Material Impact: None if dry.
  - Comments: Nitrogen mustard is a colorless or yellow oily liquid. In impure forms, it has the odor of fish or soap. HN3 is more stable than HN1 and HN2 making it more likely to be encountered. Nitrogen mustards are faster acting than sulfur mustards.
- Lewisite (L), Dichloro-(2-chlorovinyl) arsine
  - Formula: $ClCH{:}CHASC_2$
  - Material Impact: Little or none if dry.
  - Comments: Lewisite is a colorless oily liquid. In an impure form, it has an amber to dark brown color and an odor similar to that of a geranium. It is more volatile than mustards.

d. Blood agents

Blood agents prevent transfer of oxygen from the blood to the body tissues. They are non-persistent, highly volatile, and dissipate rapidly. They evaporate more quickly than gasoline. The mucous membranes and the intact skin readily absorb both. Initial symptoms are characterized by violent convulsions and increased deep respiratory movements, which are followed by cessation of respiration within 1 minute, then slowing of heart rate to death. High concentrations exert their effects rapidly; however, a patient that is still alive after the cloud has passed, will probably recover spontaneously. Hydrogen cyanide (AC) and cyanogen chloride (CK) are the most typically used blood agents.

- Hydrogen Cyanide (AC)
    - Formula: HCN
    - Material Impact: AC is incompatible or reactive with amines, oxidizers, acids, sodium hydroxide, calcium hydroxide, sodium carbonate, water, caustics, and ammonia.
    - Comments: In a pure state, AC is a colorless gas. It has a faint odor similar to that of peach kernels or bitter almonds.
- Cyanogen Chloride (CK)
    - Formula: CNCl
    - Material Impact: CK attacks many metals when stored unstabilized, but none if dry.
    - Comments: CK is a colorless gas. It has a pungent, biting odor and may go unnoticed because of its intense irritating and tearing properties. The metallic salt-impregnated charcoal filters in the protective mask also poorly absorb it.

3.3 Aircrew Vulnerability

A hazard assessment shows that the aircrew is vulnerable during all flight segments during an NBC attack where liquid agents are released from an airborne detonated bomb:

- Ingress/egress - During the process of ingress or egress, if the aircraft is left unprotected in an unsheltered area, the crew can become directly contaminated by falling droplets from an agent cloud or from agent evaporation from a contaminated runway.
- Loading/unloading - Similar to the above condition, on cargo aircraft, the aircrew can become contaminated if the aircraft is loaded or unloaded in an unprotected contaminated area.
- Taxiing, takeoff and landing - When the crew is in the aircraft during taxiing, takeoff and landing, agent will be ingested into the cockpit via the engine inlet, the engine and the ECS due to the suction in the engine inlet induced by the engine operation. The agent can also enter any small opening if the aircraft is unpressurized. Agent ingestion will accelerate when the aircraft operates in the exhaust streams of other aircraft, which stirs up the agent.
- Flight - During flight operations, agent will be ingested into the cockpit and the aircraft via the engines or other air supplies when the aircraft encounters agent clouds during low-altitude operations. Exposure of the aircrew/aircraft to NBC agents during this phase of operation is relatively low. However, for helicopters and aircraft operating at low altitude, this phase may be significant.

The total threat to the aircrew is found by combining NBC exposure in all phases of operation.

3.4 Avionics Vulnerability

On current aircraft, avionics are usually cooled by ram air or air supplied from the ECS, thereby becoming contaminated by NBC agents under the same conditions that cause the aircrew to become contaminated. Though the potential to become contaminated is similar for both crew and equipment, the effects upon each are very different. The toxic effect of agents upon humans will take place within seconds or minutes, while at similar exposure levels avionics equipment may not show signs of physical or performance degradation for weeks or even months. In fact, more damage may be done to the equipment during an attempt at decontamination, since, during decontamination, the equipment is washed or bathed in solutions that tend to be caustic. Persisting agents can get into the devices by the conditioned or ventilation air systems of the aircraft and can expose maintenance personnel to danger.

Unless materials are used that readily sorb vapors (see Section 7), vapors do not pose a high hazard to avionics. Liquid and particulate agents pose the significant hazard.

Liquid or closed air loops for cooling avionics can greatly reduce the hazard to the avionics as well as the maintenance personnel that have to maintain it.

3.5 Simplified Chemical Warfare (CW) Attack Scenario

A simplified CW attack scenario is shown in Figure 1 and is a plot of ambient concentration vs. time. This particular CW scenario consists of an attack frequency of one attack per day. Various agents exhibit different concentration-vs.-time behavior.

A simplified chemical agent attack scenario consists of three regimes:

a. A chemical bomb explodes, releasing a high initial concentration of liquid droplets in the air.

b. The droplets settle to the ground and the ambient concentration decays.

c. The liquid agent deposited on the ground evaporates, leaving a residual ambient concentration level.

