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ENGINEERING DESIGN HANDBOOK

ENVIRONMENTAL SERIES. PART FOUR.

LIFE CYCLE ENVIRONMENTS

ARMY MATERIEL COMMAND

31 MARCH 1975

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LIFE CYCLE ENVIRONMENTS

HEADQUARTERS, U S ARMY MATERIEL COMMAND MARCH 1975

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ENGINEERING DESIGN HANDBOOK
ENVIRONMENTAL SERIES, PART FOUR
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PREFACE

This handbook, *Life Cycle Environments*, is the fourth in a series on the nature and effects of environmental phenomena. Environmental factors – natural and induced – are discussed individually in Parts Two and Three, respectively. In this Part Four the real environment, to which materiel and personnel are subjected, is described and its effects are discussed. These are comprised of various combinations of the individual factors, often exhibiting synergistic effects.

The contents are directed at the materiel design engineer to (1) alert him to the multiplicity of environmental effects that affect materiel in a given instance, and (2) provide him with sufficient information to identify the specific environmental effects that require more extensive analyses. The emphasis is on the totality of the factors characterizing a climate, on the totality of effects experienced by classes of materiel, and on the totality of factor combinations experienced in the life cycle – separated into logistic and operational phases.

It is impractical to acknowledge the assistance of each individual or organization which contributed to the preparation of this handbook. Appreciation, however, is extended to the following organizations and through them to the individuals concerned:

a. Frankford Arsenal

b. US Army Cold Regions and Research and Engineering Laboratory

c. US Army Engineer Topographic Laboratories

d. US Army Natick Laboratories

e. US Army Tank-Automotive Command

f. Atmospheric Sciences Laboratory, US Army Electronics Command.

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CHAPTER 1

INTRODUCTION

This handbook presents information on the environment to which Army materiel is subjected during its life cycle. It is directed to the materiel design engineer (1) to alert him to the multiplicity of environmental effects on materiel, and (2) to provide him with sufficient information to identify specific environmental effects that require more extensive analysis. The emphasis in the chapters that follow is on the totality of factors characterizing a climate, on the totality of effects experienced by classes of materiel, and on the totality of factor combinations experienced in the life cycle separated into logistic and operational phases. That the presentation is incomplete reflects on the limited availability of information on life cycle environments and on practical limitations on the recovery of this information from diverse sources.

This handbook is Part Four of the Environmental Series of Engineering Design Handbooks. Part One, *Basic Environmental Concepts*, introduces the series. Parts Two and Three provide extensive information on environmental factors taken singly, and Part Five provides a glossary. Although this series is coordinated, each part may be employed separately. There is, therefore, a desirable degree of overlap in the contents, although the objective of each of the handbooks is distinct from the others. For example, a pervasive environmental factor may be discussed for different purposes in a number of chapters; e.g., temperature is the subject of one chapter in Part Two where it is treated as a distinct factor and is treated in other chapters in Parts Two and Three where its interactions with other factors are brought out.

1-1 ENVIRONMENT AND ENVIRONMENTAL FACTORS

Environment is the totality of natural and induced conditions occurring or encountered at a given time or place including climatic, edaphic, biotic, and topographic factors as well as the induced factors comprising radiation of all types, mechanical stresses, and airborne pollutants. For this handbook series, 21 environmental factors are identified and discussed. The natural environmental factors are:

Terrain
Temperature
Humidity
Pressure
Solar Radiation
Rain
Solid Precipitation
Fog and Whiteout
Wind
Salt, Salt Fog, and Salt Water
Ozone
Macrobiological Organisms
Microbiological Organisms

The induced environmental factors are:

Atmospheric Pollutants
Sand and Dust
Vibration
Shock
Acceleration
Acoustics
Electromagnetic Radiation
Nuclear Radiation

For some purposes the term "environment" covers all possible combinations of factors—it is a monolithic whole. By this definition, any subdivision of the environment into segments is a violation of the definition and is completely arbitrary. However, there are practical reasons for defining specific environments or regions of the environment characterized by the occurrence and severity of various combinations of environmental factors. This permits logical derivation of environmental concepts and provides a means for discussing a complex, multiparameter, multivalue situation. Certain combinations of environmental factors occur with sufficient frequency to be useful in categorizing environment without redefining the occurrence and magnitude of environmental factors each time. Finally, the use of a broader definition is attractive because categories of environment can be identified (correlated) with specific events or stages in the life cycle of materiel.

The practice in this handbook series is to allow identification of types of environments or specific regions of the environment. It does not, however, extend to the identification of an environment by one environmental factor; i.e., terminology such as "the electromagnetic radiation environment" is in contradiction to the definition. The environment is the totality of all factors at a given time or place and the use of "tropical" or "logistics" serve only to identify the time or place.

One useful way in which environment is classified is by climate—the occurrence of particular combinations of natural environmental factors and factor values in particular geographic regions. Table 1-1 demonstrates the relationship among the various individual environmental factors and the four major climatic types: temperate, arctic, desert, and tropical. It is important to note that a classification system based on climate is not related directly to effects on materiel.

The climatic environment in a particular geographic location at a particular time is the same for all materiel in that location regardless of the status of the materiel, unless it is modified by special measures taken to protect the materiel. It turns out, however, that the climatic environment experienced by materiel in a given location at a given time does, indeed, vary with status—not because the climatic environment has changed, but because the status of materiel is related to the amount of protection provided the materiel. As a result, it is possible to correlate exposure to climatic factors with specific events or phases in the life cycle of materiel, based on the protective measures employed. A prime example would be the difference in materiel exposure to ambient climatic factors resulting from open storage versus dehumidified, covered storage.

Three of the natural environmental factors—terrain, macrobiological organisms, and microbiological organisms—are not primarily functions of climate, although the severity of effects produced by the three factors is influenced greatly by climatic factors. Generally, the severity of the effects of these three factors must be assessed for each climatic type independently.

The induced environmental factors are mixed in their relationship to natural and climatic factors—some are strongly related to certain natural factors in their effects on materiel and some are virtually independent of all other environmental factors, natural or induced. It is instructive to consider the relative independence of the induced factors separately.

Atmospheric pollutants interact with humidity, rain, solar radiation, salt, salt fog, salt water, and ozone (a pollutant itself at times) to accelerate corrosion and other deteriorative processes. Induced sand and dust are caused primarily by vehicular movement. Yet, if rain or even high humidity is present, the likelihood of sand and dust being generated by vehicle traverse is nearly zero. Terrain also is related since, if sand and dust are not present on the surface of the terrain (hard rock surfaces), no reasonable amount of vehicle traffic will induce sand and dust problems.

TABLE 1-1.
RELATIONSHIP OF ENVIRONMENTAL FACTORS TO CLIMATE

Factor	Temperate	Arctic	Desert	Tropical
Terrain	+++	+++	+++	+++
Low temperature	++	+++	0	0
High temperature	+	0	+++	++
Low humidity	0	0	++	0
High humidity	++	+	0	+++
Pressure	0	0	0	+
Solar radiation	+	++	+++	++
Rain	++	+	+	++
Fog	++	++	0	0
Solid precipitation	++	++	0	0
Whiteout and ice fog	0	++	0	0
Salt, salt fog, salt water	+	+	+	++
Wind	+	++	+	+
Ozone	*	*	*	*
Macrobiological organisms	+	0	0	+
Microbiological organisms	+	0	0	+++
Atmospheric pollutants	*	*	*	*
Sand & dust	+	0	+++	+
Shock	*	*	*	*
Vibration	*	*	*	*
Acceleration	*	*	*	*
Acoustics	*	*	*	*
Electromagnetic radiation	*	*	*	*
Nuclear radiation	*	*	*	*

+++ Key factor
++ Important factor
+ Active factor
0 Unimportant or absent factor
* Little or no climatic relationship

Shock, vibration, and acceleration forces are applied to most materiel, primarily during transportation and handling. The shock and vibration of materiel during surface transit is related directly to the surface characteristics of the terrain traversed. Some materiel such as vehicles and weapons are subject to shock and vibration during normal use. Acceleration is rather unique in that highly unusual circumstances are required before accelerations of magnitude sufficient to have an effect on materiel occur. The occurrence of significant acceleration magnitudes lies so far outside the normal environment of military materiel (with the possible exception of rockets and projectiles) that it is rare. Because of the infrequent occurrence of this factor in significant magnitudes in the normal life cycle of materiel, it will not be discussed further in this volume.

The induced radiation factors are almost independent of other environmental factors. Electromagnetic radiation produces two effects on materiel: (1) RF heating whose effects are additive to those produced by temperature and solar radiation, and (2) electromagnetic interference, which is essentially independent (except for terrain blocking effects) of other factors. It also should be noted that electromagnetic interference effects are rather specific affecting only specialized types of materiel (primarily electronic equipment and then mostly equipment that radiates or receives electromagnetic energy). Acoustics is a similar factor. Noise, as normally encountered, primarily affects personnel and can be neglected for most discussions of materiel, although it can be technically significant in materiel design when silence is necessary or useful for concealment purposes, or when the noise frequency and intensity is injurious to personnel.

Nuclear radiation is a very low probability event, requiring nuclear war or an accidental nuclear explosion. Should such a nuclear event occur, however, the effects produced on materiel nearby are so overwhelming that all other environmental factors pale into insignificance.

In this volume certain specific environmental factors will not be discussed. Those omitted were selected by using two criteria:

(1) If a factor is virtually independent of all other factors, it will not be discussed because its effects already have been covered fully in the single-factor discussions of Parts Two and Three.

(2) If occurrence of a factor is considered to be a low probability event in the materiel life cycle, it is not discussed.

The factors thus exempted from discussion herein are acceleration, acoustics, electromagnetic radiation, and nuclear radiation. A number of other factors are discussed in little detail because their interrelationships are rather simple, so that the single-factor discussions are adequate approximations to their overall effects. In life cycle discussions herein, primary emphasis is given to those complexes of interrelated and simultaneously occurring factors that produce significant effects on materiel. The probability of simultaneous occurrence of natural factors is delineated clearly when these natural factors are categorized by climate. Because of the existence of this correlation, climatic types form the foundation for discussion of natural climatic factors in the life cycle environment. Discussion of nonclimatic factors in life cycle environments is integrated within this structure.

1-2 MATERIEL

Materiel is defined as all items necessary for the equipment, maintenance, operation, and support of military activities without distinction as to their application. While this handbook is concerned with all materiel, it places emphasis on those classes of materiel that (1) constitute more of a problem because of their susceptibility to environmental effects, (2) are critical to military activities, or (3) are of high value. For example, little emphasis is placed on fuel in the logistic environment because of the few adverse effects to consider but much emphasis is placed on personnel equipment items and vehicles in the operations environment because of the important effects of environment on these items and because of their critical roles.

The interaction of materiel with environment is characterized in a variety of ways. One indication of the interaction level of various classes of materiel and some operations is given in Table 1-2. These data are

TABLE 1-2.
INTERACTION OF ENVIRONMENT WITH MATERIEL AND OPERATIONS (Ref. 2)

Environmental factor	Personnel equipment			Food supplies		Medical facilities and supplies				Weapon operation				Munitions					Fuels				Vehicle operation				Aircraft: Fixed-wing		Aircraft: Rotary wing		Communication equipment			Construction	
	Personnel	Combat support	Noncombat and life support	Preserved: canned, etc.	Perishable	Permanent structure	Temporary structure	Instruments	Perishable medical supplies	Individual	Mortar	Field art.	Rockets, missiles	Small arms, grenades	Artillery, bombs	Mines	Incendiaries	Rockets	Aviation gasoline	Gasoline and diesel oil	Lubricants	Solids	Wheeled	Tracked	Crossing and fording	Water	Transport	Reconnaissance	Transport	Reconnaissance	Line transmission	Air transmission	Visual transmission	Road building, bridging	Water supply
Climate																																			
Haze and optical phenomena, shimmer and glare	2									1	1	1	1										1	1	2	1	1	1	1	1			1		
Fog	1									1	1	1	1										1	1	1	1	1	1	1	1		2	1	2	
Cloud cover and base										2	2	2	2										2	2	2	2	1	1	1	1		1	1		
Blowing sand and dust	1	1	2	2	1		1	2	1	1	1	1	1						2	2	2	2	1	1	2	2	1	1	1	1	2	1	1	1	2
Precipitation	1			1	2		1	2	1	1	1	1	1	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1	1	2		1	1	2
Moon and star intensity	1									1	1	2	2										1	1	1	1	2	2	1	1			1	2	
Temperature-maximum and range	1	2	1	1	1	2	1	1	1	2	2	2	1	2	2	2	2	1	1	1	1	2	1	1	1	1					2	2		1	1
Humidity	1	2	1	2	1	2	1	1	1					1	2	2	1	1													2	2			
Wind direction and fluctuations	1						1			1	1	1	1		2		2	2					2	2	1	1	1	1	1	1	2	2		1	2
Solar radiation	1	1	1	2	1	2	1		1	2	2	2	2						1	1	1	2	2	2	2	2								2	
Evaporation rate	1		2	1	1				1								2		1	1															
Atmospheric pressure	2																		2	2			2	2			1	1	1	1		2			
Terrain																																			
Landforms and features						2	2			2	2	2	2										2	2	2		2	[illegible]	2	2		2	2	2	2
Elevation	2					2	2	2	2		2	2	2						2	2			2	2	2		1	1	1	1		2	2	2	2
Relief	2					2	2			2													1	1	1		1	1	2	2	1	1	1	1	2
Slope	2					2	2			2	2	2	2										1	1	2		1	1	2	2	1	2	2	1	2
Surface materials	2					2	2				2	2	2										1	1	1	2			2	2				1	1
Hydrology	2		2	2		1	2			2	2	2											1	1	1	1					2			1	1
Vegetation																																			
Vegetation color	2		1			2	2																										1		
Perennials, annuals	2					2	2								2		2	2					2	2	2	2		2	2	2			2	2	
Trunk base size	2									2	2	2	2	2	2	2	2	2					1	1	2	2							1	1	
Shallow rooted-deep rooted	2																						1	1	2									1	
Plants and plant communities	2					2	2			2	2	2	2	2	2	2	2	2					2	2	2			2	2	2	2		1	1	
Animal life	1		2	1		2	2		2																		2	2							

Legend: Environmental factor exerts pronounced (1), moderate (2), or no notable (blank) influence.

*Based on consensus (subjective) of study team

subjective; i.e., they are based on the consensus of a knowledgeable study team.

1-3 PHASES OF THE LIFE CYCLE

Life cycle as applied herein to materiel has a somewhat different meaning from that applied to systems. A system life cycle can be divided into five phases: (1) concept formulation, (2) contract definition, (3) development, (4) production, and (5) operation (Ref. 1). This is an inclusive definition encompassing every step in the development of military systems from concept to final operating unit. This definition is not suitable for discussing the life cycle environment of Army materiel. Although information on the environment to which materiel is exposed is important in the materiel design and development process, the actual life of a given item of materiel begins when it is procured by the military. For most manufactured items, the life of the materiel begins with delivery from the supplier and extends to the point of expenditure or disposal. It is within this context that the term "life cycle" is employed in this handbook. Life cycle refers to the totality of events experienced by materiel from the point of procurement until its final disposition.

Matrriel procured by the Army is procured for use, regardless of whether that use consists of (1) a single occurrence in which the materiel is expended or destroyed, or (2) repetitive uses over a relatively long period of time. Generally, Army materiel is not acquired at the geographic location at which it is used, it is transported from the point of procurement to the point of use. Most materiel is procured sometime prior to its use and consequently must be stored until needed.

The materiel life cycle--extending from procurement to expenditure or disposal--consists of two phases: (1) the transportation and storage necessary to give place and time utility to materiel, and (2) operational use of the materiel. These two phases can be defined as being the logistic and the operational phases of the materiel life cycle. The environment experienced by materiel in these two phases of the life cycle are sufficiently different to be uniquely characterized as the logistic environment and the operations environment.

1-3.1 LOGISTIC PHASE

The *Dictionary of Military and Associated Terms* defines logistics as the science of planning and carrying out the movement and maintenance of forces (Ref. 3). In its most comprehensive sense, it comprises those aspects of military operations that deal with design, development, procurement, storage, movement, distribution, maintenance, evacuation, and disposition of materiel. In this handbook, logistics has a narrower usage. First, the design and development stages are not included since the environments of these activities do not affect procured materiel. Second, maintenance, evacuation, and disposition of materiel are not included since the environment in these portions of the logistic cycle have little importance--if it is to be reused, the materiel will first be refurbished. Within these constraints, the logistic cycle begins at the point of procurement and extends until issue of materiel to operating personnel.

The logistic cycle as illustrated in Fig. 1-1 consists of procurement packaging transport, storage, and issue. Within this cycle it is apparent that handling is an important part of the logistic environment because of its repetitive nature and severe stresses (primarily mechanical shock and vibration). In the diagram, the storage-transport loop illustrates the repetitive pattern of storage, handling, and transport of materiel in the logistic cycle. For example, materiel may be transported from the point of procurement to a warehouse within the continental United States and stored for a period of time. It may then be transported to an overseas base and again stored for an additional period of time. Finally, it may be transported to a lower echelon and stored again, with issue to the operating unit occurring after a number of such cycles.

1-3.2 OPERATIONS PHASE

The operations environment is defined in the *Dictionary of Military and Associated Terms* as a composite of the conditions, circumstances, and influences that affect the employment of military forces and bear on the decisions of the commander (Ref. 3). The operational phase of the materiel life cycle is defined in this handbook to mean those conditions, circumstances, and influences that affect materiel during the period of time from issue to a user organization until expenditure or disposal.

Once materiel has been issued to the using unit, it is in the operational environment. Fig. 1-2 illustrates the major events that occur in the operational cycle. Most materiel is not used immediately upon issue but rather must await the proper circumstance before its use. Materiel in the hands of the user, but not in use, is in operational storage. After operational storage, materiel is transported to the

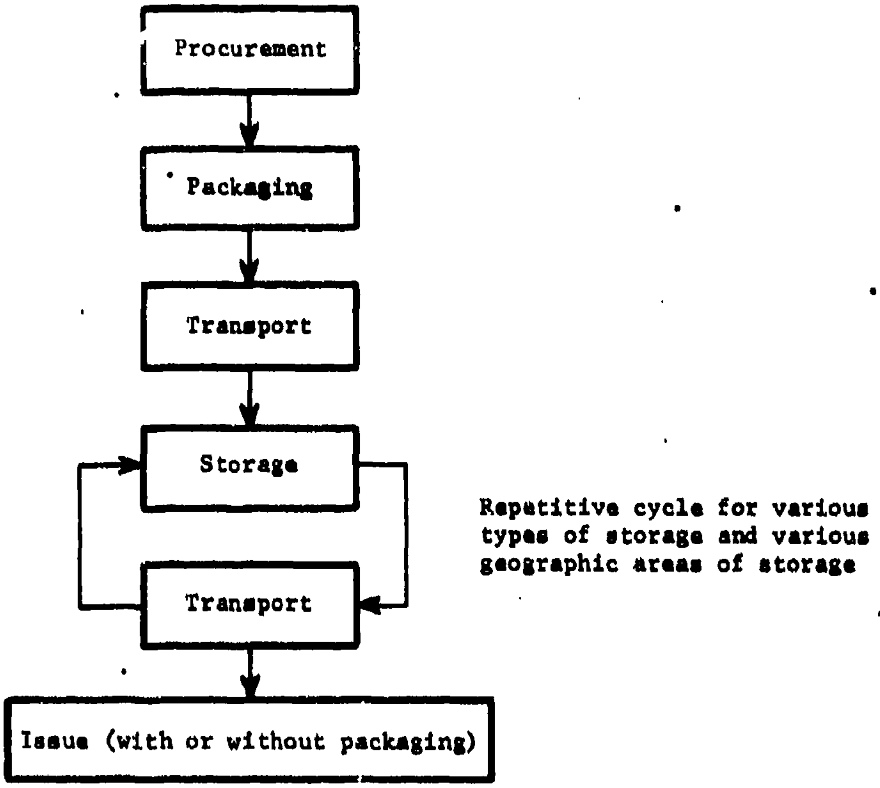


Figure 1-1. Logistic Cycle

point of use and finally used for the purpose for which it was designed. If materiel is reusable or reparable after use, it may be transported to a depot for repair and servicing, after which it reenters the logistic system for reuse. These cycles, outlined in Fig. 1-2, have some variation as indicated by the multiple loops. When equipment or materiel has reached the point that maintenance and repair are no longer profitable, the materiel is transported for disposal. The cycle outlined in Fig. 1-2 is applicable to major maintenance only; much minor repair and maintenance is done by the user. The generalized description of the operational phase varies greatly among the different types of materiel.

The operational use of materiel provides the most important encounter with the environment. To this point in the life cycle, emphasis is on maintaining the materiel in something close to its original condition. In operational use, materiel is not protected. If the materiel is expendable, it must function while being used—ammunition, fuel, and rations must perform their intended functions regardless of climate or other environmental factors. Nonexpendable materiel—vehicles, shelters, weapons, tools, electronics, and utilities—must continue to function, often with wide variations in environmental factor value. Often, the maximum stress is caused by an extreme environmental condition. For example, typical extreme stresses on vehicles are encountered in mud, snow, or river crossings; for shelters, extreme temperatures, wind, and precipitation constitute extreme operational stresses. The effects of the operational environment often constitute the

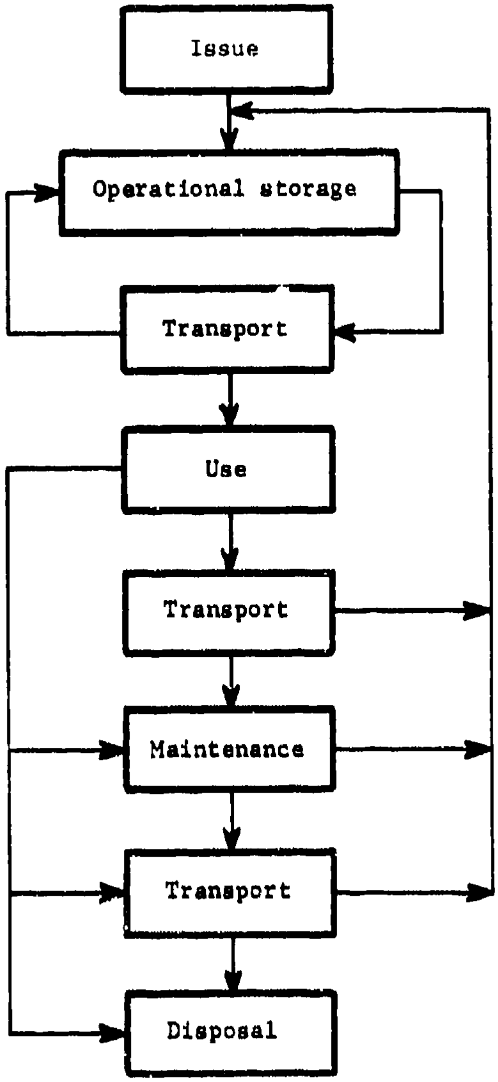


Figure 1-2. Operational Cycle (Reusable Items)

major reason for materiel failure, thereby determining the length of the operational phase of the life cycle.

The operational cycle for expendable items is considerably less complex as shown in Fig. 1-3. In this case, materiel that is issued to the using unit is placed in operational storage and transported to the location where its use is required. Of course, for expendable items, this use terminates the life cycle of the item.