Figure 2 shows a typical concentration attack decay profile and some of the pertinent parameters with their relationship to the concentration-vs.-time curve. These parameters are:

a. Maximum attack concentration: This is the highest ambient concentration to which a vehicle is expected to be exposed and is required to be protected against.

b. Attack duration: This is the length of time from start of concentration buildup until the dosage has decayed to a small value. For purposes of this example, the end of the attack was arbitrarily taken as the time at which the concentration decayed to 0.1 percent of the peak value.

c. Total attack dosage: This is the cumulative concentration multiplied by time (CT) resulting from the attack. The area under the concentration decay profile represents it.

d. Average attack concentrations (not shown, but derived from curve parameters): This is the total attack dosage, or CT value, divided by the attack duration.

These key parameters are different for various agents. Once the concentration-vs.-time profiles are specified for the agents of interest, the filter design requirements can be determined.

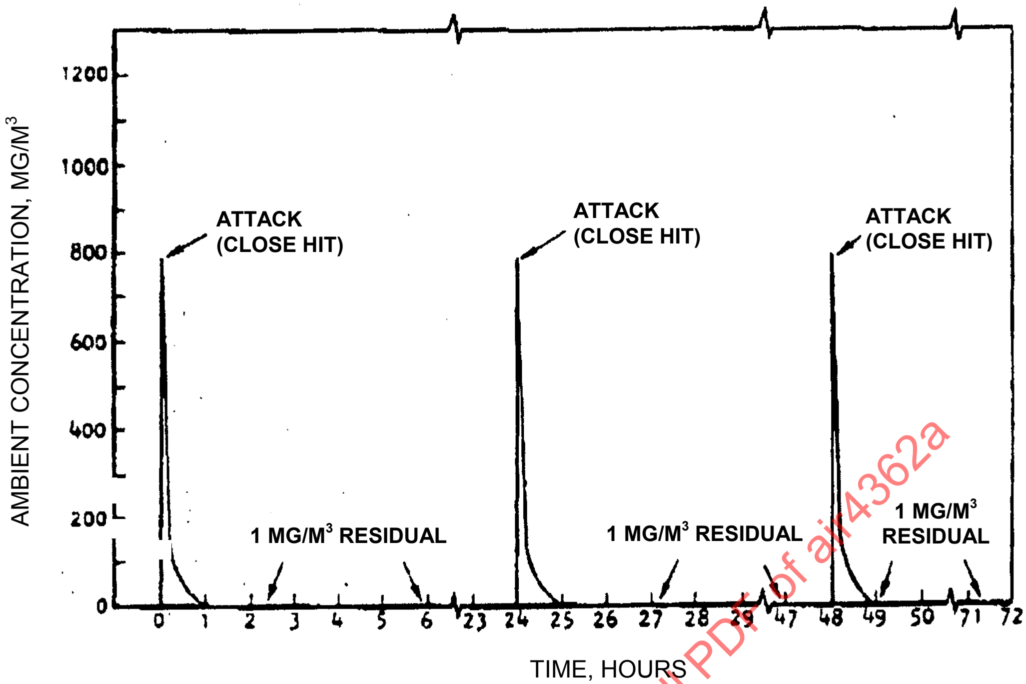

FIGURE 1 - TYPICAL, SIMPLIFIED CW THREAT SCENARIO SHOWN AS A CONCENTRATION VERSUS TIME PROFILE

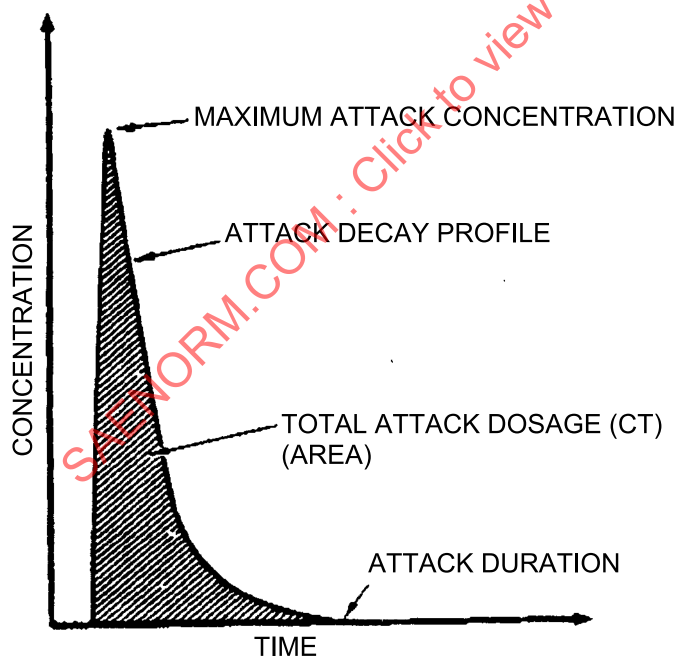

FIGURE 2 - TYPICAL CONCENTRATION DECAY PROFILE OF A CW ATTACK

4. DETECTION

4.1 Military Detection System Categories

There are two basic categories of detection systems defined within the defense community:

4.1.1 Point Detectors

A “point detector” is a detector which senses a contaminant within its immediate environment, at a “point”. These types of detectors typically detect chemical agent vapor concentration, but also include liquid agent detectors. Technologies employed for point detection include electrochemical cells, colorimetric or paper tape type detectors, ion mobility spectrometry (IMS), surface acoustic wave (SAW), and several other developmental concepts.

4.1.2 Stand-Off Detectors

A “stand-off” detector detects agents at “stand-off” distances, allowing the identification of agents without being within the immediate environment where contaminants are present. Stand-off detectors can potentially detect agent vapor or liquid droplets. Technologies employed for stand-off detection include passive infrared and several other developmental concepts.

4.2 Relationship to Industrial Applications

The terms point and stand-off detector are peculiar to military applications; however, these same type of detectors are used in a wide variety of industrial applications and are categorized as chemical agent vapor or liquid monitors, dosimeters, paper tape monitors, or a variety of other terms. The primary differences between military and industrial applications are:

Industrial applications are generally oriented more toward longer term monitoring of exposure levels that may cause chronic effects in humans. Exposure levels are defined with regard to long-term low-level exposure to contaminants. Military applications are generally oriented more toward short-term warning of exposure levels that may cause acute effects in military personnel.

Industrial applications typically use detectors for a specific location where a limited number of contaminants may be released as a result of an industrial process or from a storage facility. This allows for specific design and calibration of the detection system for the intended target application. Military systems, on the other hand, must have the ability to detect a wide variety of contaminants and also should have an ability to be programmed to add new substances in response to the growing offensive threat.

Military applications must identify agents that cause threshold effects in humans at levels that can be orders of magnitude lower than typical industrial contaminants. For example, nerve agents such as GB and VX are lethal at very low exposure levels. Material safety data sheets are available for the chemical agents as well as for industrial contaminants; however, many of the threshold effects levels are not well documented due to the scarcity of actual human exposure data.

For these reasons, many of the more mature technologies typically used in industry do not meet military requirements. There are many current developmental programs within the military to produce detection systems for critical military applications.

4.3 Applications to Military Aircraft

Chemical agent detection has been considered as part of an integrated approach to defense for military aircraft applications. There are several key functions served by a detection system:

a. Contamination Avoidance. Contamination avoidance is the preferred method of defense. A stand-off detector or a remotely located point detector with communications uplink can provide advance warning of a contaminated area or landing zone. The aircraft can then avoid contamination by identifying an alternate flight path.

b. Warning. A point detector that can detect at levels below threshold effects levels in humans can provide a warning for personnel to don protective equipment.

c. Monitoring. A point detector can continuously monitor the contamination level at a location over a period of time. One application is the determination that decontamination efforts have been successful, in order that personnel may remove protective equipment. The monitoring function also provides a survey capability to assess the extent and location of contamination after an attack.

These categories are broadly defined within the present general discussion with regard to mission phases: prior to exposure (contamination avoidance), during exposure (warning and monitoring), and after exposure (monitoring). Detector functions are defined and categorized in greater detail for specific applications.

4.4 Aircraft ECS Applications

Chemical agent vapor detectors have potential application within, and in conjunction with, aircraft ECS to provide warning of contaminants entering inhabited spaces. Detection can be used as part of a personal protection system (crew protection), a collective protection system (aircraft overpressure), or a combination system of defense.

The location of these detectors would have to be considered with regard to several factors. First the detector would have to be situated such that the time required for the sampled air volume to reach personnel would not result in exposure levels above threshold effects for unprotected personnel. In other words, the detector must detect and warn, and allow time (typically on the order of 10 seconds) for personnel to don protective gear, before the dosage, CT, received by personnel reaches the threshold effects levels.

Detectors would have to be specified as an integral part of the overall NBC defense system for the particular application. If personnel were assumed to have already donned protective gear, the requirements for the detector would be less stringent.

For detectors located within the ECS (as opposed to in the occupied spaces), the pressures and flow rates must be considered. Detection technologies differ in their ability to rapidly sample and identify agents under various conditions of pressure, temperature, and flow rate.

An integrated systems approach must be applied such that detection system information is appropriate for the intended application. Several detection system requirement parameters are:

a. Response Time. The time between initial agent contact and detection system information output. As stated above, for a warning to unprotected personnel, response time would have to be on the order of seconds or less.

b. Sensitivity. The lowest levels of concentration able to be detected by a given detector. Many detection technologies are not able to detect to concentration levels below the threshold effects level for highly toxic agents.

c. Specificity. The number of agents uniquely identified by a given detector.

d. Information Outputs. The format and detail of the information provided. In some applications a data logging capability may be desired.

e. Operator Interface. The display or operator interface is a critical factor. Aircraft integration versus a stand-alone system is a consideration.