1-4 ENVIRONMENTAL EFFECTS IN THE LIFE CYCLE

Having defined the logistic and operational phases of the materiel life cycle in the preceding paragraph, it is apparent that storage and transport are important in both. To illustrate relationships between transport modes and environment, Table 1-3 presents a comparison of the four major modes of transport: truck, rail, ship, and air. In this table, the environmental exposures that occur for open and closed transport are described, and the environmental factors that produce the more significant effects within each environmental exposure are listed.

Table 1-4 lists the relationships between types of storage and the environment experienced by materiel. Three representative types of storage are used to illustrate the range of environmental exposure which can occur to materiel in storage. As in Table 1-3 the environment is described along with the most significant environmental factors.

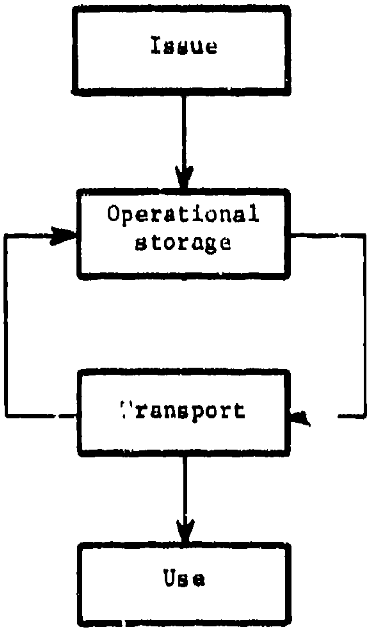


Figure 1-3. Operational Cycle (Expendable Items)

TABLE 1-3.
RELATIONSHIPS BETWEEN TRANSPORT MODES AND THE ENVIRONMENT EXPERIENCED BY MATERIEL

Transport type	Environmental exposure	Most significant elements
Truck		
Open	(1) Ambient climatic and natural factors	(1) Temperature, humidity, solar radiation, rain, solid precipitants, natural wind, and induced wind
	(2) Low to high level shock and vibration	(2) Terrain (road surfaces)
	(3) Sand and dust	(3) Terrain, wind
Closed	(1) Modified climatic and natural factors (can intensify or reduce effect of certain factors)	(1) Temperature, solar radiation, humidity
	(2) Low to high level shock and vibration	(2) Terrain (road surfaces)
Rail		
Open	(1) Ambient climatic and natural factors	(1) Temperature, humidity, solar radiation, rain, solid precipitants, natural wind, and induced wind
	(2) High level shock	(2) Switching operation, run-in and run-out
	(3) Sand and dust (less severe than for open truck because vehicle induces far less airborne sand and dust)	(3) Wind, terrain
Closed	(1) Modified climatic and natural factors (can intensify or reduce effect of certain factors)	(1) Temperature, solar radiation, humidity
	(2) High level shock	(2) Switching operations, run-in and run-out

TABLE 1-3 (Continued).
RELATIONSHIPS BETWEEN TRANSPORT MODES AND THE ENVIRONMENT EXPERIENCED BY MATERIEL

Transport type	Environmental exposure	Most significant elements
Ship		
Above decks	(1) Ambient climatic and natural factors	(1) Salt water, salt spray, salt fog, humidity, temperature, solar radiation, rain, solid precipitation
	(2) Shock, vibration, and acceleration significantly less than for rail or truck	(2) Wave impact, drive train vibration
Below decks	(1) Modified ambient climatic and natural factors	(1) Humidity, temperature, solar radiation, macrobiological organisms, microbiological organisms
	(2) Shock, vibration, and acceleration significantly less than for rail or truck	(2) Wave impact, drive train vibration
Air		
Exterior transport	(1) Ambient climatic and natural factors	(1) Low temperature, pressure, fluctuation (altitude), rain, solid precipitation, induced wind
	(2) Shock, vibration, and acceleration	(2) Structurally transmitted shock and vibration, resulting from landing, maneuvers, aerodynamic forces, aircraft components
	(3) Sand and dust	(3) Helicopter rotor wash, aircraft prop wash, jet engine exhaust
Interior transport	(1) Modified ambient climatic and natural factors	(1) Low temperature, pressure fluctuation (altitude)
	(2) Shock, vibration, acceleration	(2) Structurally transmitted shock and vibration, resulting from landing, maneuvers, aerodynamic forces, aircraft components

TABLE 1-4.
RELATIONSHIPS BETWEEN STORAGE TYPE AND THE ENVIRONMENT EXPERIENCED BY MATERIEL

Storage type	Environmental exposure	Most significant elements
Open	All ambient climatic and natural factors	Varies with climatic type
		Arctic: solid precipitants, low temperature, wind, rain
		Desert: high temperature, solar radiation, sand and dust, low humidity, wind
		Tropical: fungi, high temperature, high humidity, solar radiation, rain, macrobiological organisms, salt spray and fog
		Industrial: ozone and atmospheric pollutants can be important during open storage in industrialized areas
Sheltered	Protection provided from most climatic factors	Varies with climatic type
		All climates: temperature, macrobiological organisms
		Additional tropical and some temperate: high humidity, fungi
		Additional desert: low humidity, sand and dust
Sheltered, dehumidified	High degree of protection from exposure	Temperature, macrobiological organisms, and sand and dust can on occasion cause some problems

Table 1-5 depicts the relationship of environmental factors to various stages in materiel life cycles. In this table the natural and induced environmental factors are listed. The columns represent important stages in the logistic and operational environments. The logistic environment cycle includes transport, storage, handling, and use. The operational environment cycle includes transport, storage, handling, and use. In both cases storage is considered to be sheltered storage. Open storage is in a separate column since it is the same regardless of whether the materiel is in the logistic or the operational environment. Within this matrix, qualitative information is presented concerning the number of different materiel types affected by the environmental factor, the severity of the effect produced on the affected materiel, the significance of the factors to the phases of the life cycle, and the frequency of occurrence of the effects of the various factors. While the information presented is qualitative, the utility of the table is the concise comparison of the relative importance of environmental factors in the major phases of the materiel life cycle.

1-5 HANDBOOK ORGANIZATION

In deference to the unity of the environment, the overall natural environment for materiel, regardless of its status or phase in the life cycle, is considered in Chap. 2 in which the climates of the world are discussed. This serves to indicate the variety of climatic conditions possible. Climatic extremes are given to delineate the range of various climatic factors, and the climate of the Army is discussed on the basis of the three major severe climatic environments. These environments are emphasized because the probability of materiel degradation or other inhibitory effect is exaggerated by extreme environments.

Having delineated the range of natural environmental factors to be expected in each climatic category, the effects of these factors on materiel and personnel are considered in Chap. 3. The major effects on materiel discussed include interference, mobility degradation, and mechanical and chemical damage to materiel.

Chap. 4 approaches the effects of environment on operations from the standpoint of the total environment. The combinations of factors likely to occur in specific environments and the interactions that produce significant effects on materiel are detailed for the three extreme climatic environments. Pars. 4-2, 4-3, 4-4, and 4-5 discuss the rapid-acting environmental factors that impair operational execution, whereas par. 4-6 discusses the factors that impair operational readiness. The factors of most significance in operational readiness are those that produce materiel degradation.

The logistic environment is explored in Chap. 5. Although it may seem more appropriate to discuss the logistic environment before the operations environment since it occurs earlier in the materiel life cycle, the operational environment involves the greater exposure to environmental factors and delineates the more general environment for materiel. In the logistic environment, materiel is not exposed to the extremes experienced in operations because it is protected (the packaging and other protective measures applied to materiel in the logistic environment are designed to reduce the extremes of environmental factors applied to materiel). Thus, it can be seen that the logistic environment is a special case of the operational environment in which the extremes of certain factors are less.

Handling, storage, and transportation are three distinct functions in the logistic cycle, each with a different environment for materiel. Handling is a function in every logistic operation, occurring whenever a change in status of the materiel occurs. It produces mechanical shock and vibration stresses on materiel. The storage environment depends upon the type of storage. The transportation environment increases exposure of materiel over that in storage. For example, in open shipment such as on decks of ships or in open boxcars or trucks, the

TABLE 1-5.
RELATIONSHIP OF ENVIRONMENTAL FACTORS TO THE VARIOUS STAGES IN THE MATERIEL LIFE CYCLE

Factor	Logistics				Operational			
	Transport	Storage	Handling	Open storage	Transport	Storage	Handling	Use
Terrain	C+	NA	NA	NA	A+	NA	NA	A++
Low temperature	C-	C-	B+	A+	C+	B+	B+	A+
High temperature	C+	A+	C-	A+	C+	A+	C-	A
Humidity	C-	AO	C-	A-	C-	AO	C-	A+
Pressure	*C	NA	NA	NA	*C	NA	NA	NA
Solar radiation	C-	NA	C-	C-	C-	NA	C-	C+
Rain	C-	NA	C-	B+	C-	NA	C-	A+
Solid precipitation	C-	NA	C-	A+	C-	NA	C-	A+
Fog and whiteout	A++	NA	NA	NA	A++	NA	NA	A++
Salt, salt fog, and salt water	B+	B-	C-	A+	B-	B+	C-	A+
Wind	C-	C-	NA	C-	C-	C-	NA	B-
Ozone	*C-	NA	*C-	*C-	*C-	NA	*C-	*C-
Macrobiological organisms	C-	CO	NA	B+	C-	C-	NA	CO
Microbiological organisms	C-	A+	NA	AO	C-	A+	NA	A++
Atmospheric pollutants	*C-	*C-	NA	*C-	*C-	*C-	NA	*C-
Sand and dust	B+	NA	NA	A-	B+	NA	NA	A+
Shock	A+	NA	A+	NA	A+	NA	A+	A+
Vibration	B+	NA	C-	C-	B+	NA	B+	A+
Acceleration	*C-	NA	NA	NA	C-	NA	NA	B+
Acoustics	*C-	*C-	*C-	*C-	*C-	*C-	*C-	C-
Electromagnetic radiation	*C-	*C-	*C-	*C-	*C-	*C+	*C+	C+
Nuclear radiation	*A++	*A++	*A++	*A++	*A++	*A++	*A++	*A++

Frequency

* Low

All other relationships occur frequently, dependent, however, on specific circumstances.

Scope of effects

A Many materials
B Some materials
C Few materials

Degree

++ Very severe
\+ Severe
\- Little
0 Moderate

NA Not applicable

packaged materiel is exposed to the full range of the operational climate as well as to shock and vibration induced by the transporting vehicle.

Chap. 6 discusses specifications and standards, particularly in relationship to the environment. Discussion of specifications and standards is important since the characteristics of the materiel that enters the military logistic and operational environments are determined primarily by specifications and standards. These specifications and standards produce the materiel design. Materiel design, in turn, determines its resistance to environmental effects, thus determining the length of the life cycle. In Chap. 6 an overall discussion of specifications and standards relating briefly the history and impact of standards and specifications is given, along with a discussion of those standards and specifications particularly related to environment.

REFERENCES

1. *Defense Standardization Program*, Department of Defense Directive 4120.3, Washington, D C, 13 January 1967.
2. G. H. Howe et al., *Classification of World Desert Areas*, TR 69-38-ES, U S Army Natick Laboratories, Natick, Mass., December 1968.
3. *Dictionary of Military and Associated Terms*, Joint Chiefs of Staff, Department of Defense, Washington, D C, 3 January 1972.

CHAPTER 2

OPERATIONAL CLIMATES OF THE ARMY

2-1 INTRODUCTION

The operational climate of the Army clearly encompasses the full spectrum of terrestrial climates. In nonmilitary activities, extreme climatic stress conditions can be and usually are avoided, but in military operations this option cannot be exercised. The exposure of materiel to environmental extremes constitutes, therefore, the most important difference between the climate of the Army and climates encountered by nonmilitary materiel. Most military materiel will not be exposed to extreme conditions and that which is will only be exposed for a small percentage of its life cycle. Nevertheless, when such exposure occurs, the materiel must perform its intended function. Thus, this chapter on the climates of the Army includes general descriptive information on world climates with particular note of climatic extremes, but most attention is given to those climatic types that provide the most stress on materiel—the tropical, desert, and arctic environments.

Part One of this Environmental Series of Engineering Design Handbooks contains descriptions of world climates, and Parts Two and Three include descriptions of climate as relevant to particular environmental factors. Thus, a portion of the material in this chapter is redundant with information in other parts of this handbook series, but the duplication is necessitated by the importance of climate in consideration of materiel life cycles.

All real environments involve a number of environmental factors acting in parallel or in concert. Even in simulation, it is difficult to subordinate the effects of all factors except one. Thus, a description of climate requires identification of the factor values associated with a given type of climate in order to understand how they may work together to produce materiel effects.

Natural environmental factors that affect materiel can be categorized into three groups: climatic factors, terrain factors, and biological factors. Climatic factors include temperature, humidity, pressure, solar radiation, rain, solid precipitants, fog, wind, salt, ozone, and sand and dust. Terrain includes topography, soils, hydrography, and vegetation. Biological factors may be subdivided on the basis of size; i.e., macrobiological and microbiological organisms.

In the discussions of individual environmental factors given in previous parts of this handbook series, various combinations of factors are considered. For example, environmental factors that produce additive effects or effects that are greater than the sum of the effects of environmental factors occurring singly, i.e., synergisms, have been identified. However, no concerted effort has been made to identify combinations of factors that are likely to occur in the various natural climatic types or to delineate the effect of the combined environmental factors on materiel. Because of the large number of factors and value ranges in the various natural climates and the extremely large number of possible combinations of environmental factors, attempts to perform multifactor analysis of environment have been limited largely to simple examples. The simplest and most obvious approach is that characterized as single-factor environmental analysis, which permits detailed discussions of the individual factor and its effect without becoming so complex or lengthy as to compromise its usefulness.

The next level of sophistication in environmental analysis is to examine pairs of factors. In this type of analysis, environmental factors are grouped into pairs based upon their likelihood of cooccurrence or upon their synergism. Two-factor analysis was introduced in Part One and is discussed further in Chap. 3 of this handbook. Although multifactor analysis has been studied, little progress has been made in modeling this general and complex case. Possibly, a computer technique may be developed for treating the multifactor environment which will be adequate for prediction and analysis of such environmental effects.

Two-factor combinations that have been studied are generally those characterized as climatic factors. For example, meteorological studies have been accumulating data for many years; hence, more is known about the cooccurrence of climatic factors than for any other multifactor combinations. This emphasizes the importance of climate in man's activities it is no less important to the military.

In contrast to other studies, military efforts have included vegetation and terrain along with the more obvious factors—temperature, windspeed, precipitation, relative humidity, and air pressure—as part of the climate. This is appropriate because the climate determines the nature of the vegetation (as well as the remainder of the macrobiological and microbiological environment) and because many characteristics of the terrain depend on natural factors and are important for military purposes.

In this chapter we are concerned with climate and thus the natural environmental factors. Since induced environmental factors are results of man's activities, they may be created anywhere and at any time. The regular patterns of climate, however, are readily identifiable and provide a basis for materiel design.

It has been pointed out that there are important differences between the conditions considered normal for military operations and those considered normal for civilian activities. Conditions considered normal to the military environment are decidedly abnormal for civilian activities. A good example of this is found in off-road use of trucks, which is normal in military operations. In on-road civilian applications of trucks, the engines and other vehicle components are expected to have a life of at least 100,000 mi but the same truck can fail in 2,000 mi or less when used in military applications. This is a direct result of extreme climatic and terrain stresses and illustrates the fact that Army materiel must considerably different from nonmilitary materiel; the differences are derived directly from the requirement for performance in extreme environmental conditions.

AR 70-38 defines four broad types of climate and eight climatic categories (Ref. 1). Each of the eight categories is defined primarily by given ranges of temperature and humidity. Table 2-1 lists the four climatic types and their relationship to the eight climatic categories. The geographic distribution of these climatic categories is given on a map in Part One of the Environmental Series of Engineering Design Handbooks and is also found in AR 70-38.

While the definitions of climatic types and categories given in AR 70-38 are official for Army materiel design purposes, other climatic classification systems have been defined for special purposes (Ref. 2). In one of these, six climatic types—icecap and arctic, desert, tropical, maritime, continental, and highland—were designated. These are described in Table 2-2.

Experience has shown that a strong correlation exists between climate and materiel effect. Just as is done for nonmilitary materiel, designers tend to design for normal temperate climate. When materiel is used in one of the extreme climatic conditions, the materiel often fails. If materiel is designed to perform in the extreme climate, it will very

TABLE 2-1.
CLIMATIC TYPES AND CATEGORIES

Climatic type	Climatic category
A. Hot-dry	1. Hot-dry
B. Hot-wet	2. Wet-warm 3. Wet-hot 4. Humid-hot Coastal Desert
C. Intermediate	5. Intermediate Hot-dry 6. Intermediate Cold
D. Cold	7. Cold 8. Extreme Cold

seldom fail in the intermediate climate because the stresses are less. It follows that, if materiel is designed to survive extreme climatic conditions, it will perform well in the intermediate climatic regions; hence, these need not be considered in any detail.

Extreme climatic types, previously identified, are these: tropical, corresponding to the wet-hot category of AR 70-38; desert, corresponding to the hot-dry category; and arctic, corresponding to the cold and extremely cold climatic categories.

2-2 WORLD CLIMATES

General guidance for materiel design engineers may be obtained from knowledge of general climatic patterns; more specific information is to be obtained from detailed information on extreme climates. The purpose of this paragraph is to provide information on general climatic patterns. In Part One of this handbook series, the nature of world climates is introduced but, aside from that, this is the only discussion in the Environmental Series of all of the important factors associated with world and continental climates. A design engineer with a strong background in geography probably will not find this material useful, and, if information on any specific environmental factor is required, reference to either Part Two or Part Three probably will be more informative.

2-2.1 GEOGRAPHIC CORRELATIONS OF CLIMATE

Climate is by definition strongly correlated with geography. The reasonably well-informed individual associates cold, heat, high humidity, and frequent rain or snow with reasonably well-defined regions of the earth. Of these various climatic factors, temperature, humidity, and precipitation are most often correlated with geographic areas. Other factors such as fog, wind, salt, and microbiological organisms also are associated with local regions, but this association often is based on specific known conditions and is restricted in extent. It is equally useful to identify areas in which certain of the environmental factors do not affect materiel. In the remainder of this paragraph, world patterns of temperature and precipitation are examined.

The temperature at any particular place on earth depends primarily on the amount and distribution of solar energy, but it is

TABLE 2-2.
A CLIMATE CLASSIFICATION SYSTEM (Ref. 2)

Climate type	Description
Icecap and arctic	-65°F outside air temperature, plus blowing snow at 15 mph and higher (4-hr duration)
Desert	+125°F outside air temperature, plus 120 W ft^{-2} solar radiation (4-hr duration)
Tropic	(a) +75° to 95°F outside temperature, plus 4 in. hr^{-1} of rain (2-hr duration)
	(b) +75° to 95°F outside air temperature, plus salt spray (4-hr duration)
	(c) +95°F outside temperature, plus 120 W ft^{-2} solar radiation (4-hr duration)
	(d) +75° to 90°F outside temperature, plus 95% relative humidity (4-hr duration)
Maritime	(a) +65°F outside air temperature, plus fog (4-hr duration)
	(b) +80°F outside air temperature, plus 90% relative humidity (4-hr duration)
	(c) +70°F outside air temperature, plus salt spray (4-hr duration)
	(d) +75°F outside air temperature, plus 4 in. hr^{-1} of rain (2-hr duration)
	(e) +100°F outside air temperature, plus 120 W ft^{-2} solar radiation (4-hr duration)
Continental	(a) +90°F outside air temperature, plus 120 W ft^{-2} solar radiation (4-hr duration)
	(b) +80°F outside air temperature, plus sand and dust (4-hr duration)
	(c) +90°F outside air temperature, plus 95% relative humidity (4-hr duration)
	(d) +20°F outside air temperature, plus blowing snow at 40 mph and higher (4-hr duration)
Highland	Highlands are those regions above 6,000 ft altitude. Variations in climate between highland areas are great, and no typical conditions can be specified.

also affected by wind patterns, topography, and ocean currents. The amount of solar energy received depends primarily on latitude. Fig. 2-1(A) and (B) show the average earth surface temperature for the months of January and July, respectively.

It may be noted that, in the winter of the Northern Hemisphere, the poleward temperature gradient north of latitude 15 deg N. is very steep over the interior of North America; i.e., the lines of constant temperature (isotherms) are closely spaced. The temperature gradient is also steep in the vicinity of the cold pole of Asia, indicated by a −50°F temperature.

The more widely spaced isotherms over western Europe, to the east of the Atlantic Ocean and the North Atlantic Current (where westerly winds prevail), show that the temperature changes are much more gradual.

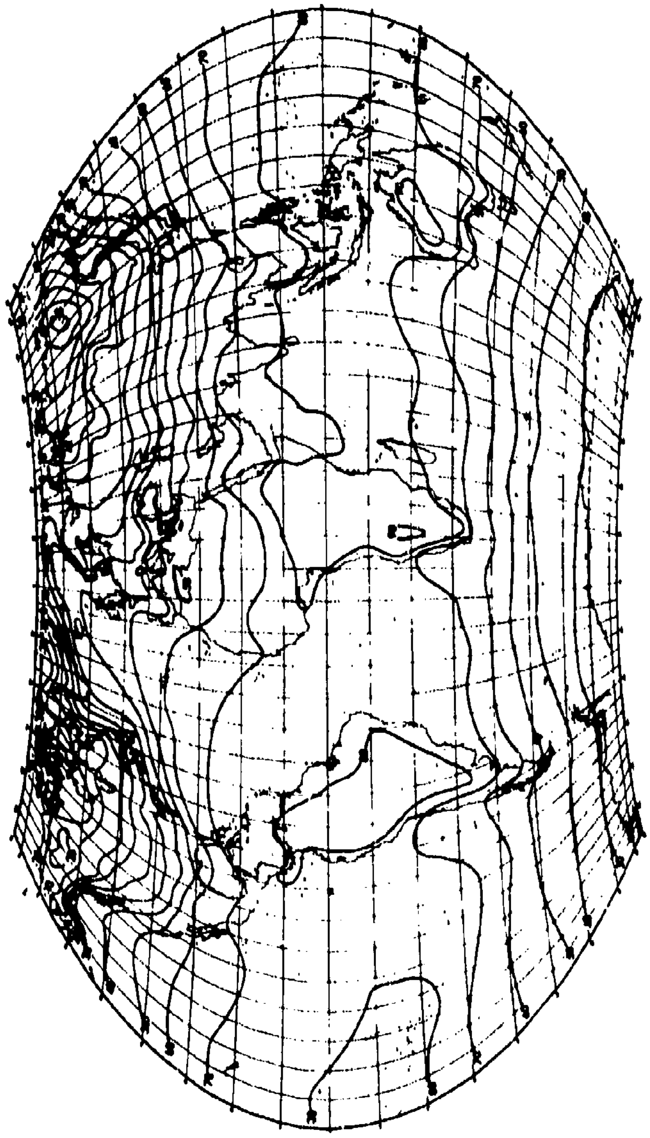
In the winter of the Southern Hemisphere (as shown on the map of Fig. 2-1(B)), the temperature decrease as one moves south is very gradual and isothermal deflections from the east-west direction are of minor importance because of the relative lack of continental effects. In both hemispheres, summer temperature gradients are very much less than those that occur in winter. This is particularly true over the middle and higher northern latitudes because of the greater warming of the extensive interiors of North America and Eurasia.