5. HARDENING

5.1 Airframe Hardening Requirements

The aircraft concept of operations (CONOPS) and the expected nuclear dust cloud and biological/chemical warfare agent environment should determine airframe hardening requirements. The aircraft CONOPS provides the basis for determining what aircraft operations will be performed in an NBC environment. These will include, but not be limited to, normal sortie generation, turn around, and maintenance actions in the NBC environment. The defined NBC environment will determine the extent of hardening required during these operations. The CONOPS should also identify the allowed degradation over a specified period and the number of exposures to agents and decontaminants.

Hardening requirements should include the ability of the ECS to withstand nuclear dust and chemical and biological (CB) warfare agent decontamination using approved materials and procedures without structural or functional degradation. The required use of NBC resistant materials enhances the hardness of the ECS. Materials should be selected based on "Q" value (mg/cm^2/min), which is a measure of the off gassing rate. The lowest "Q" value is the best.

Consideration of maintenance actions in the CB warfare agent environment leads to further hardening requirements. Maintaining the integrity of maintenance personnel's CB ensemble is of utmost importance. Sharp edges, corners and fasteners used in the design of ECS components, chassis, and mounting racks can puncture, tear, or otherwise compromise the CB ensemble and should be avoided. Safety wire, with its sharp edge, is an example of an item that should not be used. Ease of handling during installation and maintenance should also be considered in the design of the ECS. Attention should be given, in particular, to the compatibility of handle-grasp areas with the CB ensemble.

When locating ECS components, consideration should be given to the maintainer's potential lack of dexterity and lack of visibility caused by the CB ensemble.

The design of the ECS components should not impair the access of decontamination agents to contaminated areas due to the low viscosity of liquid warfare agents, e.g. lapped surfaces should be avoided or sealed.

Fasteners should be sealed to prevent the CW agents from being drawn under the fastener's head by capillary forces.

Recesses around fastener heads should be filled. Access covers should be designed such that no contaminants can gravitate between cap and flange.

Electrical connectors should be recessed and shielded by a hinged cover.

Removal and replacement procedures of nuclear dust filters during sortie turnaround must be addressed. The procedures should allow the easy replacement of contaminated filters by maintenance personnel in CB ensemble without them exceeding allowable radiation dosages.

5.2 Avionics

Because of their sensitivity, avionics can be susceptible to damage from agents or decontaminants. The desorbing of agents can be hazardous to maintenance personnel who will later have to repair the equipment. Discarding of high cost avionics due to contamination is also undesirable. Hardening against agent or decontaminant or preventing contamination is therefore very important. The prevention of decontamination can impact the ECS design, since typically the ECS provides cooling air to the avionics. This impact will vary depending upon whether or not the air is blown into the avionics or if it is contained in a cold plate sealed from the avionics. Typically the military did not allow air to be blown over avionics components, but the current trend toward the use of commercial equipment will probably change this.

The degree of hardening of electronics to radiation is dependent upon both the environment and the system requirements. The environment may include any of the following radiation – alpha, beta, neutrons, gamma, and weapons debris. Note that systems hardened for one environment are not necessarily hardened to the effects of another. The system requirements are usually specified in terms of the criticality of the avionics in one of the following three categories:

a. Full, uninterrupted operation in the nuclear environment

b. Degraded performance in the nuclear environment

c. Normal operation after exposure to the nuclear environment

Residual radiation poses far less of a threat to electronics than the initial nuclear blast. As noted, effects from the initial nuclear blast are beyond the scope of this document. The primary radiation threats from residual radiation are alpha and beta particles. These particles are easily shielded against and will not pose a hazard to sealed electronics units. Weapons debris particles are usually large compared to chemical and biological particles and thus easier to filter.

Although the ECS engineer may not have control over the avionic design, the following are recommended practices for avionics design that will minimize the impact of agents being delivered by the ECS to the avionics:

a. All printed circuit boards should be conformal coated. The five coatings are, in order of capability to prevent outgassing - parylene, epoxy, urethane, acrylic and silicone.

b. As with airframe systems, NBC resistant materials should be used wherever possible (see Section 7).

c. As indicated above, cold plate designs that eliminate the direct contact of cooling air with the electronic components should be used.

d. Drain holes should be eliminated wherever possible.

5.3 Fuel

The fuel system should be carefully considered during NBC analyses. In addition to the external contamination issues typical of any aircraft system, fuel consumption typically results in the intake of outside air and consequently the potential for contamination of the fuel tanks and exposure of NBC agents to the elastomers used in the fuel system. The threat considered should be the immediate affect of agents on fuel system components, and the potential for subsequent personnel exposure.

Helicopters and other aircraft with fuel bladders have the additional challenge of agent adsorption/absorption on the external surfaces of the bladder(s), and the subsequent challenges of decontaminating these typically difficult to reach surfaces after exposure.

To minimize the potential for agent intake into the fuel tanks, On Board Inert Gas Generating Systems (OBIGGS) have been coupled with NBC filtration systems. These systems typically maintain a positive pressure in the fuel ullage (vapor volume above liquid in fuel tanks), and therefore significantly reduce the likelihood of contaminant ingress. This approach could of course also be considered with a non-inerted filtered air source if appropriate.

6. DECONTAMINATION

Selecting a decontaminant is very difficult. The most effective decontaminants are caustic, corrosive or toxic, potentially causing more damage than the agents they are removing. These compounds include Super Tropical Bleach (STB), Calcium Hypochlorite (HTH), High Test Bleach (HTB), High Test Hypochlorite, and Decontamination Solution No. 2 (DS2) and are not recommended for use on aircraft or aircraft subsystems. Aircraft typically have to be decontaminated with hot soapy water (steam jet). Since this procedure does not break down the agents, the runoff from this cleaning will be contaminated. Even the hot soapy water can cause corrosion and other problems if the system is not designed to keep out or drain this fluid when it is applied. The procuring activity should be contacted to determine what decontaminants will be used with the aircraft. The ECS design and materials must be compatible with the decontaminant and the method to be used for decontamination

If a collective protection system is not going to be employed, special attention should be paid to the design of the ventilation system to aid in removal of contaminants. The addition of outside air to the normal cockpit exhaust air used to ventilate equipment compartments should be considered. The use of a closed loop cooling system or stealth requirements may make this difficult. Bays that may be exposed to the outside, such as wheel wells and weapons bays should be isolated from the air vehicle ventilation system.

Additional information can be found in FM 3-11.5.

7. SEALING

If a collective protection system is going to be deployed to protect the cockpit, cabin or equipment compartments, the compartments will need to be sealed in addition to positive pressure applied to the compartment. For aircraft that are normally pressurized, this is not a large impact, but for normally unpressurized aircraft such as helicopters, this may have a weight impact as well as added manufacturing time. If sealing is used, it should be hardened against agents as well as decontaminants and not sorb them. As with other materials, there is not a complete database on the compatibility of sealing materials with agents and decontaminants. The services are building databases. Prior to selecting materials, the databases should be consulted through the procuring activity. The NBC Materials Handbook Volume I [1984], Southern Research Institute [1984] and Dunn [1986] provide information on testing done to date. Additional testing of materials may be required if the material is not in the database. In general, fluorinated and butyl rubbers appears to be the most resistant elastomers and epoxy based compounds the most resistant sealant to both agents and decontaminants. Silicones, polysulfides, polyolefins and Buna-N material are likely to sorb agents. A compatibility analysis should be performed on all materials used in the system.

8. INGRESS AND EGRESS:

The highest vulnerability to contamination for both the aircraft and aircrew occurs during ingress and egress. Currently there are no viable procedures for a clean aircrew to enter or exit the aircraft in a contaminated environment without contaminating the aircraft and the aircrew's outer garments. Detail procedures can be established to prevent liquid agent from entering the aircraft with the aircrew or from contaminating the aircrew's permanent garments. The major focus is the hands and feet. The feet can be protected with a plastic overboot that is removed just prior to entering the aircraft or donned just prior to exiting the aircraft. Contamination of the aircrew's gloves can be avoided by having the ground crew decontaminate any handholds. A protective cape can be used if covered transportation is not available to take the aircrew to or from the aircraft. Even if liquid contamination is kept out of the aircraft, gaseous contamination will enter whenever canopies or doors are opened. When the aircrew has no protection and lands in a contaminated area, ground crew will have to quickly provide individual protection, especially respirators, to the aircrew. During aircraft turnarounds, keeping the aircrew in the cockpit reduces contamination risk, but may add to crew heat stress in hot environments.

ECS design may be impacted by these various procedures for ingress and egress. If recirculated air loops are used, consideration should be given to a method of purging cabin and cockpit air of contamination after takeoff. Overcoming heat stress on the ground may place a larger burden on the ECS, since ground cooling capacity is generally limited. Also, if the capability to keep the aircraft clean on the ground, with the crew remaining on board, is desired, over-pressurization will have to be provided on the ground as well as filtration to remove contaminants from any source of fresh air. If respirators or ventilation devices from the crew's individual equipment are going to be connected to the ECS, the ECS designer needs to consider how these connections will be made in a contaminated environment without contaminating the air entering the crew's equipment.

9. PROTECTION

The ability to survive an NBC attack at an air base and sustain air operations in an NBC environment is dependent upon the integration of defensive measures. These measures should protect the aircrew during operations in the aircraft, during ingress/egress from the aircraft and during rest periods away from the aircraft and should protect the aircraft during operation and maintenance periods. These measures involve:

- The selection of new aircraft and ground support technologies or altering present systems
- Wearing of NBC protective ensembles that allow personnel to function in an NBC environment
- Avoidance of contamination by removing or avoiding contaminated areas.
- The selection of hardened and decontaminable materials.