The form of precipitation, solid or liquid, depends largely on the temperature, which may be influenced more by elevation than by latitude. This is evidenced by the perpetually snow-covered mountain peaks close to the Equator in both South America and Africa. Fig. 2-2 shows the general pattern of annual precipitation measured in inches of water. Precipitation is governed by the water vapor content of the air and by the processes that lead to condensation. This condensation generally is caused by air ascending to great elevations, either in thunderstorms or in the convective wind systems typical of the Tropics. Water vapor laden air also may be forced to rise by topographic features along the prevailing wind direction as occurs on the southern or windward slopes of the Himalayas and in the path of the southwest monsoons of India. In the United States, migratory low pressure formations produce gradual rising air patterns, producing condensation and precipitation.

Heaviest precipitation is found in the Tropics where the high temperatures cause a large water vapor content in the atmosphere—although rainfall occurs only where conditions favor condensation. Also, certain regions in the high latitudes—such as southern Alaska, western Norway, and southern Chile, where relatively warm moist winds from the sea are forced to climb to high elevations—experience heavy rainfall.

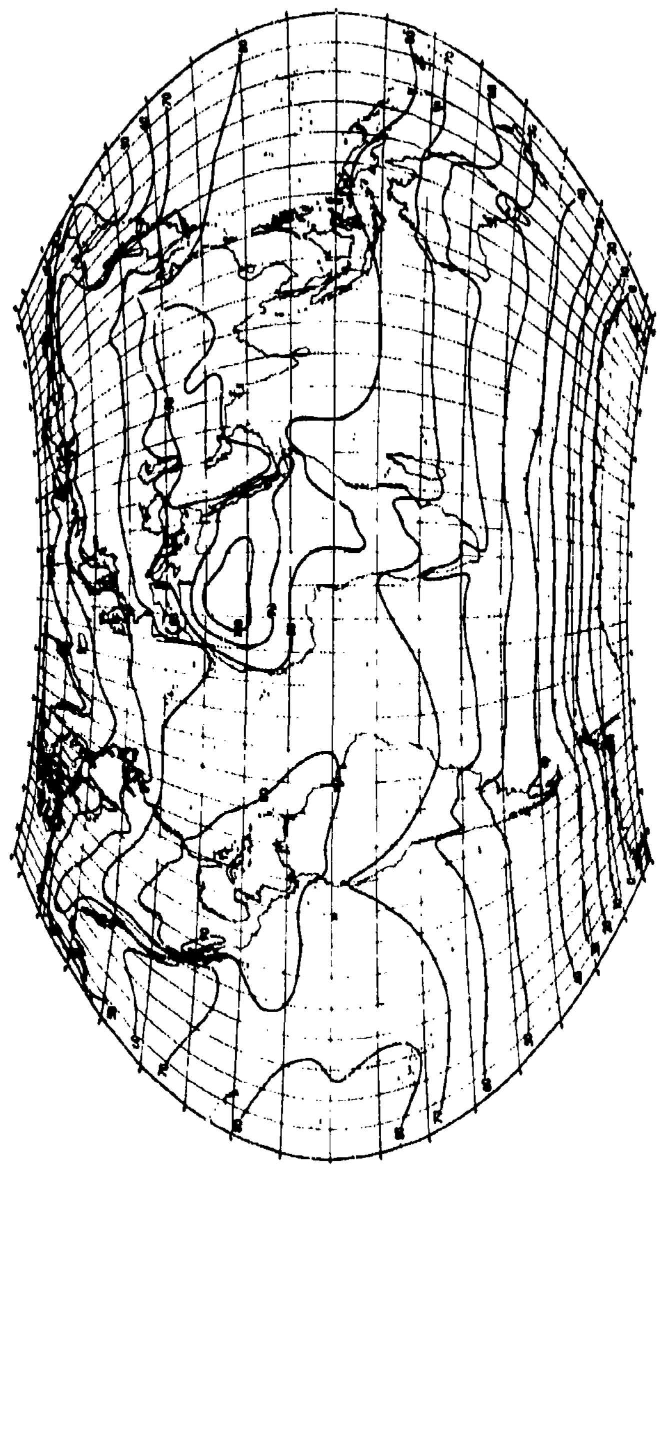
In stark contrast to the rainy regions are the dry polar regions where the water vapor content of the air is always very low because of low temperatures and very limited evaporation. Dry areas also are found in the subtropical belt of high atmospheric pressure (in the vicinity of latitude 30 deg on all continents, especially from the extreme western Sahara over a broad, somewhat broken belt to the desert of Gobi) and the arid strip on the lee side of mountains on whose windward slopes precipitation is heavy. These low latitude areas are dry although the temperature may be high because conditions are unfavorable to the condensation of whatever water vapor may be present in the atmosphere.

Most other geographical correlations of climatic factors result from specialized conditions of limited extent. For example, fog is common off the coast of Labrador where the Gulf Stream interfaces with cold arctic winds; there are hail belts in midcontinental regions of both North America and Eurasia; warm coastal regions with prevailing wind from the sea are subjected to large amounts of airborne salt; and the polar regions with



(A) January

Figure 2-1. Average Earth Surface Temperature (°F) (Ref. 3)



(B) July

Figure 2-1 (continued). Average Earth Surface Temperature (°F) (Ref. 3)

Figure 2-2. General Pattern of Annual World Precipitation (Ref. 3)

24-hr summer days experience the highest daily solar radiation rate.

2-2.2 CONTINENTAL CLIMATES

The primary concern of the Army is with climate on land areas of the earth. In this paragraph the general climatic features of each of the major land bodies are discussed briefly (Ref. 3). Knowledge of marine climatic factors may also be required. In the *Marine Climatic Atlas of the World*, information is given on winds, pressure, storms, precipitation, visibility, cloud cover, air temperatures, and sea temperatures for each month of the year (Ref. 4).

2-2.2.1 North America

The North American continent, with its land area mainly in the middle and northern latitudes, has a large central area with a typical continental-type climate; i.e., with marked seasonal temperature extremes. These midcontinental extremes are not found in the coastal regions where both summer and winter temperatures are moderate. The prevailing westerly wind movement carries the continental-type climate eastward so that the region of moderate temperatures along the Atlantic coast is relatively narrow.

In the southern parts of the North American continent, the climate varies from subtropical at low elevations to temperate at the higher levels. The northern areas of the continent are very cold, but the midwinter low temperatures are not as low as those experienced in the cold pole region of northeastern Siberia which is surrounded by a larger landmass.

On the northwestern slope of the continent a narrow strip of land reaches from the Aleutian peninsula to northern California, which is west of the crest of the mountains. In this region annual precipitation is over 40 in.; it exceeds 100 in. at some points along the coast of Canada. East of this coastal region, precipitation levels decrease abruptly to annual totals of less than 20 in. In the eastern part of the North American continent, the average annual precipitation is more than 40 in. In some southern regions of the continent, rainfall is much greater, but these regions are limited in extent and are determined by local topography and wind direction.

The climate of the large midregion of the continent varies between the extremes of the arid west and the moderate east. Other environmental factors are less geographically defined. Seasonally, hurricanes are found in the southeast, fog on the northeast and northwest coasts, the hail belt in the midcontinent area, snow cover over the northern half of the continent, and airborne sand and dust in the arid southwest.

2-2.2.2 South America

A large part of South America lies within the Tropics and has a characteristically tropical climate. The remaining rather narrow southern portion is not subject to the seasonal extremes of heat and cold that are found where wide land areas give full sway to the continental-type climate as in North America and Asia. Major temperature anomalies are the results of the elevation of the Andean regions which stretch from Panama to Cape Horn.

The Arctic Current and its cool Humboldt branch spread along the western coast northward to the Equator and, with a prevailing onshore wind, exert a strong cooling influence on the western coastal regions of South America except for Colombia. On the east coast, the southerly moving current from tropical waters has an opposite, warming effect except along southern Argentina.

In the northern part of South America, the sharply contrasted dry and wet seasons are related to the regime of the trade winds. In the dry season (corresponding to winter in the Northern Hemisphere), these winds sweep the entire region, while, during the wet season (corresponding to summer in the

Northern Hemisphere), calm and variable winds prevail. In the basin of the Amazon River, rainfall is related to the equatorial belt of low pressure and to the trade winds, which give the maximum amount of rainfall in the extreme west, where they ascend the slopes of the Andes.

The desert areas on the west coast of South America, extending from the Equator southward to the latitude of Santiago, Chile, are due primarily to the cold Humboldt or Peruvian current. Because the moist cool ocean air is warmed in passing over the land, the relative humidity decreases, the dew-point is not reached, and condensation of vapor does not occur until the air reaches the high elevations in the Andes. There, temperatures are much lower than along the coast. In southern Chile, the summer has moderate rainfall and winters are wet. The conditions that prevail farther north are not present here, and condensation of moisture from the ocean progresses from the shores up to the crest of the Andes. By the time the air passes these elevations, however, the moisture has been so depleted that the winds on the leeward slopes are dry, becoming more so as they are warmed at lower levels. The mountains cast a great "rain shadow" (an area of little rain) over southern Argentina.

2-2.2.3 Europe

Europe does not have an extensive north-south mountain system, as found in the Americas, and the general east-west direction of the mountain ranges in the south causes a gradual change in climate from the Atlantic to the east. Generally, rainfall is heaviest on the western coast, where in some places it exceeds 60 in. annually, and diminishes towards the east except in the elevated Alps and Caucasus to less than 20 in. in western Russia. There is a well-defined rain shadow in Scandinavia, with over 60 in. of rain in western Norway and less than 20 in. in eastern Sweden.

Over much of Europe, rainfall is both abundant and evenly distributed throughout the year. The chief seasonal variation in precipitation is the marked winter maximum and the very dry summers along the Mediterranean coast. Generally, elevations and the continental landmass have few effects on isotherms, such as are found in North America. In Scandinavia, however, the winter map shows an abrupt fall in temperature from the western coast of Norway to the eastern coast of Sweden and a continued fall eastward, tending to be more continental in contrast to the oceanic climate on the west.

2-2.2.4 Asia

The large size of the Asian landmass gives full opportunity for continental conditions to develop a cold area of high barometric pressure in winter and a low pressure, hot area in summer. The former is northeast of the Himalayas and the latter stretches from west to east in the latitude of northern India. These distributions of pressure give India the well-known monsoon season, during which the wind comes from one direction for several months and affects the rainfall over all of eastern Asia.

In winter, air circulation is outward over the land from the cold pole, and precipitation is very light over the entire continent. In summer, on the contrary, there is an inflow of air from the oceans; even the southeast trade winds flow across the Equator and merge into the southwest monsoon that crosses India. This usually produces abundant rain over most of that country, with excessively heavy amounts when the air is forced to rise, even to moderate elevations, in its passage over the land. At Cherrapunji (4,450 ft) on the southern side of the Khasi Hills in Assam, the average monthly rainfall in winter is about 1 in., while in both June and July it is approximately 100 in. This heavy summer rainfall meets an impassable barrier in the Himalaya Mountains, while the much lighter summer rainfall over Japan and eastern Asia does not extend very far into China because of lesser elevations. Consequently, while the southeast quadrant of Asia (including the East Indies) has heavy rainfall, the remainder of the continent is dry with vast areas receiving less than 10 in. annually.

North of the Himalayas, the low plains are cold in winter and temperatures rise rather high in summer. At Verkhoyansk in the cold pole area and north of the Arctic Circle, the mean temperature in January is about −59°F and in July approximately 64°F.

In southwestern Asia the winter temperature control is still the interior high pressure area, and temperatures are generally low, especially in high elevations. In summer in low elevations, excessively high maxima are recorded, e.g., in the Tigris-Euphrates Valley.

2-2.2.5 Africa

Africa, like South America, lies largely within the Tropics, and its temperature distribution is determined mainly by altitude. Along the southern portion of the western coast, the cool Benguela Current moves northward; while, the warm tropical currents of the Indian Ocean flow along the eastern coast, creating conditions closely paralleling those found around the South American continent. In the strictly tropical areas of Africa, conditions are characterized by prevailing low barometric pressure, with convectional rainfall; while, in both the north and the south, the ruling influences are the belts of high barometric pressure.

Except in the Atlas Mountains in the northwest where high elevations form a barrier in the path of trade winds and produce moderate rainfall, desert conditions typified by the Sahara extend from the Atlantic to the Red Sea and from the Mediterranean south to well beyond the northern tropic to about the latitude of southern Arabia. South of the Sahara, rainfall increases rapidly, becoming abundant to heavy from the west coast to the central lakes with annual maxima of 80 in.

This marked increase of precipitation does not extend to the eastern portion of the middle region of the continent where the annual amounts received are below 40 in. and decrease to less than 10 in. on the coast of Somalia. A rapid fall in precipitation occurs south of the central rainy area toward the arid regions of southwest Africa. Heavy rainfall occurs over sections of Ethiopia from June to October, when more than 40 in. fall, causing the overflowing of the otherwise arid Nile Valley—one of the outstanding features of seasonal distribution of rainfall on the earth.

Moist equatorial climate is typified by conditions in the Congo region; arid-torrid climate by those in the Sahara; and moderate plateau climate by those found in parts of Ethiopia, Guinea, and Tanzania.

2-2.2.6 Australia

In the southern winter, a high pressure belt crosses the interior of Australia, and all except the southernmost parts of the continent are dry. In summer, this pressure belt moves south of the continent, still giving dry conditions over the southern and western areas. Thus, the total annual precipitation is less than 20 in. except in the extreme southwest and in a strip curving from southeast to northwest. The average annual precipitation is less than 10 in. in a large south-central area.

In the south the winter precipitation is the cyclonic type. The heavy summer rains of the north are of monsoon origin; and those of the coast are of orographic origin, owing to the presence of the highlands in the immediate vicinity of the coast. In the outer border of the rainfall strip along the coastal region, the mean annual rainfall is over 40 in. and in many localities over 60 in.

Because of the location of Australia, temperatures far below freezing are to be found only in the south at high elevations. In the arid interior, extreme maximum temperatures are very high (maximum reported is 128°F), ranking with those of the hottest regions of the earth.

2-3 EXTREME VALUES OF NATURAL ENVIRONMENTAL FACTORS

Weather extremes for the world and for North America are given in Figs. 2-3 and 2-4, respectively, and in Table 2-3. In the table, the data are in order of decreasing severity and are based on observations obtained in accordance with protocol concerning site, instrumentation, and procedures of the World Meteorological Organization. When an extreme phenomenon is observed and recorded and the record is accepted by the appropriate meteorological service, it indicates that the particular value is possible because it has been observed. It does not necessarily, or even probably, mean that it is the highest value that could occur or has ever occurred. Extreme weather data are not always recorded—in fact, meteorological records are relatively incomplete—the stations are few and records have been kept for only a short time. In addition, the size of the earth has prohibited the obtaining of a reasonable sample of the weather over the entire surface until the recent development of meteorological satellites.

The recorded extremes for temperature, relative humidity, absolute humidity, precipitation, and solar radiation, along with the locations in which these extremes have occurred, are compared with the requirements of AR 70-38 and MIL-STD-210 in Table 2-4 (Refs. 1,5).

2-4 THE TROPICAL ENVIRONMENT

Tropical climates generally are defined as being typical of the hot-wet tropics or torrid zone of the earth. The outstanding common characteristics of tropical regions are high temperatures and high humidities. Temperature extremes in the Tropics are given in Table 2-5.

High temperatures and humidities cause many materiel problems, including corrosion of steel and copper alloys caused by electrolytic action; fungous growth on organic materials such as canvas, felt, gasket materials, sealing compounds, and optical equipment; and deterioration through corrosion and fungous growth in insulation, rotating electrical machinery, demolition and mine detection equipment, meters, dry cell batteries, storage batteries, cables, and a variety of lesser components. Termites attack wooden parts not impregnated with a repellent agent.

In the paragraphs that follow, the factor values associated with the tropical climate are discussed and representative tropical days are described. In these discussions, the climatic factors are often discussed for the entire region of the Tropics. This is not to imply that all parts of this region exhibit the characteristics of a tropical climate. Desert and temperate climates also are included in the tropical zone. Only those areas with sufficiently high temperatures and humidities are described properly as having a tropical climate.

2-4.1 TROPICAL CLIMATIC FACTORS

The various natural climatic factors associated with the Tropics are described individually in the paragraphs that follow (Ref. 7).

2-4.1.1 Temperature

Most of the tropical troposphere is characterized by small horizontal temperature gradients. Some large local temperature gradients are produced by land-sea breeze effects and by cold upwelling ocean currents; however, these diminish rapidly with altitude. Even the strongest cold fronts that penetrate the Tropics are scarcely discernible in the surface temperature field. Fig. 2-5 gives the mean sea level temperature for January and July in the Tropics. The temperatures shown are averages of hourly temperature observations over a period of years.

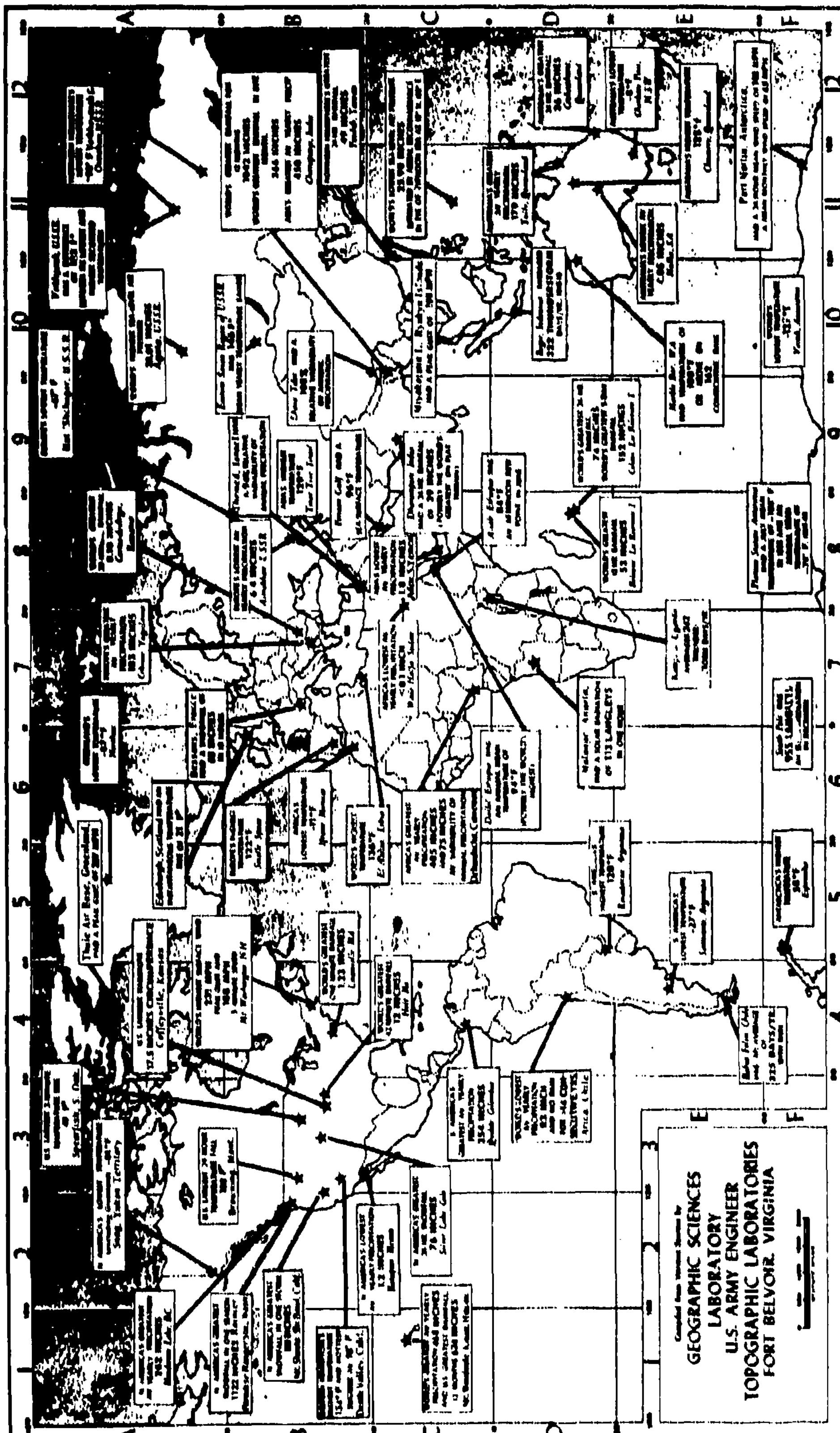


Figure 2-3. Weather Extremes Around the World (Ref. 6)

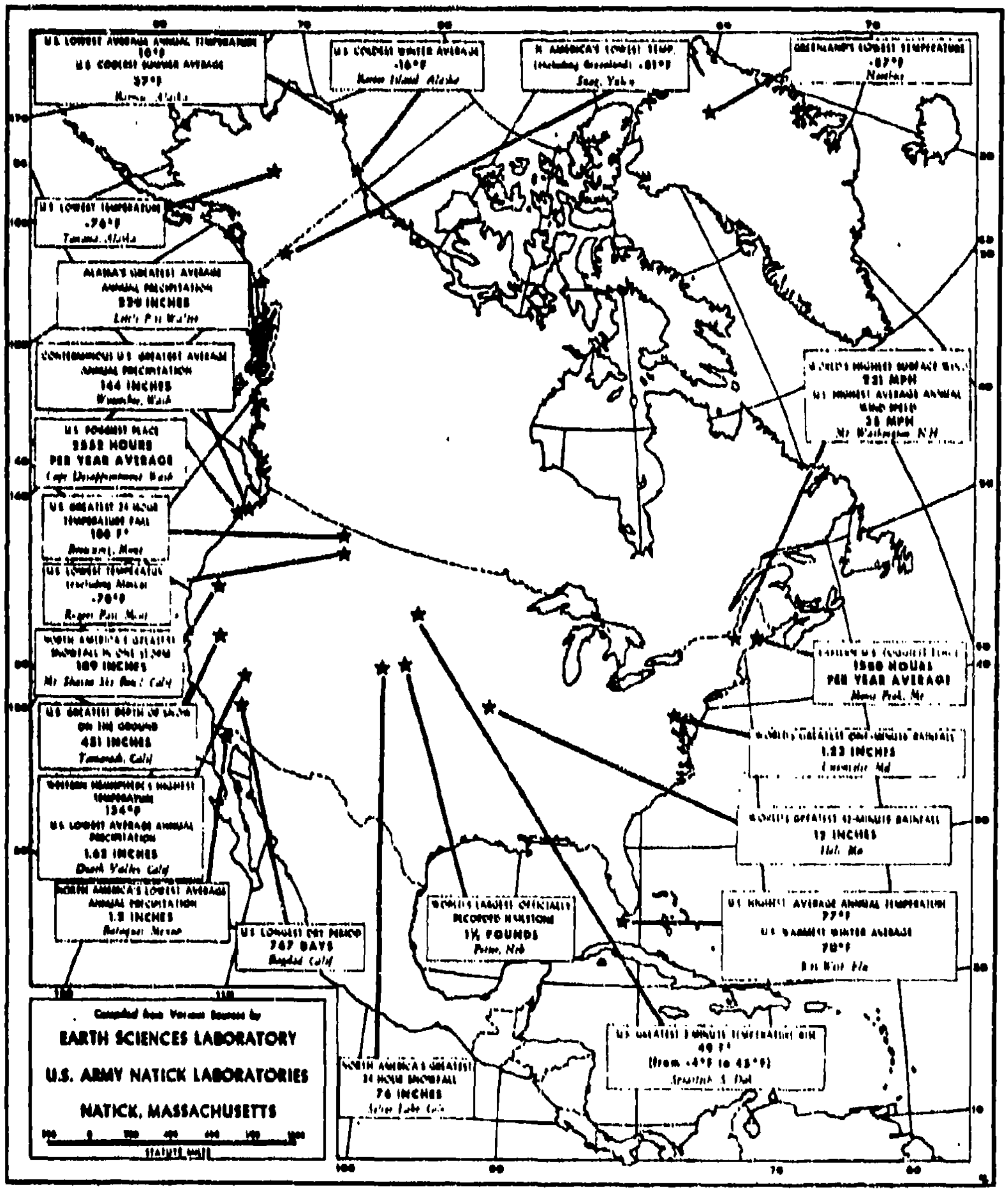


Figure 2-4. Weather Extremes in North America (Ref. 6)

TABLE 2-3.
WEATHER EXTREMES (Ref. 6)

Highest temperatures

1. World: El Azizia, Libya; 136°F on 13 September 1922
2. Western Hemisphere: Death Valley, Calif.; 134°F on 10 July 1913
3. Asia: Tirat Tsvi, Israel; 129°F on 11 June 1942
4. Australia: Cloncurry, Queensland; 128°F on 16 January 1889
5. Europe: Seville, Spain; 122°F on 4 August 1881
6. S. America: Rivadavia, Argentina; 120°F on 11 December 1905
7. Antarctica: Esperanza, Antarctic Peninsula; 58°F on 20 October 1956
8. Persian Gulf: Sea surface; 96°F on 5 August 1924
9. Australia: Marble Bar, W. Australia, had temperatures of 100°F or above on 162 consecutive days, 30 October 1923 to 7 April 1924

Highest average temperatures

1. Africa: Dallol, Ethiopia; 94°F average annual (possibly the highest on earth)
2. United States: Key West, Fla.; 77°F, highest U.S. average annual; 70°F, warmest U.S. average winter
3. Western Hemisphere: Death Valley, Calif.; 98°F, highest average summer

Lowest temperatures

1. World: Vostok, Antarctica; -127°F on 24 August 1960
2. Northern Hemisphere: Verkhoyansk and Oimekon, U.S.S.R.; -90°F on 5 and 7 February 1892 and on 6 February 1933, respectively
3. Greenland: Northice; -87°F on 9 January 1954
4. N. America (excluding Greenland): Snag, Yukon; -81°F on 3 February 1947
5. United States: Tanana, Alaska; -76°F in January 1886
6. United States (excluding Alaska): Rogers Pass, Mont.; -70°F on 20 January 1954
7. S. America: Sarmiento, Argentina; -27°F on 1 June 1907
8. Africa: Ifrane, Morocco; -11°F on 11 February 1935
9. Australia: Charlotte Pass, New South Wales: -8°F on 14 June 1945 and 22 July 1947

TABLE 2-3 (Continued).
WEATHER EXTREMES (Ref. 6)

Lowest average temperatures
1. Antarctica: Plateau Station; -100°F mean monthly, July 1968; -70°F average annual, 1966-68
2. United States: Barrow, Alaska; 10°F lowest average annual; 37°F lowest average summer
3. United States: Barter Island, Alaska; -60°F lowest average winter

Greatest ranges of temperature
1. U.S.S.R.: Verkhoyansk; -89.7° to 93.5°F, a difference of 183 deg F
2. U.S.S.R.: Eastern Sayan Region; -53.2° to 93.2°F, a difference of 146 deg F, average annual range
3. United States: Spearfish, S. Dak.; -4° to 45°F, a difference of 49 deg F, greatest 2-min temperature rise, 22 January 1943
4. United States: Browning, Mont.; 44° to -56°F, a difference of 100 deg F, greatest 24-hr temperature fall, 23-24 January 1916
5. United States: Rapid City, S. Dak.; three temperature rises and two falls of 40 deg F or over during a period of 3 hr 10 min., 22 January 1943

Greatest rainfall
1. World: Unionville, Md.; 1.23 in. in 1 min, 4 July 1956
2. World: Curtea-de-Arges, Romania; 8.10 in. in 20 min, 7 July 1889
3. World: Holt, Mo.; 12 in. in 42 min, 22 June 1947
4. World: Belouve, La Reunion I.; 53 in. in 12 hr, 28-29 February 1964
5. World: Cilaos, La Reunion I.; 74 in. in 24 hr, 15-16 March 1952
6. Northern Hemisphere: Paishih, Taiwan; 49 in. in 24 hr, 10-11 September 1963
7. India: Dharampuri; 39 in. in 24 hr (possibly the world's greatest on flat terrain), 2 July 1941
8. Australia: Crohamhurst, Queensland; 36 in. in 24 hr, 3 February 1893
9. World: Cilaos, La Reunion I.; 152 in. in 5 day, 13-18 March 1952
10. World: Cherrapunji, India; 366 in. in 1 mo, July 1861
11. World: Cherrapunji, India; 1,042 in. in 12 mo, August to July 1861

Greatest average annual precipitation
1. World: Mt. Waialeale, Kauai, Hawaii; 460 in. (30-yr period)
2. Asia: Cherrapunji, India; 450 in. (74 yr-period)
3. Africa: Debundscha, Cameroon; 405 in. (32-yr period)
4. S. America: Quibdo, Colombia; 354 in. (10-16 yr period)
5. N. America: Henderson Lake, British Columbia; 262 in. (14-yr period)

TABLE 2-3 (Continued).
WEATHER EXTREMES (Ref. 6)

Greatest average annual precipitation (continued)
6. Alaska: Little Port Walter; 220 in. 7. Europe: Crkvice, Yugoslavia; 183 in. (22-yr period) 8. Australia: Tully, Queensland; 179 in. (31-yr period) 9. United States (conterminous): Wynoochee, Washington; 144 in. 10. Chile: Bahia Felix; average of 325 days yr^{-1} with rain
Least precipitation
1. Chile: Iquique; no rain for 14 consecutive years 2. United States: Bagdad, Calif.; longest dry period, 767 days, from 3 October 1912 to 8 November 1914
Lowest average annual precipitation
1. World: Arica, Chile; 0.03 in. (59-yr period) 2. Africa: Wadi Halfa, Sudan; < 0.1 in. (39-yr period) 3. N. America: Bataques, Mexico; 1.2 in. (14-yr period) 4. United States: Death Valley, Calif.; 1.63 in. 5. Asia: Aden; 1.8 in. (50-yr period) 6. Australia: Mulka, S. Australia; 4.05 in. (34-yr period) 7. Europe: Astrakhan, U.S.S.R.; 6.4 in. (25-yr period)
Variability of precipitation
1. Cameroon: Debundscha; 75 in. average annual variability 2. Line Islands: Malden I.; 71% average annual variability 3. Tibet: Lhasa; 108% average annual variability (1935-38)
Hail
1. United States: Potter, Nebr.; largest officially recorded hailstone, 1-1/2 lb, 6 July 1928
Snowfall
1. N. America: Silver Lake, Colo.; 76 in., 14-15 April 1921 2. N. America: Mt. Shasta Ski Bowl, Calif.; 189 in. in one storm, 13-19 February 1959

TABLE 2-3 (Continued).
WEATHER EXTREMES (Ref. 6)

Snowfall (continued)
3. N. America: Paradise Ranger Station, Wash.; 1,000 in. in one season, 1955-56
4. United States: Tamarack, Calif.; 451 in., greatest depth of snow on the ground, 11 March 1911
Thunderstorms
1. Uganda: Kampala; 242 average annual thunderstorm days
2. Indonesia: Bogor; 322 average annual thunderstorm days, 1916-19
Sea level air pressure
1. U.S.S.R.: Barnaul; highest, 31.84 in., January 1900
2. Philippine Sea; lowest, 25.90 in., 24 September 1958, estimated in the eye of Typhoon Ida at latitude 19 deg N., longitude 130 deg E.
Solar radiation
1. South Pole; 955 ly, average daily in December
Windspeed
1. World: Mt. Washington, N.H., 231 mph peak gust, 14 April 1934
2. World: Mt. Washington, N.H., 188 mph (5-min period), 12 April 1934
3. United States: Mt. Washington, N.H., 35 mph average annual
Dewpoint (humidity)
1. Ethiopia, Assab; 84°F average afternoon dewpoint in June
Fog frequency
1. United States: Cape Disappointment, Wash., 2,552 hr, highest average annual
2. Eastern United States: Moose Peak, Maine; 1,580 hr, highest average annual

TABLE 2-4. WORLDWIDE CLIMATIC EXTREMES (Ref. 2)

Item	Measured				Specifications	
	High	Low	Highest annual average	Lowest annual average	AR 70-38 (Ref. 1)	MIL-STD-210A* (Ref. 5)
Temperature	136°F (57°C) Libya	-127°F (-88°C) Antarctica -90°F (-67°C) Siberia	94°F (34°C) Ethiopia	-70°F (-57°C) Antarctica	125°F (51.7°C)† -70°F (-56.7°C)	125°F (51.7°C) -65°F (-53.9°C)
Relative humidity	Greater than 95% for months at a time	Seldom below 5% for longer than 4 hr	—	—	100% at all temperatures, up to 95°F (35°C)	97% at 80° to 85°F (26.7° to 29.4°C) 100% at 75° to 80°F (23.9° to 26.7°C)
Absolute humidity	13 gr ft^{3}‡ Equivalent to dewpoint of 85°F (29.4°C)	0.017 gr ft^{3}‡ max at temperatures of -40° to -58°F (-40° to -50°C)	—	—	—	13 gr ft^{3}‡ Equivalent to dewpoint of 85°F (29.4°C)
Precipitation	74 in. of rain in 24 hr Cilacs, La., La Reunion I.	—	460 in. of rain, Mt. Waialeale, Hawaii	Iquique, Chile, had no rain for 14 consecutive years	9.5 in. of rain in 12 hr—windspeed of 35 mph 5.5 in. of rain in 1 hr—windspeed of 35 mph	32 in. of rain in 24 hr—windspeed of 40 mph
Solar radiation intensity (sea level)	1,322 Wm^{-2} (approx. 48% visible and 52% infrared) theoretical maximum. Actual intensity depends on angle of incidence, cloud cover, etc.				1,134 Wm^{-2}	1,134 Wm^{-2} (approx. 44% visible, 50% infrared, and 6% ultraviolet)

*Values not exceeded more than 10% of most extreme month.
†Air temperatures within buildings and closed containers can reach 155°F (68.3°C).
‡1 grain = 0.0648 gram.

TABLE 2-5.
TROPICAL TEMPERATURE EXTREMES (Ref. 8)

Condition	Temperature extremes
Damp heat, high relative humidity, seasonal rainfall, mold growth, destructive insects	Day: 40°C (104°F)* Night: 20°C (68°F)* Exposed surfaces: 70°C (158°F)*

*Humidity can approach saturation.

The tropical oceanic regions are characterized by a mean temperature near 80°F throughout the year. The highest mean temperatures are found in the subtropical continental areas during the summer. Large temperature gradients are evident near the east coasts of Asia and North America in January. Lower temperatures along the west coasts of the continents are caused by the prevailing equatorward surface flow (both in ocean and atmosphere) associated with the oceanic high pressure centers and related upwelling of cooler water near the coast.

The mean air temperature over the ocean is controlled largely by the mean sea-surface temperature. These two temperatures are generally within a few degrees of each other over the tropical oceans. Near the east coasts of Asia and North America in winter, however, the mean air temperature is significantly colder than the sea-surface temperature due to the prevailing offshore flow of cold continental air. Fig. 2-6 shows the mean sea-surface temperature for January and July. One of the prerequisites for tropical cyclone formation is a sea-surface temperature exceeding 80°F. The regions exceeding this value are shaded in the figure. Over tropical landmasses, the mean temperature distribution is influenced by land-sea effects near coastlines and large lakes, elevation differences, and other local effects.

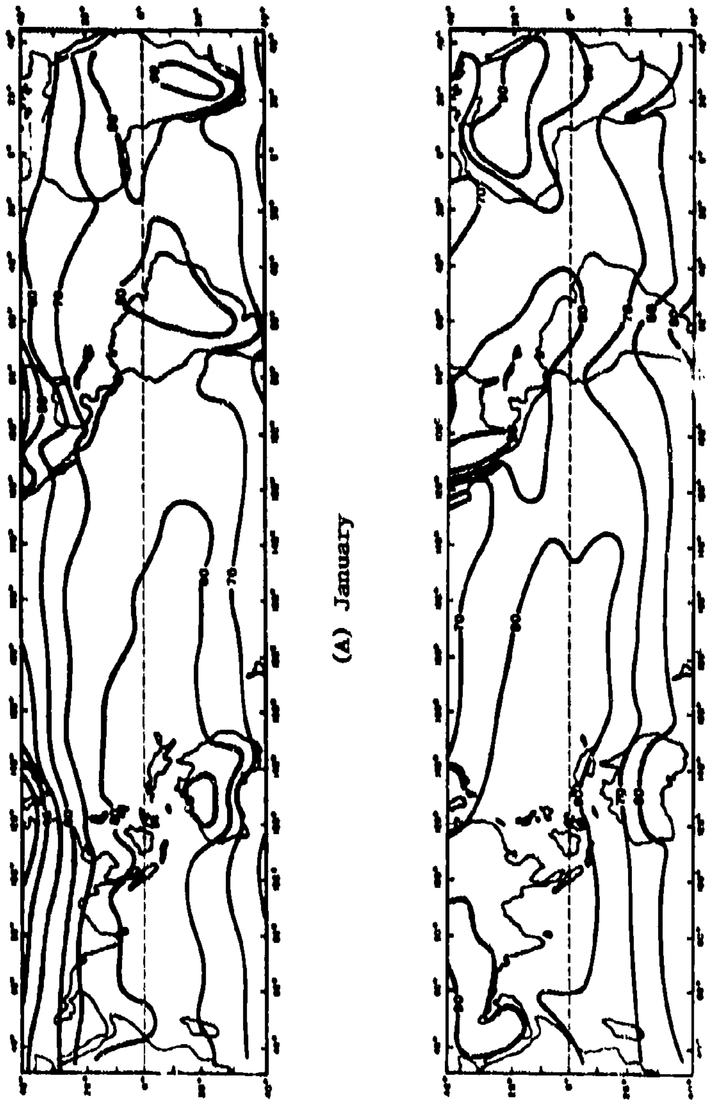
2-4.1.2 Atmospheric Moisture

Compared with the temperature field, the water vapor distribution of the tropical troposphere is much more variable. This variability results from seasonal changes in the large-scaly tropical circulation and from daily changes associated with synoptic-scale systems.

A measure of the total moisture in a vertical column of the atmosphere is the precipitable water. This is defined as the depth of liquid water that would be obtained if all the water vapor above a unit area of the earth surface was condensed. Fig. 2-7 illustrates the mean precipitable water in inches for January and July in the Tropics. In January, mean precipitable water ranges from less than 0.5 in. over northern Africa to greater than 1.75 in. over much of the low latitude Tropics, especially in the Southern Hemisphere. Extremely high values are observed over southern Asia with maximum values of 2.50 in. near Bangladesh.

2-4.1.3 Annual Precipitation

The mean annual precipitation for the world is shown in Fig. 2-2. The relatively large amounts received in the tropical regions as compared to the rest of the world



(A) January

(B) July

Figure 2-5. Mean Temperature (°F) for January and July (Ref. 7)

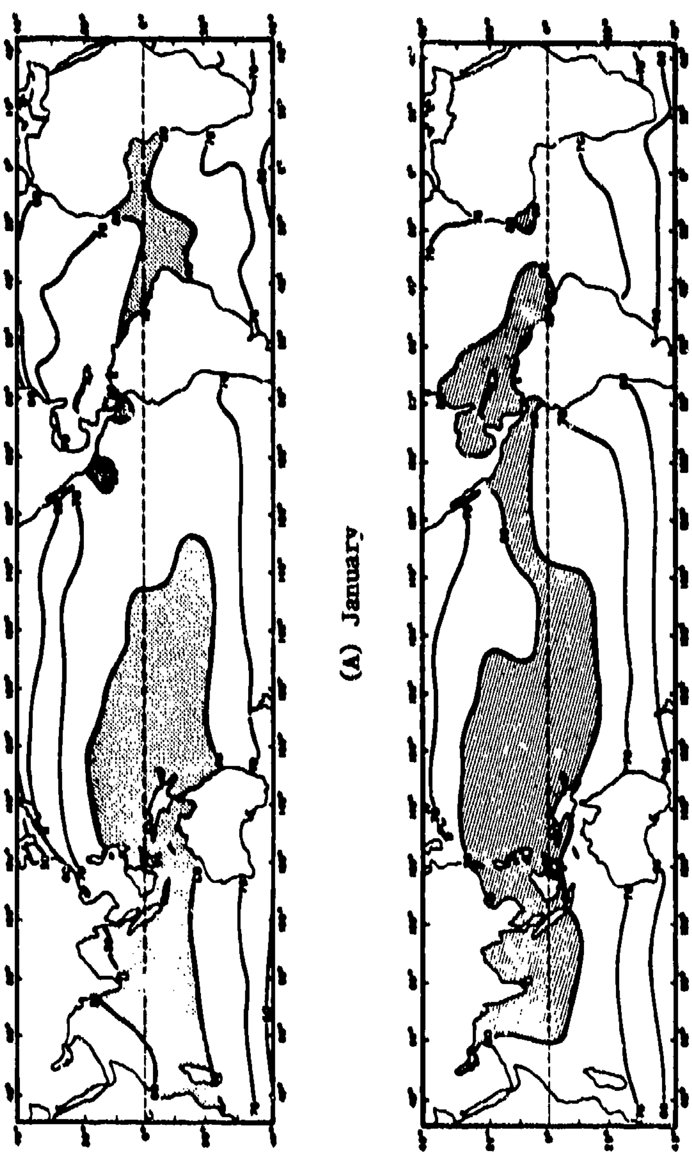
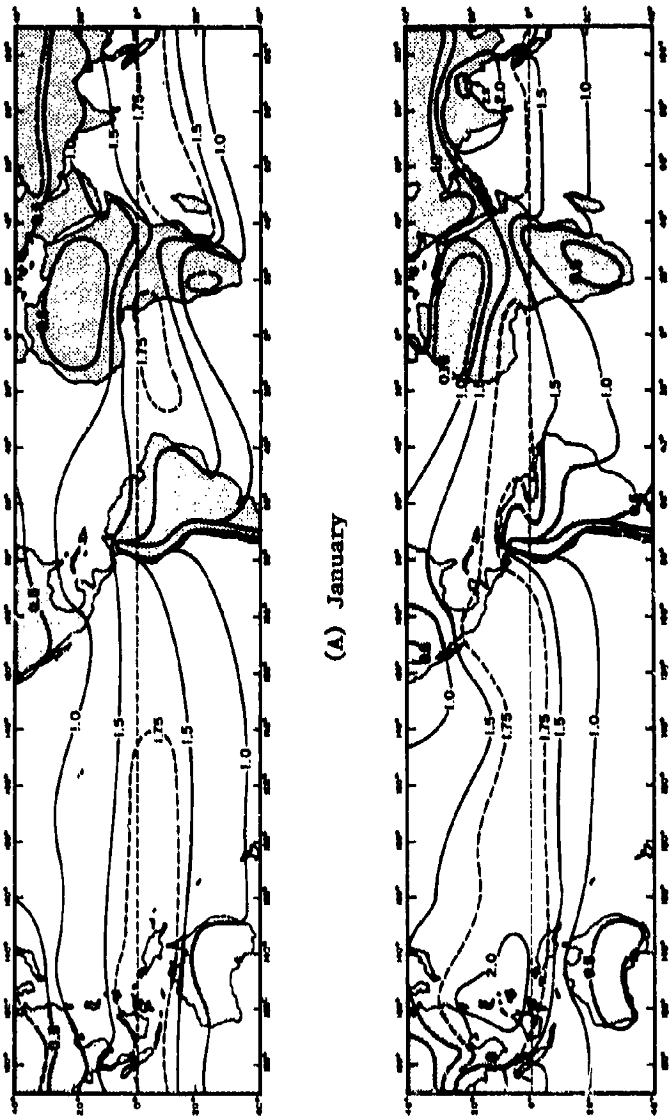


Figure 2-6. Mean Sea Surface Temperature (°F) for January and July; Stippled Areas Warmer than 80°F (Ref. 7)



(A) January

(B) July

Figure 2-7. Mean Precipitable Water (in.) in the Tropics (Ref. 7) is evident. Except for regions with orographic barrier effects, regions of 80 in. or more are restricted to areas within 20 deg of the Equator. Three broad regions of very heavy rainfall are evident—Central and South America, Equatorial Africa, and Southeast Asia and Indonesia. Large longitudinal gradients in rainfall occur near 20 deg N. (1) between the extremely arid regions of North Africa and the Middle East and the heavy rainfall over southern Asia and (2) in western South America near the Equator. Regions of little rainfall are found in the subtropics along the west coast of the continents, in a more pronouced arid region along the west coast of South America, and in anomalous dry regions over land areas near the Equator in Colombia and Venezuela, northeast Brazil, and eastern Africa. Fig. 2-8 indicates the mean annual rainfall variability for the world. Relative variability is defined as the ratio of the mean absolute deviation from the mean expressed as percent.

2-4.1.4 Cloud Cover

Meteorological satellites have been used to observe cloud cover over tropical regions. Fig. 2-9 shows the mean cloud cover for a 3-yr period. The seasonal changes of cloud cover can be determined from these charts. The unit of cloud cover, oktas, corresponds to one-eighth of the sky being covered.

2-4.1.5 Thunderstorms

Thunderstorms occur much more frequently in the Tropics than in higher latitudes. Fig. 2-10 shows the mean annual number of thunderstorm days over the earth. A thunderstorm day is defined as an observational day during which thunder is heard at a station. As shown in the figure, thunderstorms occur most frequently over tropical continental areas. Regions with 140 thunderstorm days annually are found in parts of South America, Africa, and Southeast Asia. Over tropical oceanic regions, almost all thunderstorms are associated with synoptic disturbances; while over land areas, airmass thunderstorms due to convective heating and orographic lifting are also commonly observed. The preponderance of thunderstorms over tropical land areas is clear. In the equatorial belt from latitude 10 deg N. to 10 deg S., 82 percent of the observed thunderstorms occur over South America, Africa, and Indonesia while only 18 percent occur over the oceans. It should be noted that, of all the commonly reported weather parameters, thunderstorm reports are often the most unreliable.

2-4.1.6 Extreme Winds

Two primary causes account for extreme windspeeds at tropical locations—downrush winds associated with thunderstorms, and tropical cyclonic storms. Almost all surface windspeeds exceeding 30 kt in low latitude regions are caused by one of these phenomena. Localized areas of strong winds also may occur in tropical regions due to strong low level flow coupled with channeling through mountain passes and other topographical effects. For example, exposed locations along the east coast of Vietnam occasionally experience surface wind gusts of 50 kt or greater caused by strong surges in the northeast monsoon flow combined with the channeling effect of the Annam mountain range. Such cases, however, usually are highly localized in effect; the most general types of high winds nearly always are associated with thunderstorms and tropical storm system winds in the Tropics. Fig. 2-11 shows the range of expected extreme winds for stations throughout the Tropics.