Three ways of protecting the aircraft's occupants against NBC attack are:

- Individual protection
- Collective protection
- Hybrid protection (a combination of individual and collective).

9.1 Individual Protection

Personnel protection of the crew in an NBC environment requires personal protection equipment. The equipment is composed of a respiratory system and a protective suit with gloves and boots. The equipment should protect the wearer in field concentrations of CB agents and radioactive fallout particles. It must provide protection during transition from a collective shelter to the aircraft cockpit/cabin, during flight and during the transition back to the shelter. Disadvantages of individual protection are the impediment the equipment has on the crew’s ability to perform required activities and the added heat stress of the equipment.

9.1.1 Heat Stress Relief

As noted, the personal protection equipment adds to the already high heat stress that the air crews experience in certain operational environments. Relief should be provided to counteract this additional heat stress.

9.1.1.1 Definition of the Heat Stress

Heat stress of aircrews of modern military aircraft such as fighters, bombers and helicopters is caused by the heat generated by solar radiation, kinetic heating of the airframe and heat dissipation of cockpit avionics equipment. This heat stress along with the strain of low-level flight can deteriorate the crew's mental performance and, as a result, their ability to fulfill mission requirements. The heat stress is exacerbated by the necessity of wearing several layers of clothing, such as underwear, flight coverall, immersion protection garment (flight over water), thermal protection garment (in winter time, flight over water) and flight jacket. Extremely high g-loads of agile jet fighters must be countered by wearing an additional counter pressure vest. Special mission helicopter and transport plane pilots may also wear armored vests. With the many layers of garments worn in flight, even subjects at rest already have an increased heat stress. The heat stress increases further with high workload and uncomfortable environmental conditions, i.e. temperature and humidity.

In an NBC environment, the NBC protective garments add considerably to this heat stress, especially due to their impervious nature. The effect of heat stress on physical as well as mental performance is well documented. Cole [1983], Harrison [1977], Nunneley [1976], Nunneley [1977], Nunneley [1978], Stribley [1978] and Wing [1965] are just a few of such studies. Any mental or physical performance degradation is critical to military aircraft crews, where split second response and the performance of simultaneous tasks is often required in combat.

There have been many models developed to model the human thermal response. Buchberg [1968], Fanger [1969] and Wissler [1985] report on a few of such models, and Hwang [1977] summarizes many such efforts.

The human being tolerates heat storage of 630 J at a body temperature of 40 °C. Exceeding this value can lead to collapse, but degradation in mental performance occurs at body temperatures below that limit. The time of exposure to excessive environmental conditions impairs the ability to fulfill mental tasks. Wing [1965] summarized several studies showing mental impairment can occur at an effective temperature of 45.6 °C in only 6 minutes and at 35 °C in an hour. (Effective temperature is not defined in the reference, but MIL-STD-1472 has a definition.) MIL-STD-1472 indicates that a 5 °C increase in temperature should be assumed for personnel in NBC protection suits. This would mean that personnel in suits should not be exposed to a 40.6 °C maximum effective ambient temperature for more than 6 minutes or a 30 °C maximum effective ambient temperature for more than an hour.

As heat storage begins, the body's thermal regulating mechanisms come into operation, such as a sensation of heat, discomfort and deterioration of the psychomotor abilities leading to final collapse. For this reason the heat storage of the body must be prevented in the earliest stage. Investigations have shown that the limit of heat storage to be at three-fourths of the individual limit of tolerance.

The comfort experienced by human beings can be expressed by the mean weighted skin temperature, body core temperature (rectal), cumulative perspiration and air velocity at the body's skin surface. These parameters are defined in Table 3.

TABLE 3 - PARAMETERS RELATED TO HUMAN THERMAL COMFORT

Parameter	Ideal Value	Comfort Limit
Mean Weighted Skin Temperature	33.0 °C	34.4 °C
Body Core Temperature	37.0 °C	37.5 °C
Cumulative Perspiration		1% of body weight
Air Velocity	0.5 - 1.0 m/s (MIL-STD-1472)	2.54 m/s

9.1.1.2 Measures Against Heat Stress

Individual protection against heat stress can be achieved by several devices and measures:

a. Breathing of cool dehumidified air: Industrial personnel exposed to a hot and humid environment were supplied with cool dehumidified air to prolong the time of thermal tolerance with respect to this severe condition. A significant reduction of the heart rate, rectal temperature, perspiration loss or delta pH was not achieved. The cool air supply only reduced the ventilatory response to heat exposure, but it did not prevent the development of respiratory alkalosis or reduce its severity significantly below control levels.

b. Administration of drugs: Drugs are not deemed to be thermally protective, because investigations have shown that only the sweat sodium rate was significantly reduced, but the other parameters measured were not consistently altered.

c. Air ventilated suits: In the aerospace industry air ventilated suits were first employed for Gemini missions. Air ducts that distribute air to the body's extremities can achieve ventilation of the body. The back flow removes the moisture caused by perspiration. Another way of ventilation is to blow air onto the body's skin by small air outlets incorporated into a suit that is formed as an individual air compartment. Experience has shown that the air-ventilated suits allow thermal equilibrium to be attained at a lower metabolic rate of 175 W and provide enough of a reduction in the rate of body heat storage at 315 W to allow endurance times of 4 to 5 hours (Pimental [1987]). The study showed various evaporative and convective rates depending on the dry bulb and dew point temperatures. Other trials of air-ventilated suits have shown very low effectiveness at workloads above 350 W.