The highest expected extreme winds are at stations that frequently are affected by tropical storms. Values vary widely, however, depending on the station location and surrounding topography. The highest expected extremes associated with tropical storms occur at small island stations and at stations immediately adjacent to the coast. The expected extremes for coastal stations in Australia are comparable to those for coastal stations of the southeastern United States, whereas the expected extremes for

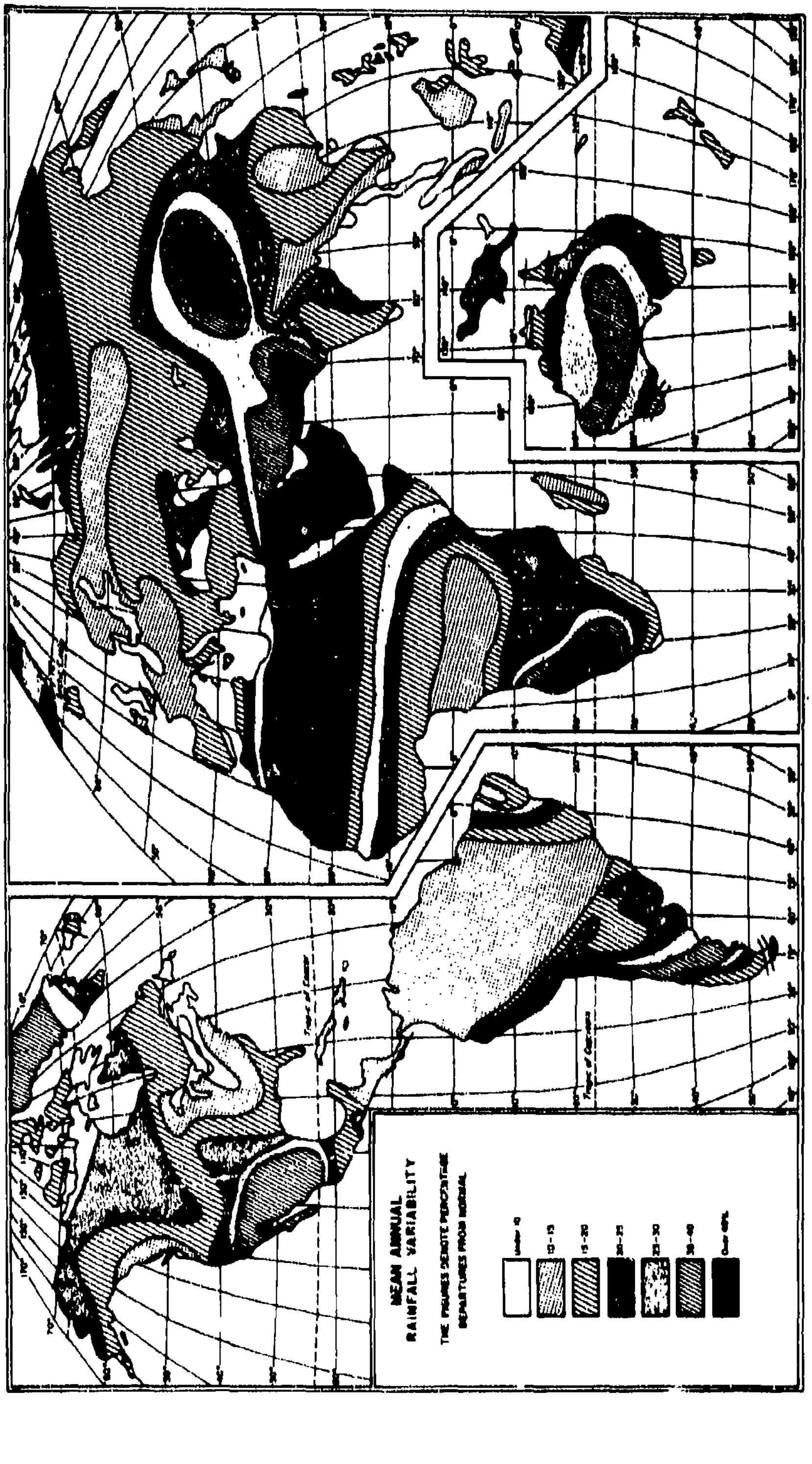
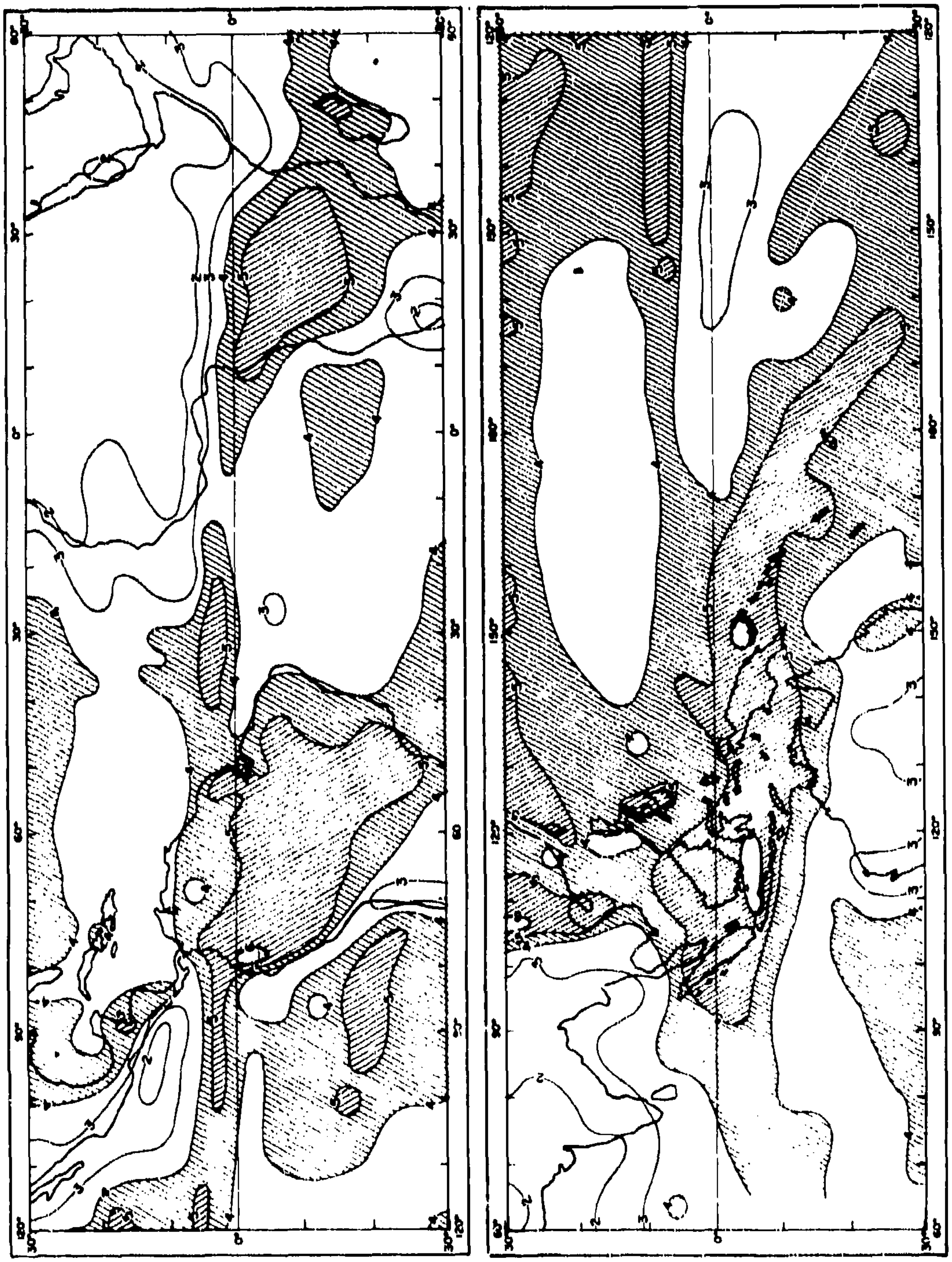
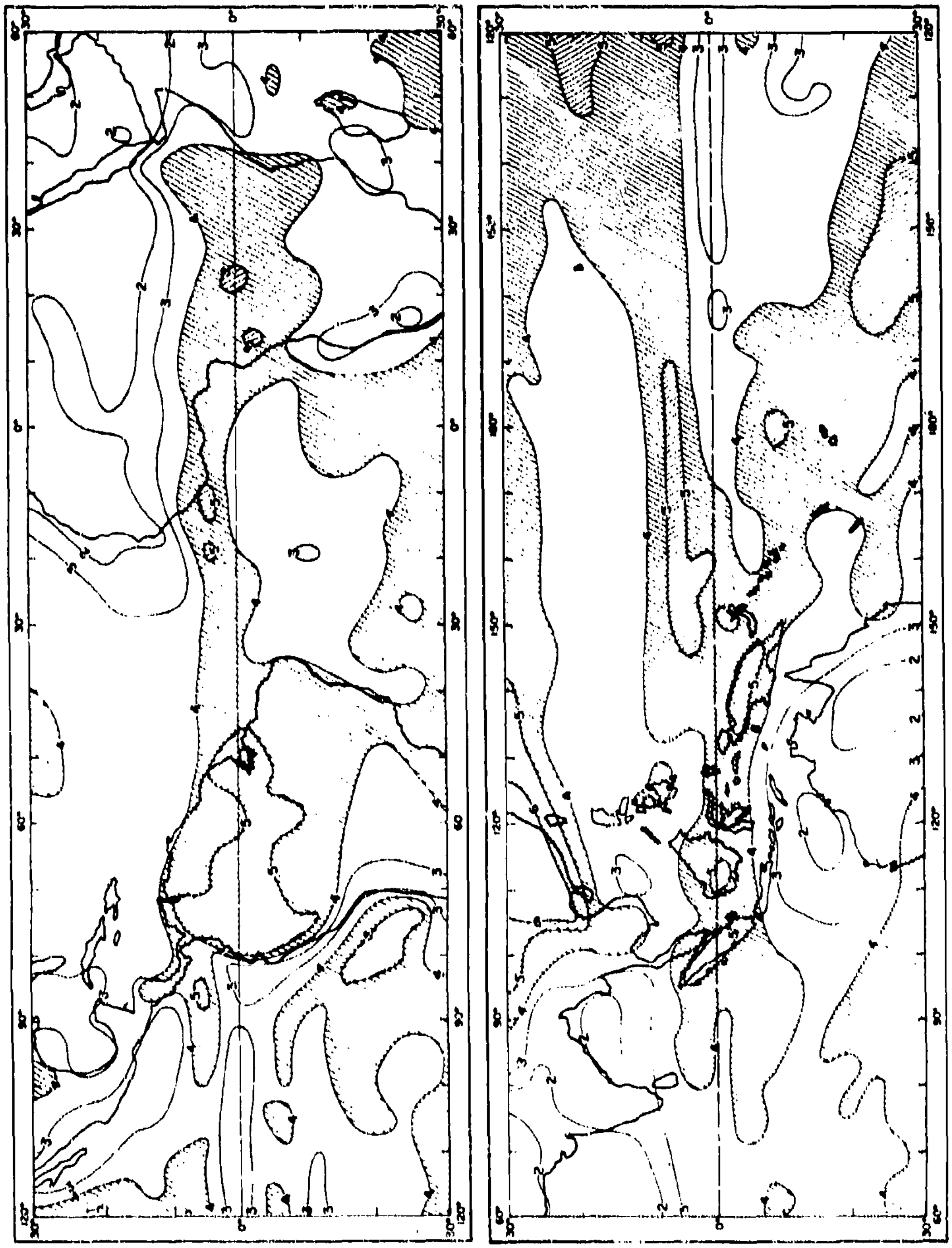


Figure 2-8. Worldwide Rainfall Variability (Ref. 7)



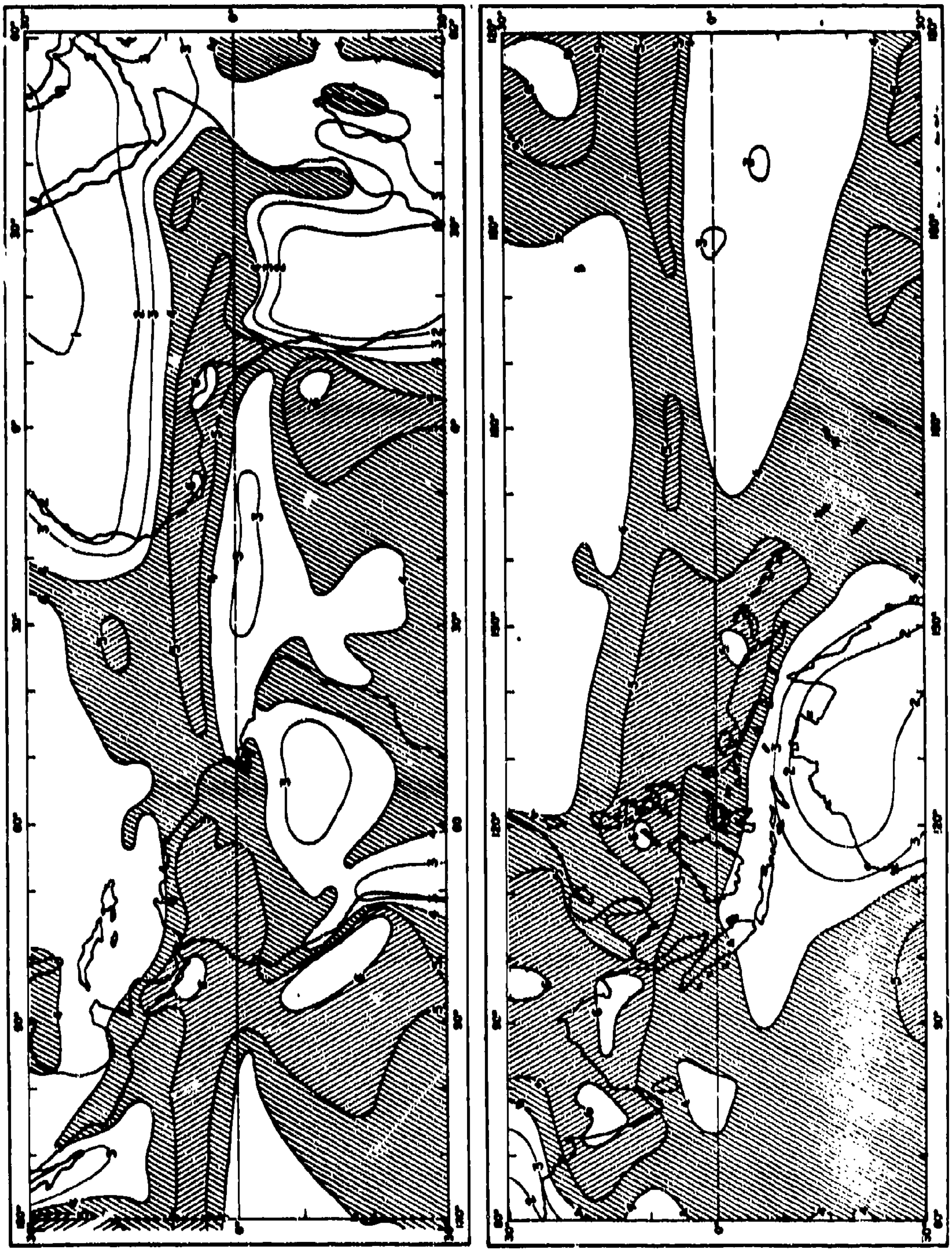
(A) January

Figure 2-9. Mean Cloud Cover (Oktas) (Ref. 7)



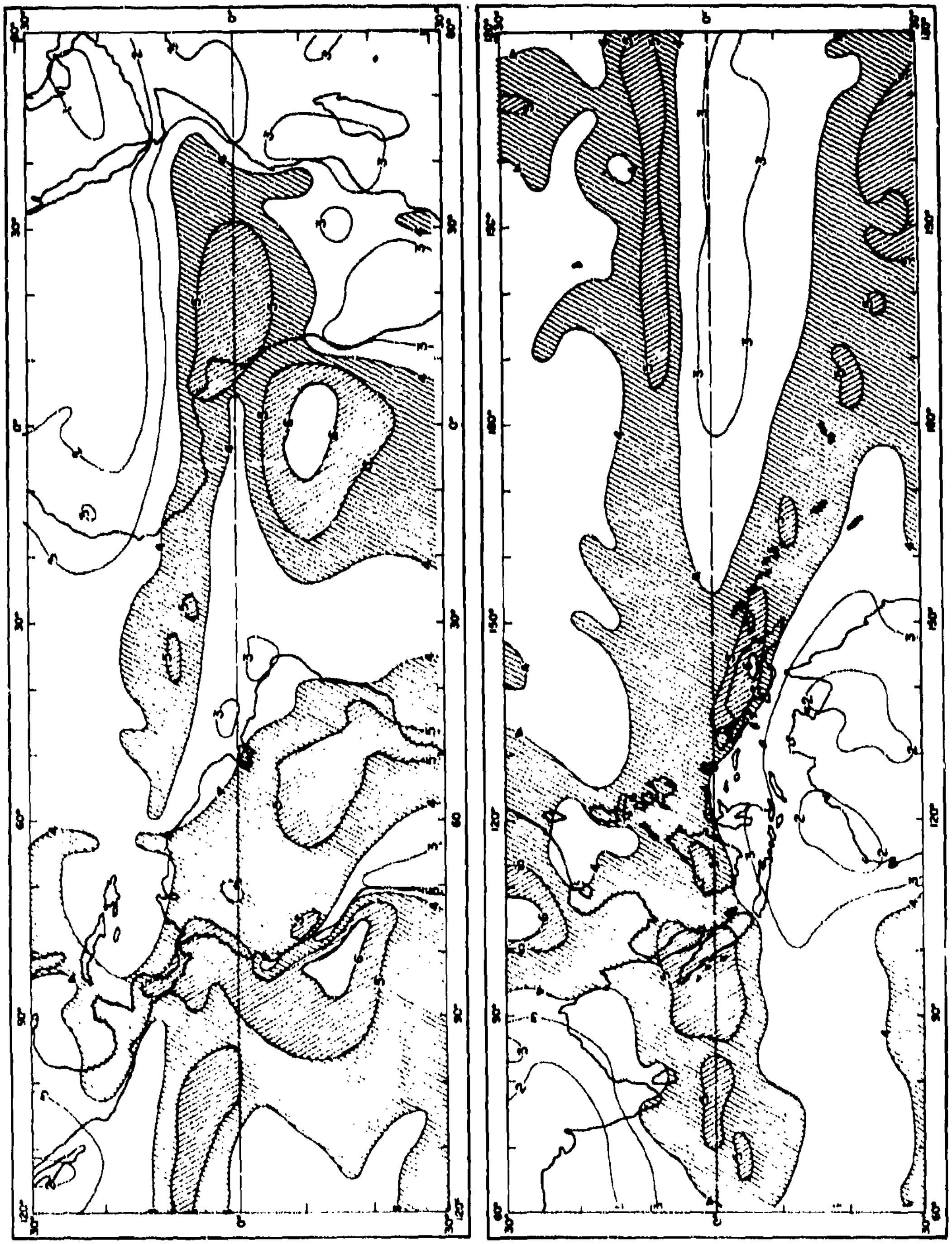
(B) April

Figure 2-9 (Continued). Mean Cloud Cover (Oktas) (Ref. 7)



(C) July

Figure 2-9 (Continued). Mean Cloud Cover (Oktas) (Ref. 7)



(D) October

Figure 2-9 (Continued). Mean Cloud Cover (Oktas) (Ref. 7)

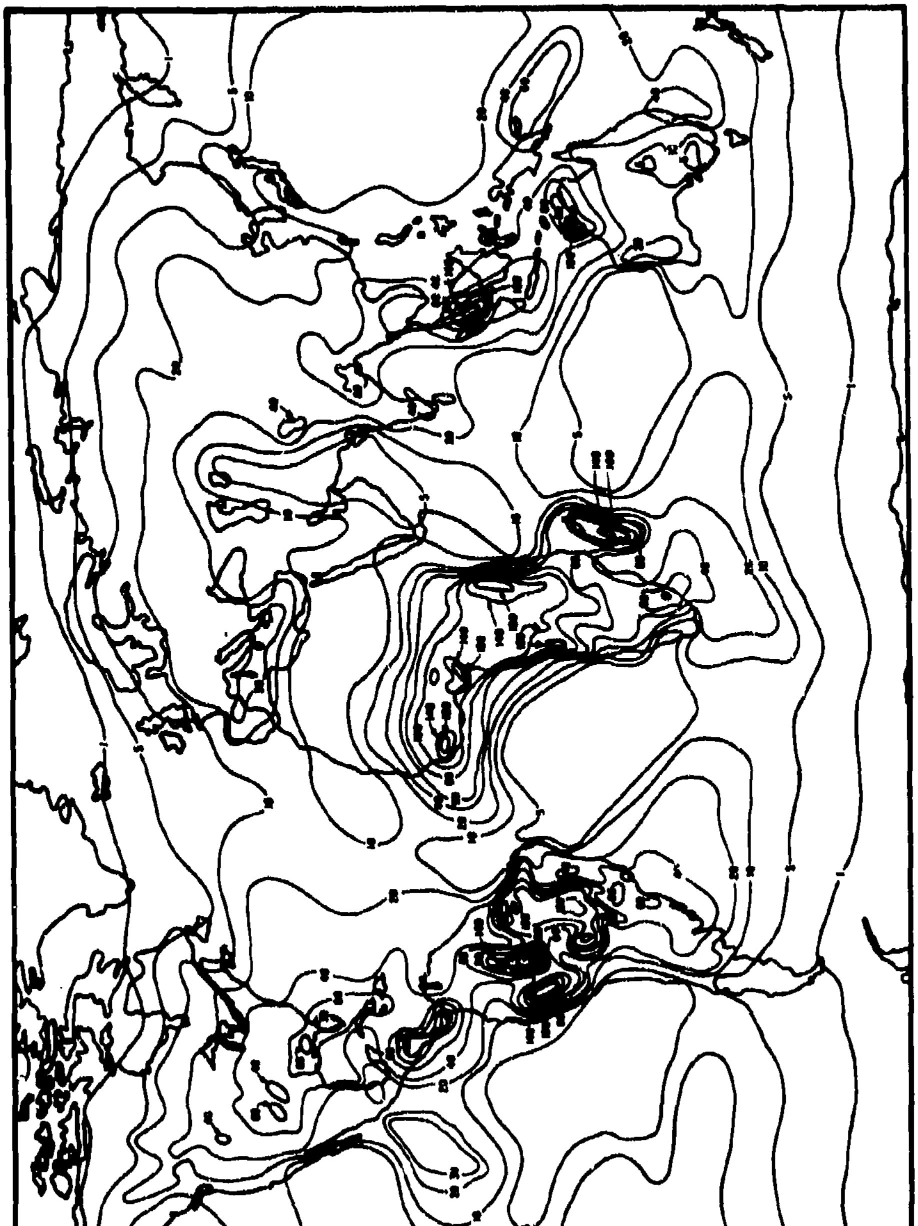


Figure 2-10. Thunderstorm Days (Mean Annual) (Ref. 7)

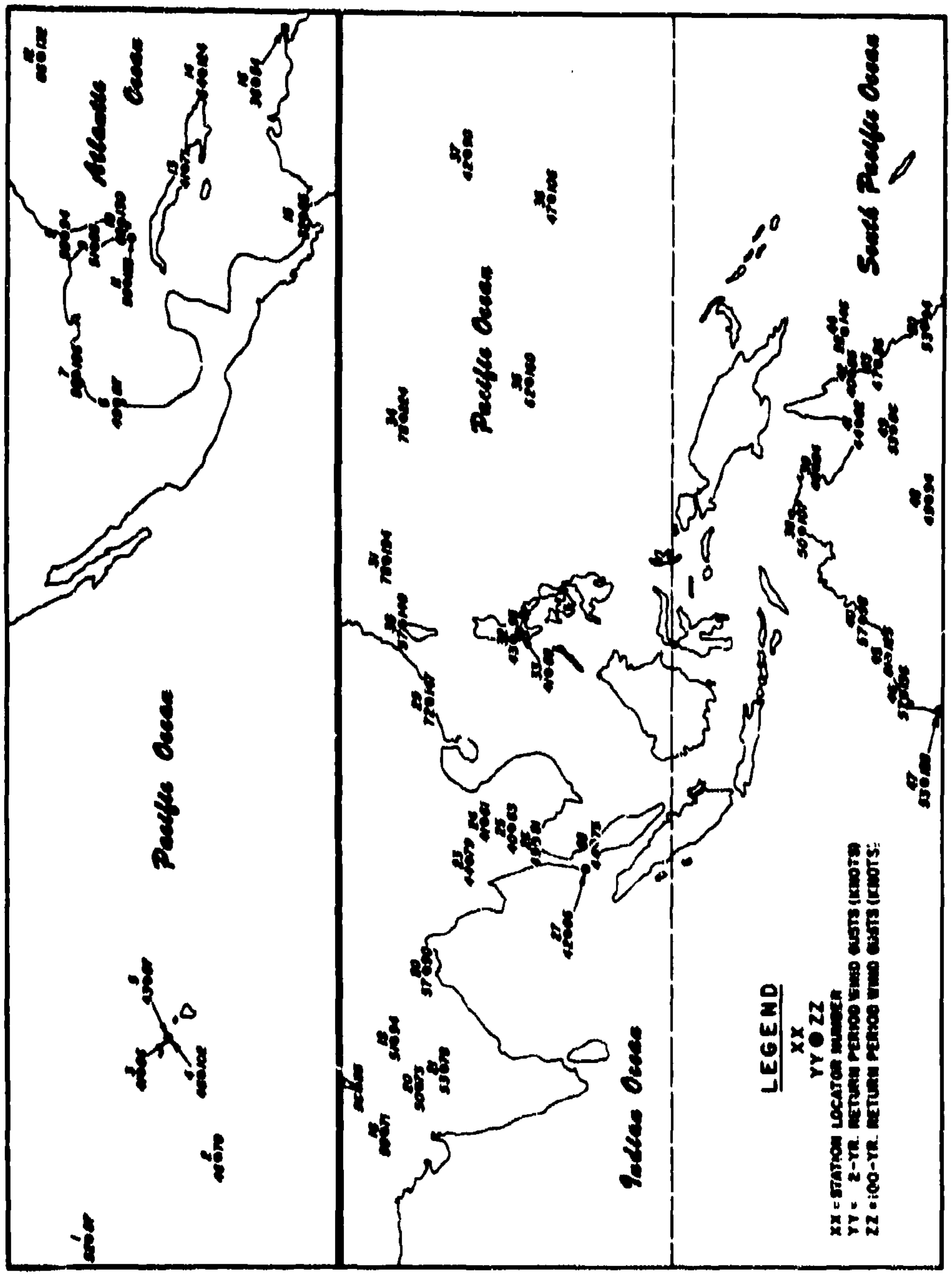


Figure 2-11. Expected Wind-gusts (kt) for 2-yr and 100-yr Return Periods for Selected Tropical Stations (Ref. 7)

several locations in the northwestern Pacific are significantly greater. For inland stations where the majority of the annual extreme winds are associated with thunderstorms, the expected extremes are much less than for stations affected by tropical storms. Typical values for inland stations range from 35 to 55 kt for the expected 2-yr extremes and from 60 to 90 kt for the 100-yr value.

2-4.1.7 Tropical Cyclones

Intense tropical cyclones (hurricanes or typhoons) are the most impressive phenomena of the tropical regions. The destructive potential for their high windspeeds, rainfall amounts, and storm tides is well known. At the present, no common international terminology distinguishes tropical disturbances and cyclones of various intensities. Whenever a comparison is to be made among data of various countries, a knowledge of the different definitions and terminology is required to provide adequate interpretation. Within the United States, the following classification system for tropical cyclones is employed:

(1) *Tropical Depression.* A weak tropical cyclone with a definite closed surface circulation, one or more closed surface isobars, and highest sustained windspeeds of less than 34 kt.

(2) *Tropical Storm.* A tropical cyclone with closed isobars and highest sustained windspeeds of 34 to 63 kt, inclusive.

(3) *Typhoon-Hurricane.* A tropical cyclone with highest sustained windspeeds of 65 kt or more. Cyclones of this intensity are called typhoons west of 180 deg and hurricanes east of 180 deg longitude.

Sustained winds in the preceding definitions refer to a 1-min average. Extreme surface wind gusts in tropical cyclones may be 30 to 50 percent higher than the reported sustained surface winds. Fig. 2-12 shows the average annual number and percent of the global total of storms occurring in each storm development area. Over half of the average global total of 80 storms per year occur in the North Pacific Ocean. The Northern Hemisphere accounts for 73 percent of the global total compared to 27 percent for the Southern Hemisphere. Fig. 2-13 shows the average monthly frequency of tropical cyclones of tropical storm or greater intensity for each of the storm development areas.

Generalized mean tracks of tropical storms by month or season are available for most storm-development regions. These tracks generally are determined by drawing isolines of the frequency distributions of cyclones of tropical storm or greater intensity that passed through various latitude-longitude grid squares over a period of years and by drawing mean tracks through the area showing a maximum frequency. The mean tracks thus determined are useful for some purposes but they do not indicate the large variability of tropical cyclone tracks. Fig. 2-14 shows the tracks of tropical cyclones of tropical storm or greater intensity in various development areas for certain selected years. In this figure, the years selected in each region are fairly typical insofar as the mean number of storms is concerned. The large variability of the tracks in all areas is clearly evident even in the one year.

2-4.1.8 Hail

Hail is defined as precipitation in the form of ice lumps with a diameter of 5 mm or more. Hail falling to the ground is a fairly rare event in most tropical areas, occurring much less frequently than over many regions in higher latitudes. The primary reason that hail is observed so infrequently at the surface in the Tropics is the relatively high freezing level equatorward of 20 deg latitude. The occasional observation of surface hail in low latitudes, however, indicates that fairly large hail may be found aloft in the more severe or intense tropical thunderstorms. Fig. 2-15 indicates the hail regime for three tropical zones. The X's on the

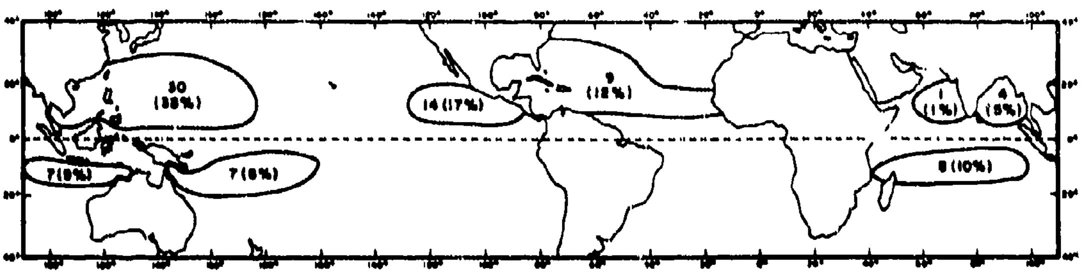


Figure 2-12. Tropical Cyclones (Average Annual Number and Percent of Global Total) (Ref. 8)

illustration indicate the months when the hail is most likely to occur at the surface.

2-4.1.9 Pressure

The mean sea level pressures between latitudes 40 deg N. and 40 deg S. for the midseason months are shown in Fig. 2-16. Certain major features, the subtropical high pressure ridges and the low pressure troughs in lower latitudes, are evident in all months. In the Southern Hemisphere the subtropical high pressure ridge is a dominant feature throughout the year and moves over a smaller range of latitude than its Northern Hemisphere counterpart. During the respective winter seasons, the subtropical oceanic ridge system and the continental high pressure areas form a continuous belt of high pressure around the hemisphere. During the summer this high pressure belt is interrupted by heat lows over continental areas, especially in the Northern Hemisphere. The oceanic highs in both hemispheres reach maximum intensity in July with average and center values of over 1,025 mb. This implies that center values often exceed 1,030 mb. The daily positions of the oceanic highs fluctuate more in the winter than in summer because of the greater influence of extratropical cyclones during winter. Large areas of mean sea level pressure less than 1,010 mb are evident in low latitudes throughout the year. The largest seasonal movements of the low pressure trough occur in the longitudes of the continents, due to effects of intense solar heating during the summer and radiational cooling during the winter over land. This is illustrated dramatically in the January and July pressure patterns over Asia and Australia. Low pressure prevails throughout the year over the large equatorial land areas of South America and Africa and extends poleward in summer over Eurasia, Australia, and North America.

2-4.1.10 Solar Radiation

Solar radiation reaching the surface of the earth in tropical climates is attenuated as a result of absorption by water vapor and carbon dioxide in the atmosphere. These absorptions, the result of quantum transitions and vibrational and rotational states of water vapor and carbon dioxide molecules, absorb significant portions of the incident solar radiation energy. As a result the solar radiation levels experienced in latitudes where temperatures characteristic of tropical climates can occur are dependent upon the amount of water vapor in the atmosphere. From a latitude standpoint, it is apparent from examining climatic maps of the globe that desert and tropical areas can occur in similar latitudinal regions. The primary difference between desert and tropical areas, insofar as solar radiation is concerned, is the amount of water vapor in the atmosphere, including clouds and precipitation.

Typically, for a given latitude a desert area receives significantly more solar radiation than does an area classified as tropical because desert areas with low humidity, low rainfall, and few clouds provide significantly less absorption to incoming solar radiation

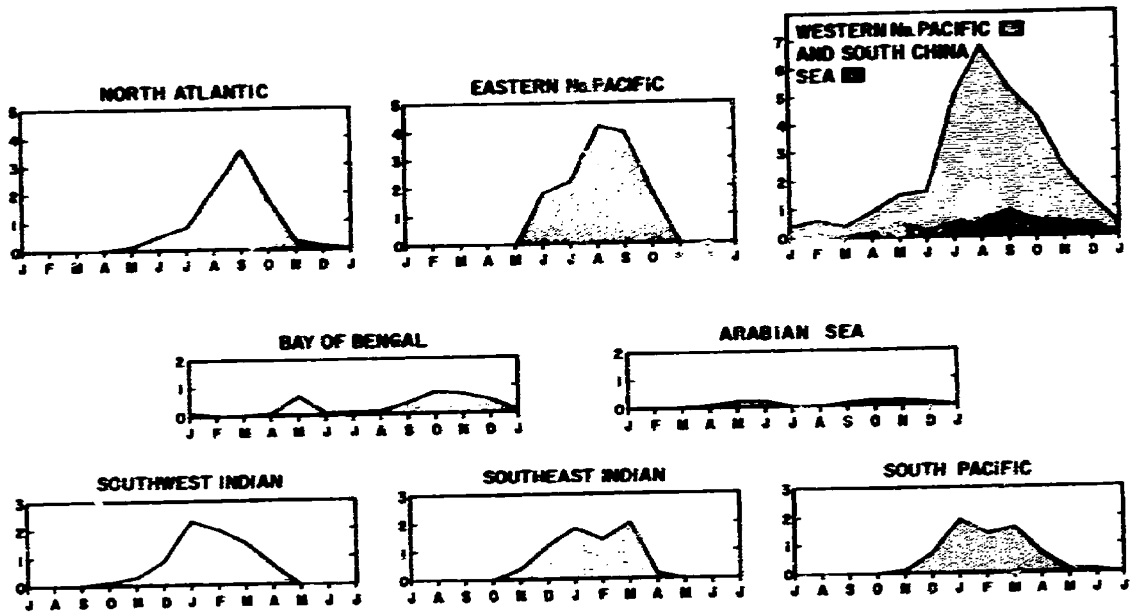
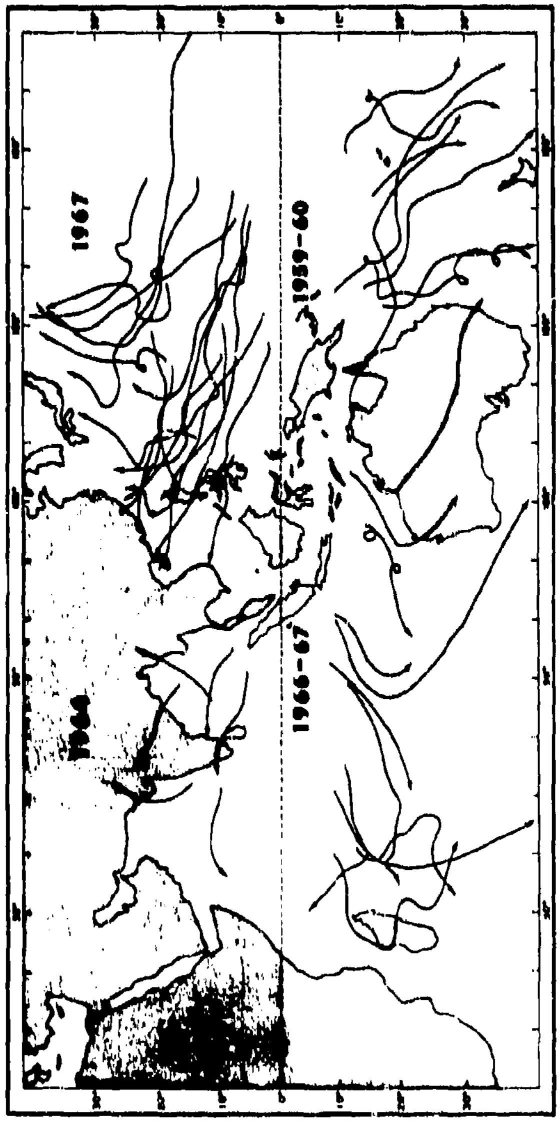


Figure 2-13. Average Monthly Frequency of Tropical Cyclones (Abscissas start with January in Northern Hemisphere areas and July in Southern Hemisphere areas) (Ref. 7)

(A) Atlantic and Eastern Pacific Oceans



(B) Western Pacific and Indian Oceans

Figure 2-14. Tracks of Tropical Cyclones (Ref. 7)

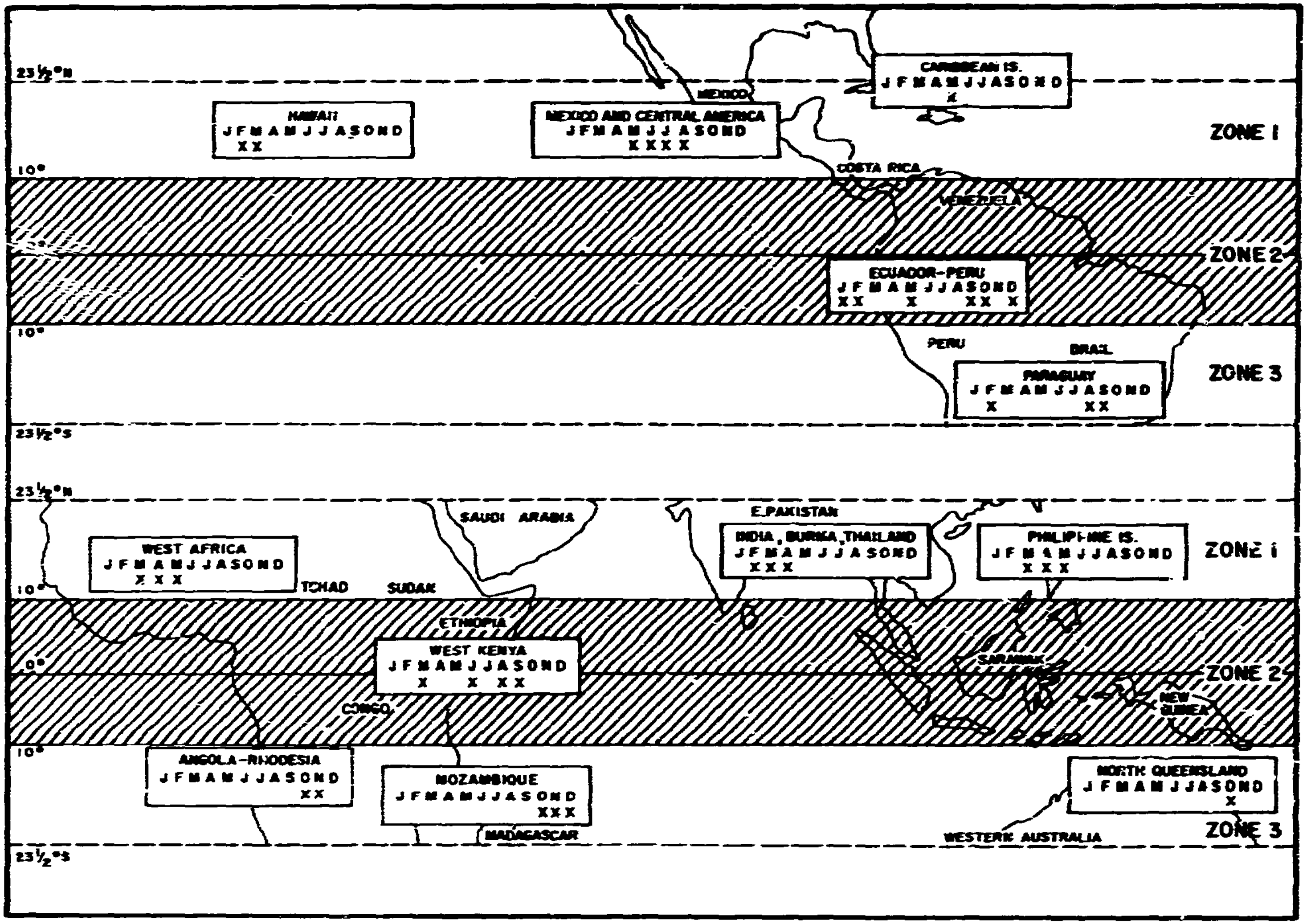


Figure 2-15. Hail Regimes for Three Tropical Zones (The X's indicate months when hail at the surface is most likely) (Ref. 7)

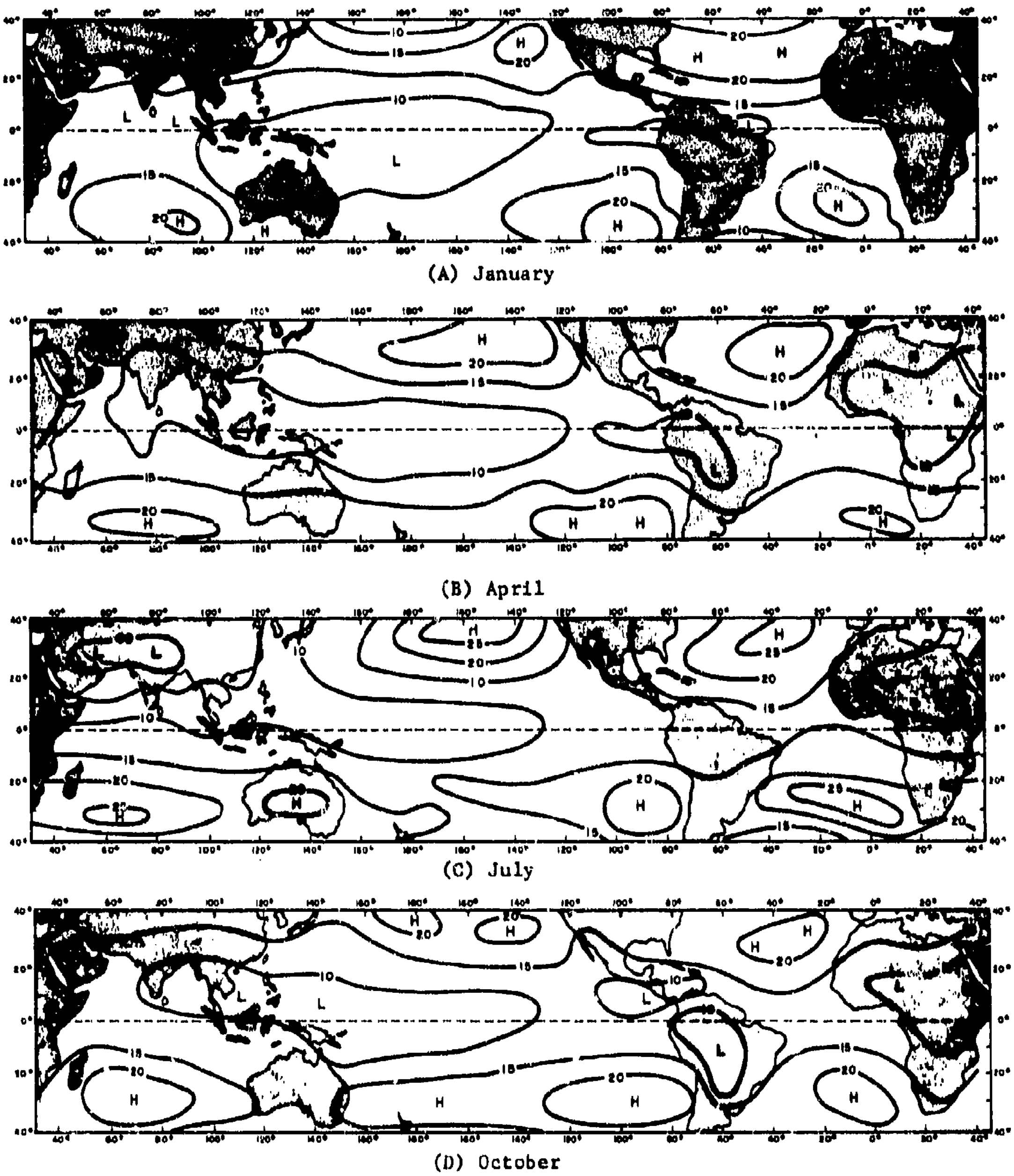


Figure 2-16. Mean Sea Level Pressure (millibars in excess of 1000 millibars) (Ref. 7)

than the humid, frequently cloudy tropical areas. Although latitude is an important variable in solar radiation, the amount of clouds and the atmospheric humidity or the amount of water vapor in the atmosphere are significant contributions as well.

Location with respect to major water bodies, which provide humid atmosphere and fogs, can have a profound influence on radiation intensity and sunshine duration. Fig. 2-17 shows the mean monthly global solar radiation. It readily can be seen that, in general, the areas of high radiation lie within the Tropics, i.e., within the latitudes encompassed by the Tropics of Capricorn and Cancer. Further examination reveals that the highest solar radiation levels are obtained primarily in inland desert areas, e.g., the interiors of Australia, the Arabian Peninsula the north-central African deserts, and the desert areas of the Southwestern United States and Mexico. The distinct regions of high global radiation values coincide in every case with areas of low cloud coverage (primarily desert areas). Monsoon regions, which have a high degree of cloudiness, have lower values of global radiation as do equatorial areas, where heavy cloud cover exists much of the time. Generally, the low latitude tropical climatic areas receive solar radiation intermediate between that of the low latitude desert areas and that of the temperate climatic areas.