The low effectiveness of air cooled suits due to the low specific heat and low density of air results in the following disadvantages (Burton [1966]): (1) large flow requirements, (2) large cross sections of pipes and ducts, (3) large pressure drop that becomes worse at altitude, (4) large pumping power requirement, (5) large system weight, and (6) high noise level. Air ventilated suits do avoid the possible problems of leaking fluid and may be more expedient if a source of cooling air is already available, such as in an aircraft flight station or cabin conditioned by an air cycle cooling system.

d. Water-cooled garments (WCG): With the higher heat capacity of water compared to air, a WCG can be designed to be more flexible with higher suit mobility. Perspiration and increased body temperature can be significantly reduced with a WCG.

For a WCG, the heat load of the body should be absorbed in a way that the skin and body temperatures are reduced to values that coincide with the thermal comfort zone (see Figure 3).

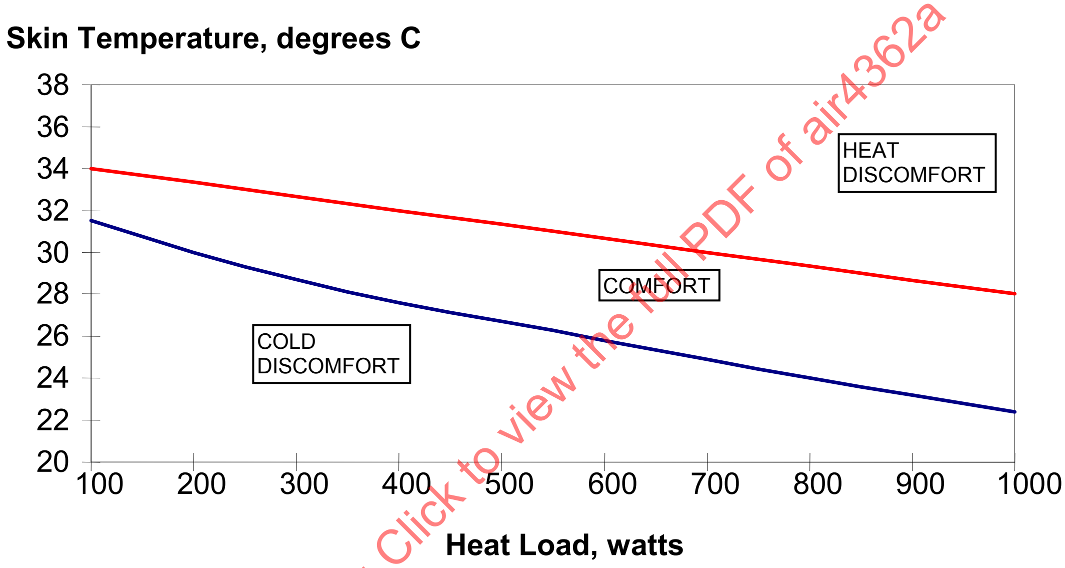

FIGURE 3 - COMFORT ZONE FOR WATER COOLED GARMENTS (BASED ON NUNNELEY, [1970])

Equally distributed liquid cooling of the body can cause uncomfortable thermal sensations of body parts (hand, feet, legs, torso, etc.) at different tasks, i.e. working muscles should be cooled more than muscles at rest. Subjects walking on a treadmill and allowed to select cooling for five independent suit segments chose high cooling rates for the legs and head with lower rates for the arms (Nunneley [1970]). The same is true for body areas particularly impacted by external heat loads such as solar radiation, i.e. the head and the upper part of the body.

Investigations have shown that the head dissipates an especially large amount of heat compared to the remaining portions of the body. Thus, the deployment of a hood can significantly increase the efficiency of a partial cooling suit. Such a garment is less bulky, easier to don and take off and has less weight, yet still offers limited thermal comfort.

e. A full comparison of air and liquid cooled garments is provided in Table 4.