2-4.1.11 Airborne Salt

Most of the salts that affect materiel are sea salt particles that contain sodium, chloride, sulfate, and magnesium ions. Some exceptions occur in alkaline deserts, large salt lakes, and industrial wastes. Salt occurs in the atmosphere as crystals or in liquid droplets, depending on the relative humidity of the air. Materiel can be exposed to the effects of salt as the result of dry fallout from the atmosphere, aqueous precipitation, salt fog, and direct exposure to sea water. Salt water sources include the ocean, inland seas, and the salt lakes. Atmospheric salt consists of salt-saturated droplets or dry particles in the atmosphere formed by bubbles produced on the sea surface or on the beach by breaking waves, by rainfall and snowfall on the sea surface, and by warming of sea water in the spring. Dry fallout under the force of gravity is important everywhere but particularly in coastal areas where the largest salt particles are found. Salt fog is an important means by which salt is deposited on exposed surfaces in maritime environments.

Because virtually all of the salt present in the atmosphere and deposited on vegetation and terrain surfaces originates from the ocean, coastal areas, in most cases, will have the highest atmospheric salt concentration, regardless of their location; i.e., whether they are situated in the Tropics or in other climatic zones. As a result, for tropical climates, those areas located near oceans and other salt water bodies will experience the highest amount of airborne salt and the highest amount of deposited salt on terrestrial surfaces. Other factors, including primarily the presence of water, high humidity, or high temperatures, influence the effect of salt on materiel.

2-4.1.12 Other Factors

In addition to the factors already discussed, several other factors are significant at times in tropical climates. Although terrain is a significant factor in all climates, it occasionally produces some special modifications that are significant in tropical climates. One of the characteristics of the large tropical areas of the world is the tropical rain forest. In these vast expanses of vegetation coupled with extremely high humidity and frequent rainfall, terrain can be significantly modified. For example, the presence of rain forest with heavy vegetation and large numbers of tall trees is unique to the tropical regions (see Fig. 2-18). Further, tropical rain forests in many cases so modify the climate that the climate above the rain forest canopy and the climate below the canopy are significantly different. For example, the amount of solar radiation re-

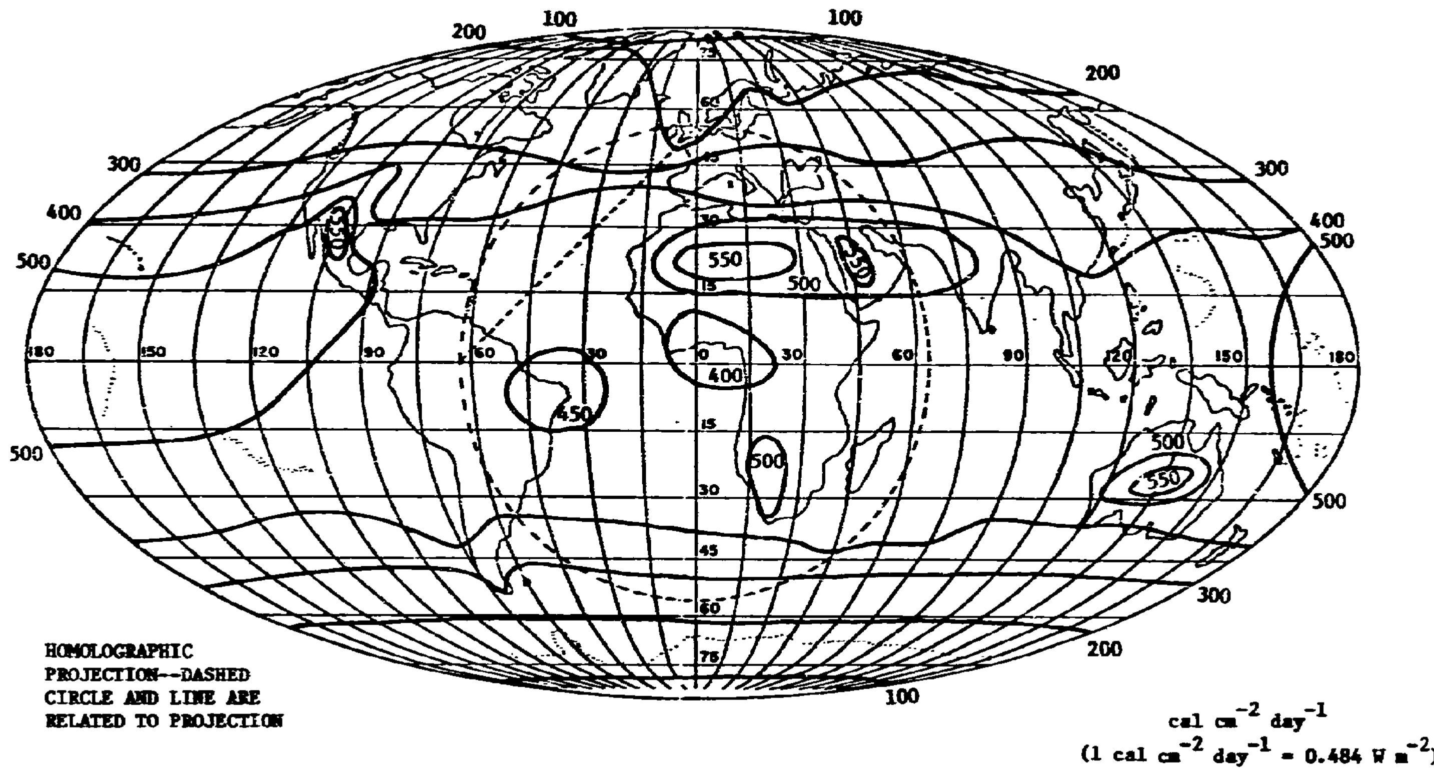


Figure 2-17. Mean Monthly Global Solar Radiation (Annual) (Ref. 9)

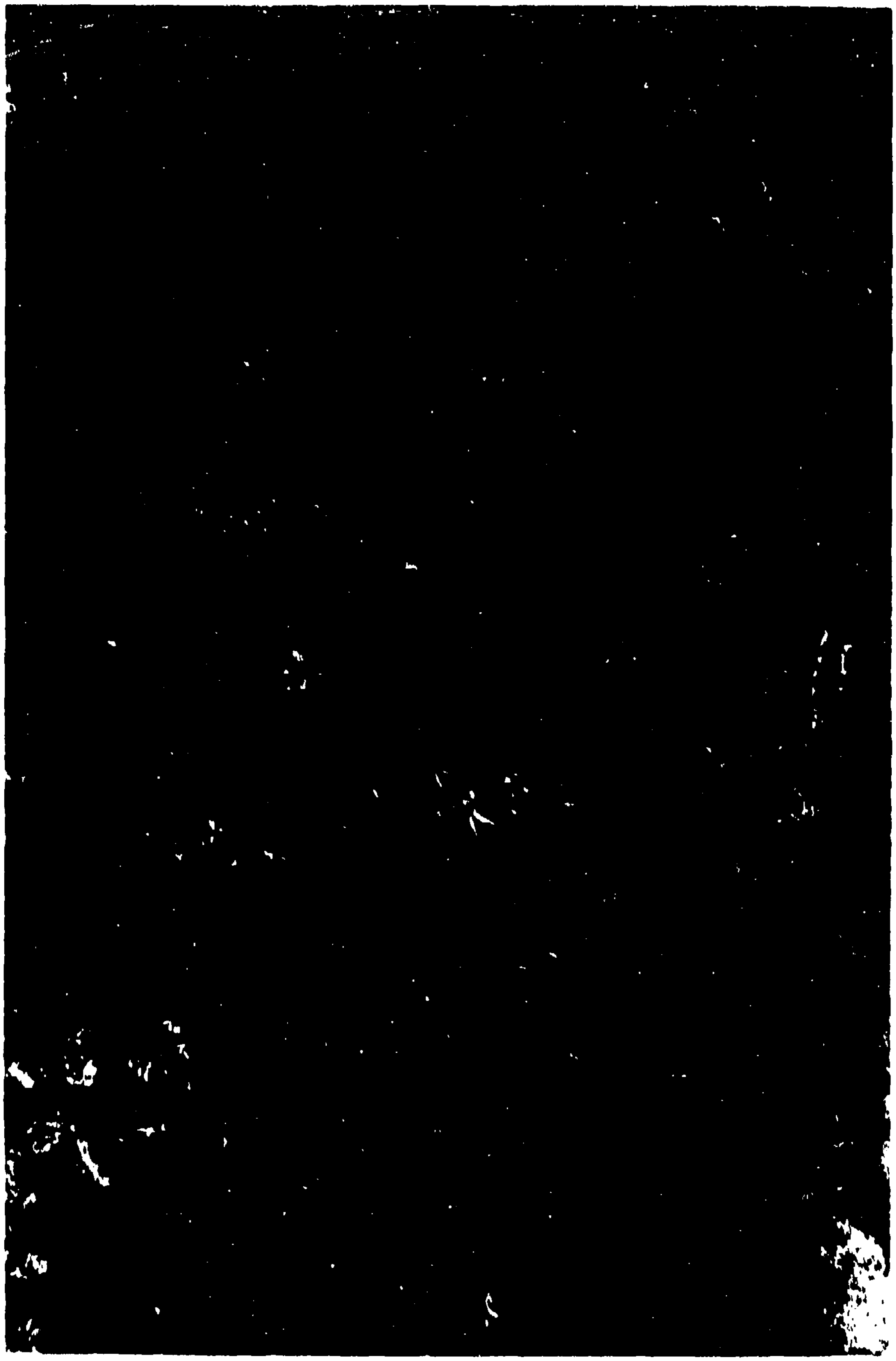
ceived at ground level in a rain forest can be quite small. Also, the humidity levels can be significantly higher within the rain forest canopy than above it. The frequent rainfall in the Tropics also can produce other effects on terrain. First, heavy rainfall leads to large numbers of streams which increase the number of land-water interfaces per unit area of the surface of the earth. Second, the presence of large amounts of water in certain silty soil types can lead to soft surfaces with extremely low bearing capacity.

Sand and dust are not normally a significant factor in the Tropics because of the relatively high rainfall, high humidity, and presence of moisture in the earth. Vegetation also produces a binding effect that reduces the probability of sand and dust particles becoming airborne. Under special circumstances, however, sand and dust can become a problem in tropical areas; e.g., sandy beaches are characteristic of much of the tropical regions and the microclimate of such beaches frequently evidences small amounts of airborne sand and dust near the beach surface. A particularly significant example of dust present in the Tropics is that which results from ground-up coral. This material is used widely by man as an aggregate in surfacing roads, airport runways, etc. The material occurs naturally, but should not be considered as a natural factor since it generally must be ground-up before it can cause dust problems.

Fog, a significant factor in many climates, occurs very infrequently in the Tropics, and is, therefore, not considered a significant parameter of the tropical climate.

(A) Subcanopy

Figure 2-18. Tropical Rain Forest (Photograph courtesy of H. L. Hamilton, Jr.)



(B) Surface Growth

Figure 2-18 (Continued). Tropical Rain Forest (Photograph courtesy of H. L. Hamilton, Jr.)

2-4.2 REPRESENTATIVE TROPICAL DAYS

While it is customary to employ average and extreme values of climatic factors, personnel and materiel are subjected to a particular combination of these factors. Thus, a more informative approach could be to consider some representative types of tropical days. Representative days cannot be determined by traditional methods of means and joint frequency distributions (Ref. 11). Averaging the values of different factors occurring in a variety of combinations to obtain an average day would result in an abstraction that may never exist in nature or may even be physically impossible. Certainly, no two days are ever exactly alike, yet most environments have typical days that are reasonably representative of many other days. Representative tropical days were identified using hourly climatic data for the year 1963 from three tropical weather stations--Ft. Sherman, C.Z.; San Juan, P.R.; and Hilo, Hawaii (Ref. 10). The data are representative of well-exposed shore sites near sea level. They do not represent conditions within the tropical forests or deep in the interior of a large tropical landmass.

The combined amount and duration of precipitation is probably the single most significant variable of tropical climates. Three types of days are identified with respect to precipitation: (1) days with heavy rain (1 in. or more), (2) days with showers of light rain (less than 1 in.), and (3) dry days with no rain. These major types are divided into seven subdivisions:

(1) Day with heavy rain
- (a) Day with intense heavy rain
- (b) Day with general heavy rain

(2) Day with shower
- (a) Daytime shower
- (b) Day with nighttime shower
- (c) Day with showers (day and night)

(3) Dry day
- (a) Sunny dry day
- (b) Cloudy dry day

Sunny days are defined as those with 450 ly or more of solar radiation during the day, or, in the absence of radiation data, with 51 percent or more of the possible sunshine. An example of each of the seven different types of days is described in the paragraphs that follow. The illustrated days actually occurred at Ft. Sherman, C.Z. Table 2-6 gives

TABLE 2-6.
FREQUENCY OF OCCURRENCE OF REPRESENTATIVE TROPICAL DAYS (Ref. 10)

Types of representative days	Number of days	Percent of days
Day with intense heavy rain	14	1.3
Day with general heavy rain	62	5.8
Day with daytime shower	95	8.8
Day with nighttime shower	165	15.3
Day with showers (day and night)	353	32.7
Sunny dry day	287	26.6
Cloudy dry day	102	9.5
TOTAL	1078	100.0

a summary of the frequency of occurrence of representative days for the three tropical stations at which data were compiled during 1963.

An important point with respect to the representative days is that there is no major seasonal change in the magnitude of any of the elements for a particular type of day. For instance—because of the small annual variation in temperature and solar radiation in the Tropics—a sunny, dry day during the dry or low sun season will resemble very closely the same type of day during the rainy or high sun season; a contrast to higher latitudes where the temperature and solar radiation for such a day in winter will be considerably lower than for the same type of day during summer.

(1) *Day with intense heavy rain (Fig. 2-19).* The most frequent occurrences of heavy rains are found in the Tropics, particularly in exposed locations where prevailing air currents are forced to rise. However, in most areas of the Tropics, intense rainfall is not common. In 1963 at Ft. Sherman only 2.5 percent of the days had 1 in. or more of precipitation in an hour. From Table 2-6 it can be seen that only 1.3 percent of the days could be classified as days with intense heavy rain for the tropical stations during 1963. Although not necessarily occurring together, high winds in excess of 30 mph sometimes accompany intense rainfall.

(2) *Days with general heavy rain (Fig. 2-20).* In most areas of the Tropics few days will have continuous rain for many hours. A day with heavy rain is generally a cooler day than the dry day or the shower day, and in the Tropics there is generally some sunshine. Only 7.5 percent of the days at Ft. Sherman and 5.8 percent of the days at all three recording stations were of this type.

(3) *Day with daytime shower (Fig. 2-21).* Early showers characteristically followed by sunshine create an uncomfortable condition with afternoon temperatures that are high, typically around 90°F. In addition, under these circumstances the dewpoint would be on the order of 80°F. At Ft. Sherman, 16.4 percent of the days were in this category; it comprised 8.8 percent of the days for the three stations.

(4) *Day with nighttime shower (Fig. 2-22).* In many respects the midday conditions of this type of tropical day are similar to the sunny dry day. There is a common impression that, in the Tropics, most shower-type precipitation occurs in the afternoon. At the Ft. Sherman weather station, however, there were more days in 1963 with nighttime showers (20.7 percent) than with daytime showers (16.4 percent). The same is generally true of the other stations with 15.3 percent of the days being in this category.

(5) *Day with showers (day and night) (Fig. 2-23).* This type of day is characterized by high winds during the rain, but otherwise the days are much like those described in the preceding paragraphs. Temperatures are slightly lower during the period of rain. The weather pattern associated with this type is usually more organized than for the convective showers of the preceding two types. Possibly, an easterly pressure wave passes the station during the period from midnight to noon. Clearing and increased solar radiation occur after the wave passes. Often, such a wave causes more than an inch of rainfall in a day so that it would be classified as a day with heavy rain. However, in the representative day being described, only 0.22 in. occurred. This type of day occurred only 13.2 percent of the days at Ft. Sherman and 32.7 percent of the days for the three stations.

(6) *Sunny, dry day (Fig. 2-24).* The tropical day is dry only in regard to precipitation. Nighttime relative humidity is 100 percent, and vegetation is as wet as if rain had occurred. The sunny, dry day is one of the warmer days in the tropical climate with morning temperatures near 80°F and afternoon temperatures near 90°F.

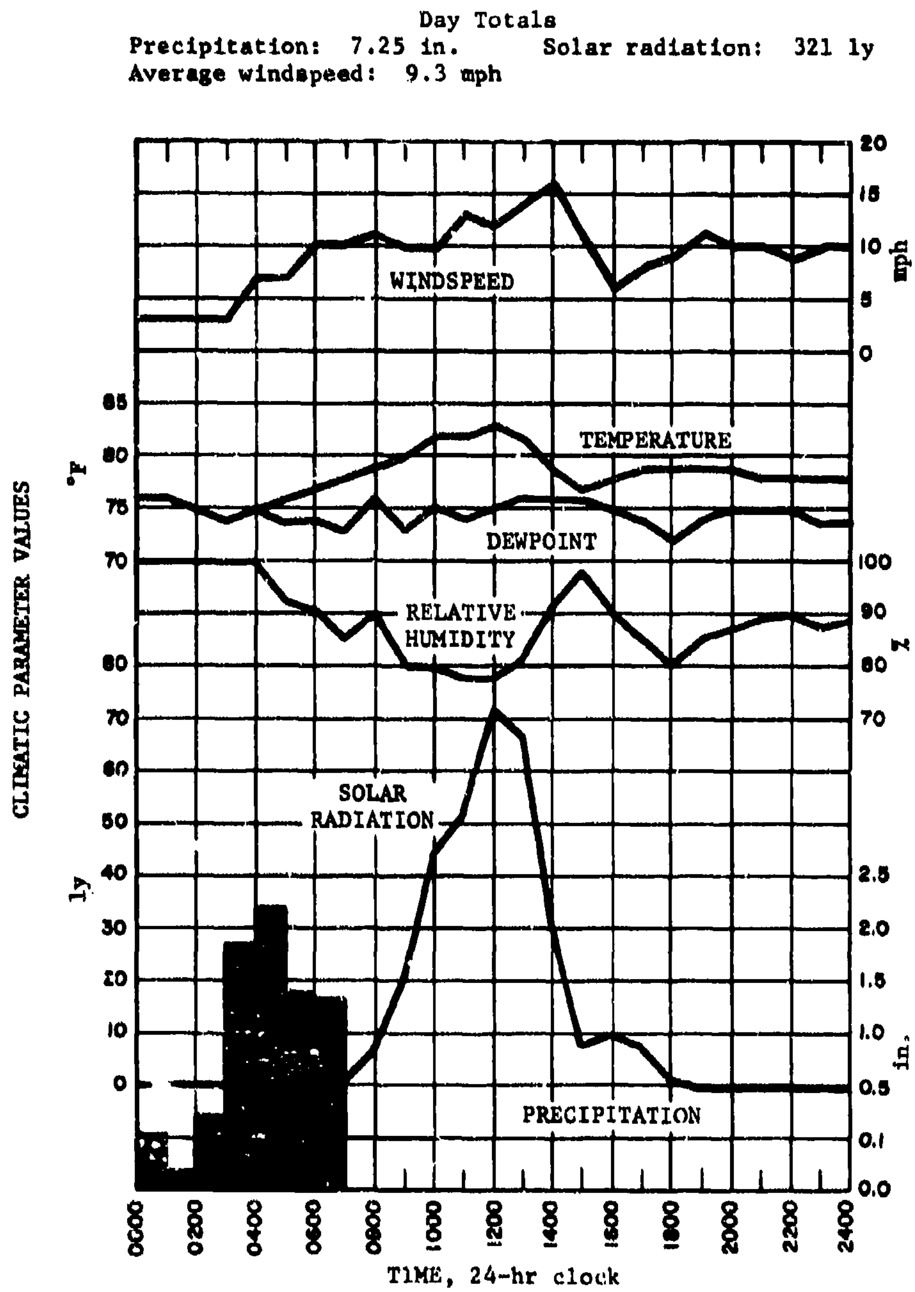


Figure 2-19. Tropical Day With Intense Heavy Rain (2.5% occurrence) (Ref. 10).

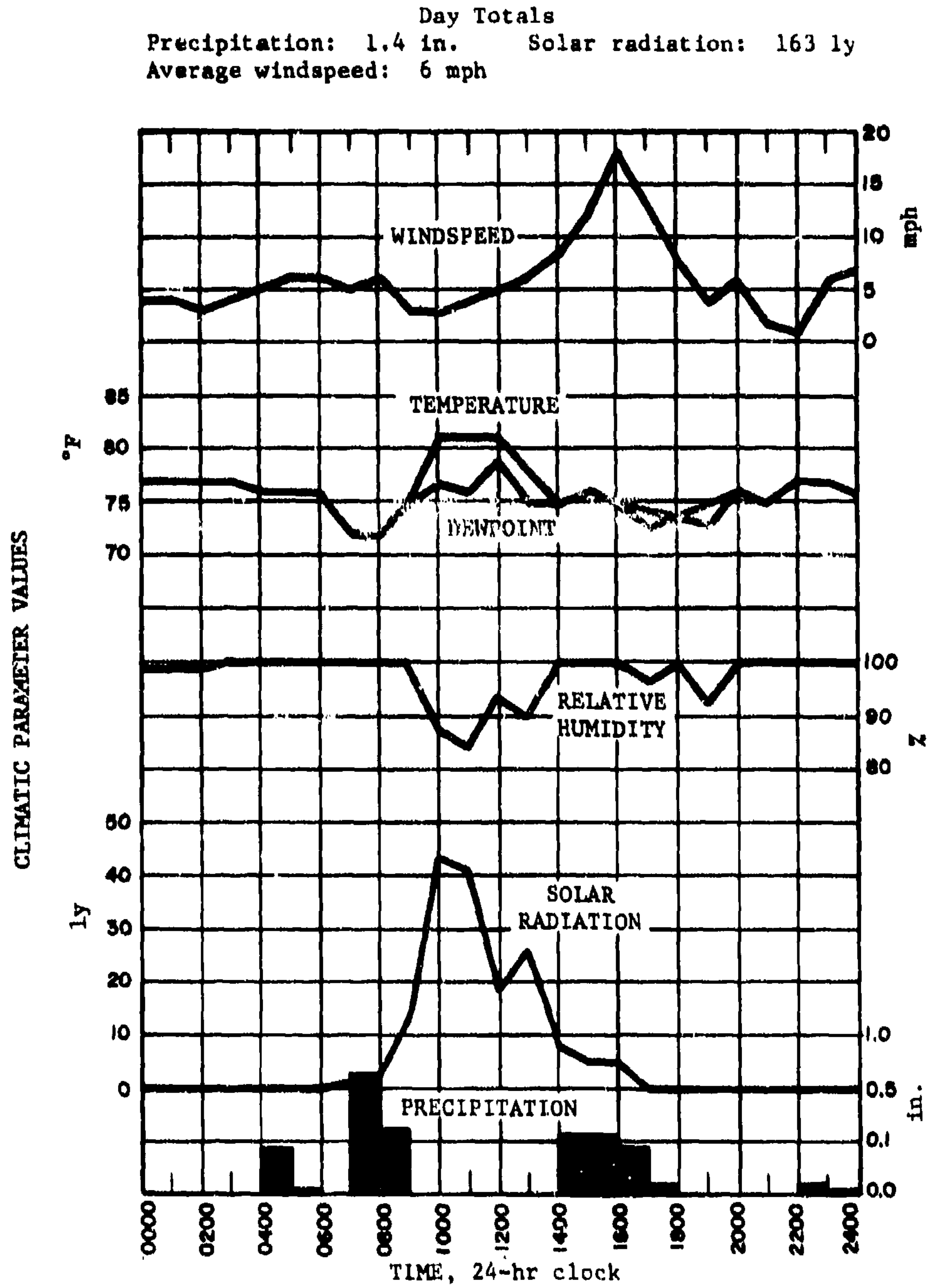


Figure 2-20. Tropical Day With General Heavy Rain (7.5% occurrence) (Ref. 10).