TABLE 4 - COMPARISON OF AIR AND LIQUID COOLED GARMENTS

Item	Air System	Liquid System
Configuration	Open Loop	Closed Loop
Heat transfer method in garment cooling	Evaporation • Requires heat stress (perspiration) to be effective. • Self-regulating • Clothing stays drier in humid environment	Conduction and convection • Usually considered more efficient than evaporation. • Frequently produces condensation in humid environment (wet clothes).
CB Protection	Requires CB filter	Very good.
Leakage potential	Small. Not critical for system operation during and/or after connection with vest.	High. Potential hazard to cockpit (avionics) and aircrew (toxicity).
LTE pre-charge	Not necessary.	Necessary prior to each flight.
Hose quick-disconnect	Simple design, non-critical fluid leakage	Elaborate, zero leak requirements
Integration with man-mounted hardware	Single hose routed through the garments (flight suit, CB, cold water immersion suit) to the vest.	Two hoses routed through garments (flight suit, CB, cold water immersion suit) to the vest.
Chiller heat exchanger	Larger unit required.	Relatively small unit required.
Cooling vest ΔP	Negligible.	Small.
Logistics	Resupply of CB filters for air systems without clean supply (CB operations only).	Requires storage of coolant and a means for charging the garments of aircraft system (if liquid other than avionics coolant).
Maintenance	Relatively easy to maintain.	Higher failure rates of liquid pumps and system leakages. Also, cold weather handling procedures are needed.

9.1.2 Respiratory System

An NBC-protective respiratory system provides protection for the respiratory tract, eyes and skin of the head by the supply of clean breathing air. The system is different for jet aircraft and helicopters because of the necessity of being supplied with oxygen for the jet aircraft crews. The basic equipment consists of an impermeable hood unit for the protection of the head, a blower unit with filter, a breathing filter, a battery pack, a communication unit and a filter support bag.

The respiratory system is worn under the aircrew flight helmet. Air hoses connect the hood unit to the aircraft air or oxygen supply system by means of quick disconnects. During ground operation, NBC protection can be accomplished by connecting the input of the filter canister to the output of a portable air blower. Aircraft communication is achieved with an integrated microphone and earphones in the helmet.

a. Jet Aircraft - The air distribution system to the hood/mask should have a connector to the oxygen supply system installed in the aircraft, a bailout bottle, a blower and a filter canister.

i) In-Flight Mode - A connection for the oxygen supply requires an adapter for an oxygen regulator, an NBC-breathing filter canister and a blower with filter canister attached to the air-inlets of the adapter. Different systems of respiratory air supply are shown in Figure 4.

ii) Ground Mode - On the ground, the blower is connected via the portable filter to the nose cup. The air necessary for de-misting is taken also from the blower and is routed into the hood, crossing the visor. See Figure 5 for alternative designs.

b. Helicopter - Air vehicles, such as helicopters, that do not need oxygen supply due to their low altitude operation will have another type of respiratory system, i.e. the blower provides the hood unit with both breathing and de-misting air. The hood should have a special visor if optical devices have to be used, e.g. night vision goggles (NVG).

i) In-Flight Mode – For the in-flight mode, two possibilities of operation are feasible:

- Use of the blower for the supply of air to the hood unit. In this case the blower sucks air from the cockpit/cabin. This means an additional electrical connector for operation of the blower. It also has to be designed to fulfill the life cycle of the helicopter.

- Supply of conditioned air to the hood unit by an ECS. In this case the blower is switched off during flight. The respiratory system is connected to the air distribution system of the ECS of the helicopter by a quick release connector. Supply pressure and airflow of the ECS must be compatible with the requirement peculiar to the respiratory system.

ii) Ground Mode - On the ground, the employment of the blower is operated as described for the jet aircraft.

9.2 Collective Protection:

NBC Collective Protection refers to the field of operating military aircraft within an environment potentially contaminated with NBC threats by protecting the aircraft crew and equipment. The primary advantages of providing collective protection is to enable the crew to operate in a shirtsleeve environment without the encumbrance imposed by individual protection equipment and to avoid the need to perform potentially damaging decontamination on sensitive interior equipment.

One method of collective protection is to slightly pressurize the cockpit and/or the cabin of the aircraft to maintain a positive pressure inside. This prevents NBC agents from infiltrating the cockpit/cabin. In order to keep the aircraft pressurized, a source of "makeup" air is needed to replace the air lost through uncontrolled leakage. There may also be requirements to introduce additional air into the cockpit/cabin to cool the interior of the aircraft and maintain a satisfactory environment for the crew. This makeup air must be filtered to remove potentially harmful agents.

For aircraft such as helicopters, collective protection has the added disadvantages of a weight increase of the structure due to the loads of pressurization and the additional cost of sealing doors and windows. However, the crew and passengers do not need to wear personal protective suits during their mission.

To prevent ingestion of NBC agent into the cockpit and avionics bays via the engines and ECS, all external air entering the cockpit and avionics bays must be restricted or filtered. One solution is to provide a closed-loop ECS in which the primary fluid circulated through the cockpit and the avionics is recirculated air. Though the technology for providing a closed-loop ECS that protects the aircrew and avionics systems against NBC agents exists, the incorporation of these designs into existing aircraft is either impractical or at best limited because of the associated penalties, namely weight, power, volume, cost and performance degradation. Future aircraft designs may lend themselves to incorporation of a closed-loop ECS, since they are considered a potential approach for fuel savings in addition to affording full NBC protection.