Day Totals
Precipitation: 0.13 in. Solar radiation: 392 ly
Average windspeed: 5.2 mph

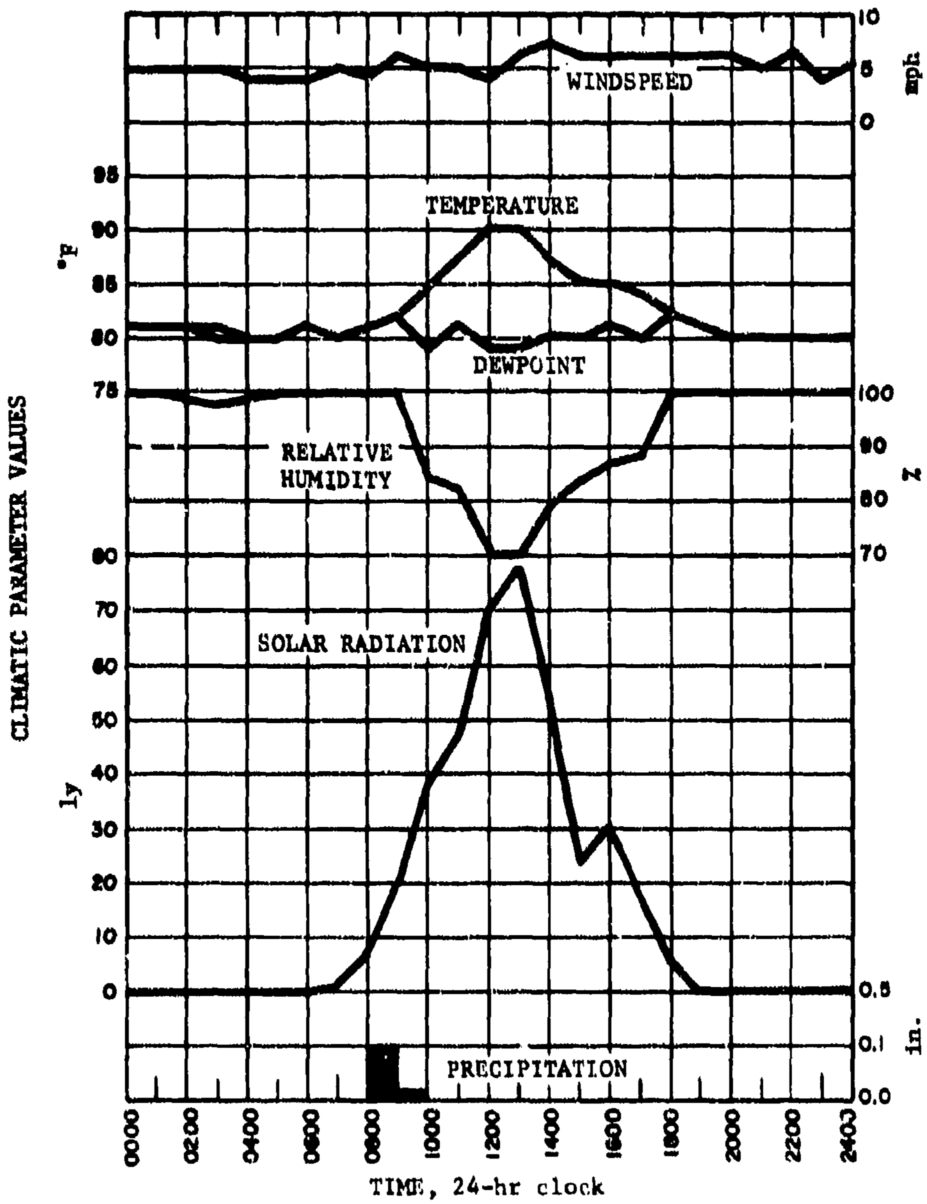


Figure 2-21 Tropical Day With Daytime Shower (16.4% occurrence) (Ref. 10)

Day Totals
Precipitation: 0.03 in.   Solar radiation: 400 ly
Average windspeed: 3.7 mph

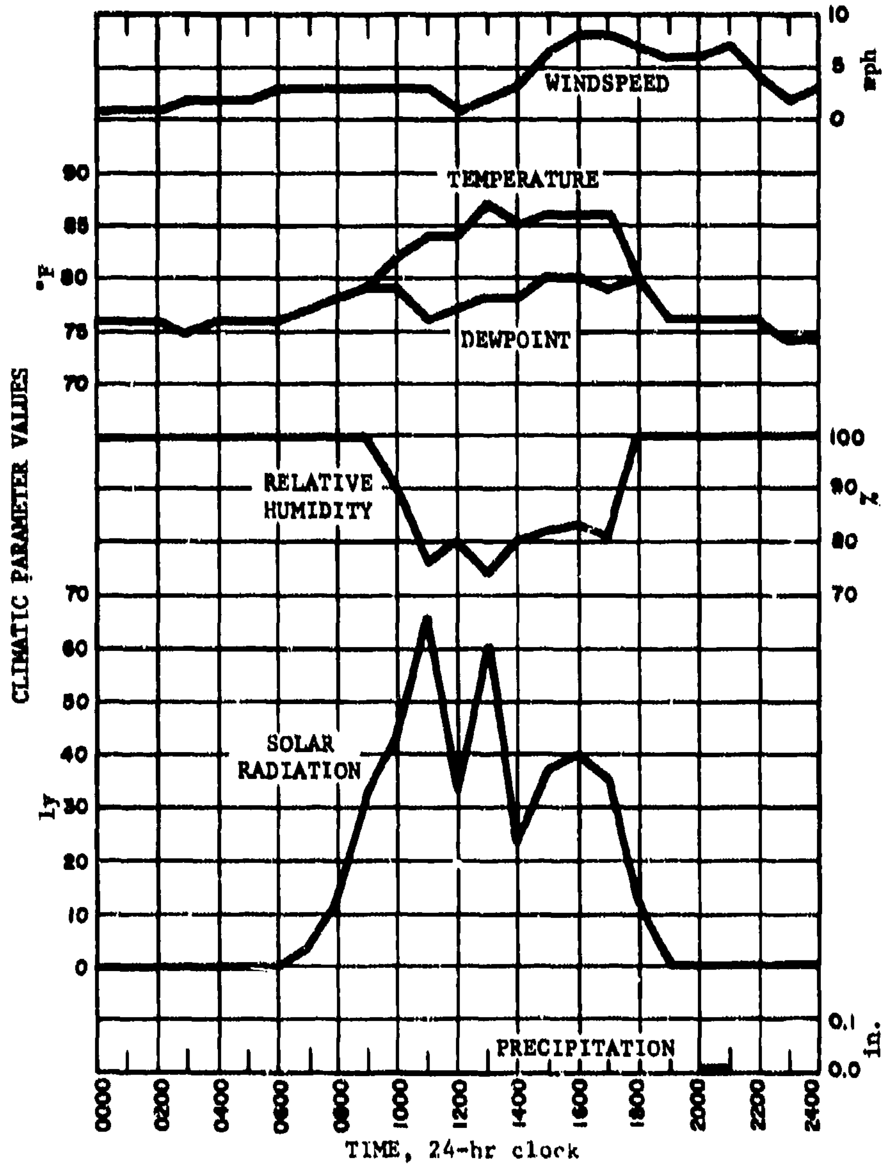


Figure 2-22. Tropical Day With Nighttime Shower (20.7% occurrence) (Ref. 10)

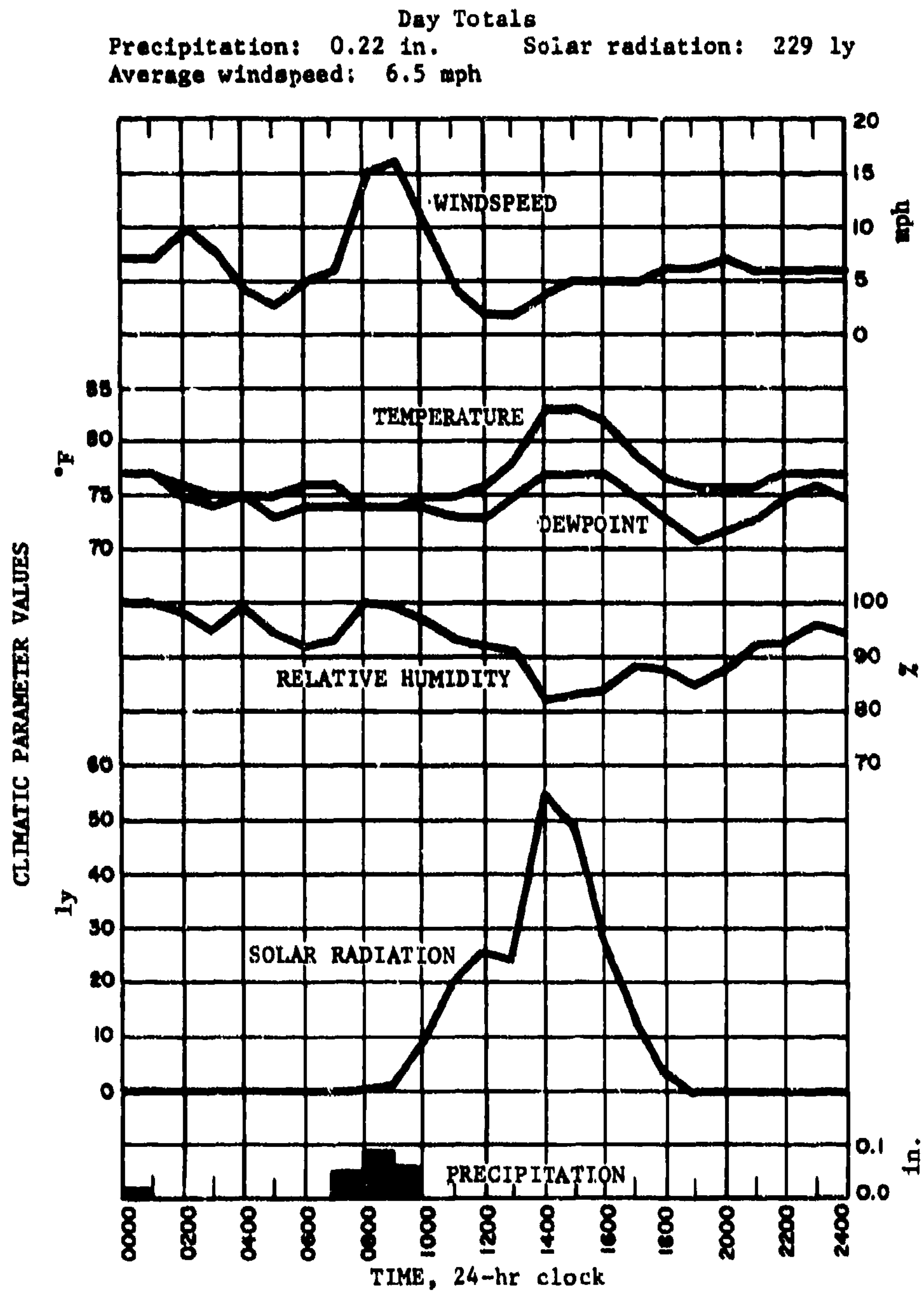


Figure 2-23. Tropical Day With Daytime and Nighttime Showers (13.2% occurrence) (Ref. 10)

Day Totals
Precipitation: 0.00 in. Solar radiation: 615 ly
Average windspeed: 9.5 mph

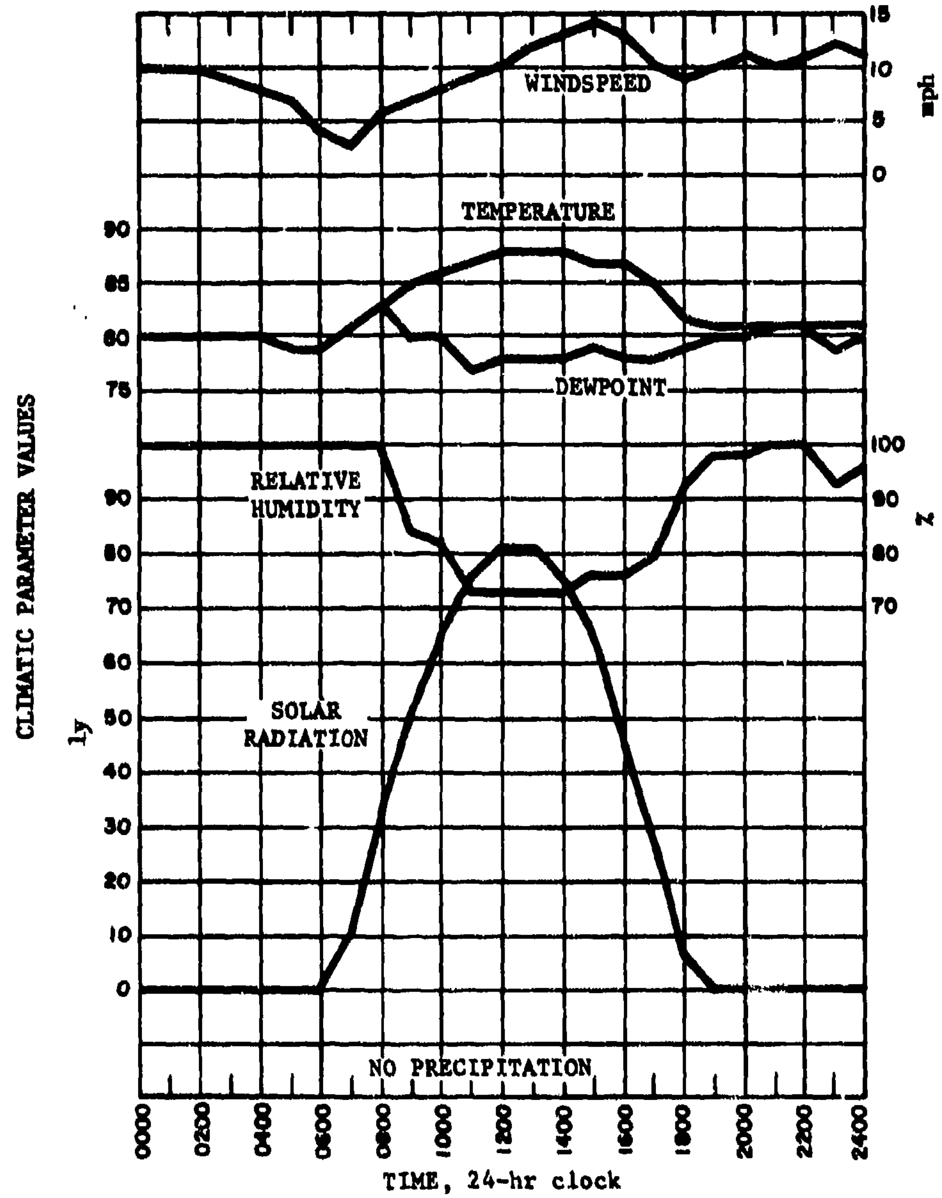


Figure 2-24. Tropical, Sunny, Dry Day (27.9% occurrence) (Ref. 10)

Dewpoints are near 80°F throughout the day which, coupled with the temperature rise in the afternoon, produces relative humidities below 80 percent. Solar radiation is high, but much higher daily totals are experienced in the deserts. At Ft. Sherman the sunny, dry day is the most frequent of the seven types, occurring approximately 27.9 percent of the days while occurring 26.6 percent of the days for the three stations.

(7) *Cloudy, dry day (Fig. 2-25).* A cloudy, dry day is defined on the basis of lower than normal amount of solar radiation which causes lower temperatures, lower dewpoints, higher relative humidities during the day, and less daily rainfall. Cloudy, dry days are not as frequent as sunny, dry days at Ft. Sherman, occurring only 11.8 percent of the time. For the average of the three stations, cloudy, dry days occurred only 9.5 percent of the days.

2-5 THE DESERT ENVIRONMENT

Desert regions occupy approximately 19 percent of the land surface of the earth. The identifying attribute of all deserts is aridity; one definition is based on an annual rainfall of less than 10 in. Deserts are further characterized by clear atmospheres and intense solar radiation (Ref. 8). The solar radiation, combined with terrain that has a high reflectance, can create high levels of glare. Other characteristic phenomena associated with deserts are atmospheric boil* and mirages. Sand and dust, which nearly always accompany dryness, are also important factors.

The high daytime temperatures, solar radiation, and sand and dust, combined with sudden, violent winds and large daily temperature fluctuations, may create many problems with respect to men and materiel. Table 2-7 indicates the temperature extremes likely to be encountered in desert regions.

The cores of the major deserts of the earth are located at approximately the same places regardless of the criteria used to identify desert climates. However, the extents of desert areas are determined in large measure by the criteria chosen (Ref. 11).

The use of temperature to classify regions as deserts is not uncommon but is inconsistent. In some classifications, arid and semiarid land areas are divided into gross qualitative thermal subtypes with lack of rain being the dominant characteristic and temperatures considered less important. As a result some arid and semiarid zones are divided into tropical, subtropical, and moderate or temperate thermal regions. Where cold is a dominant characteristic, as in polar thermal regions, lack of precipitation is largely ignored; polar or subpolar climates are rarely classified as arid or semiarid. When actual temperatures are used in defining climatic regions, the values selected usually are indirectly related to vegetation or are completely arbitrary.

A semiarid (moderately dry) climate is defined as one with 6 to 9 months of the year having no more than 3 days with 0.1 in. or more precipitation per day. The definition of arid climates requires at least 10 mo of the year having no more than 3 days per month with 0.1 in. or more precipitation. The classification "extremely arid" requires at least 10 mo of the year having no more than 1 day per month with 0.1 in. or more precipitation. Much of the extremely arid regions actually have 6 months or more with no rainy days. A number of weather stations in North Africa and southwestern Asia often report zero annual precipitation. The rare rainfalls occur less frequently than 1 day every 2 years.

The semiarid climates usually consist of two different annual regimes: (1) a distinctly

*Atmospheric boil also called terrestrial scintillation or shimmer, is a scintillation phenomenon caused by light that reaches the eye from sources within the atmosphere. It is produced by irregular refraction effects due to passage, across the line of sight, of air parcels whose densities differ slightly from that of their surroundings. Atmospheric boil is seen over paved roads on bright summer days (Ref. 12).

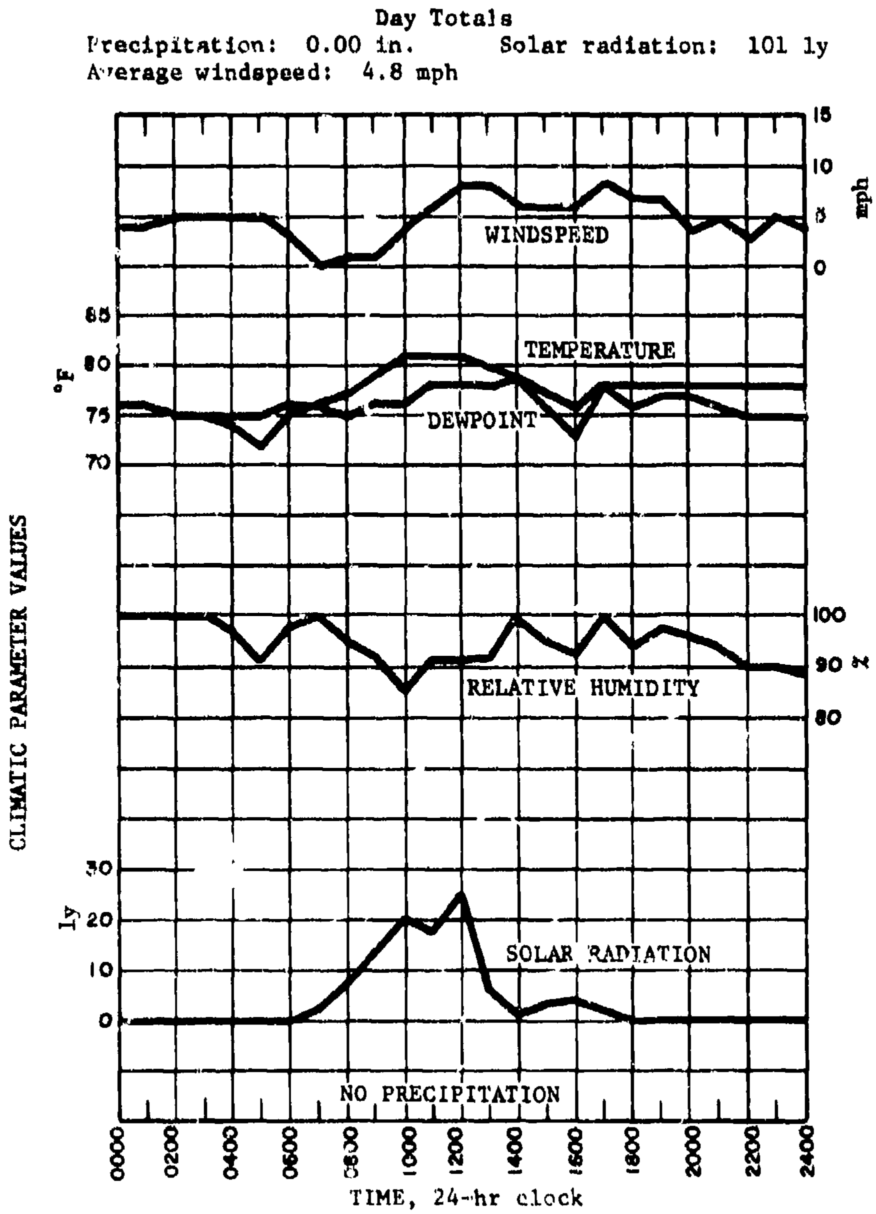


Figure 2-25. Tropical Coudy, Dry Day (11.8% occurrence) (Ref. 10)

TABLE 2-7.
DESERT TEMPERATURE EXTREMES (Ref. 8)

Conditions	Temperature	
Dry heat (RH 5%) intense sunlight, sand and dust, destructive insects	Day high:	
	Air	60°C (140°F)
	Exposed ground	75°C (167°F)
	Night low:	-10°C (+14°F)
	Daily variation	40 deg C (72 deg F) average

dry period, which lasts from 6 to 9 mo, and a relatively wet period of 3 to 6 mo, or (2) 10 to 12 mo dry and moderately dry and no more than 2 months moderately wet or wet. Regions having the second climate do not quite meet the criteria established for semiarid climate although they often have fewer total rainy days per year than places that do meet the criteria. They are classified demiarid (4 or 5 mo having averages of no more than 3 days per month with 0.1 in. or more precipitation and a total of at least 10 mo having averages of no more than 6 days per month with 0.1 in. or more precipitation).

Fig. 2-26 indicates the distribution of dry climatic types throughout the world. The climatic factors of arid and semiarid environments having military significance are discussed in the paragraph that follows together with a description of the desert terrain.

2-5.1 DESERT CLIMATIC FACTORS

Arid regions contribute more than their proportional share to the extremes of climatic elements. Both the highest recorded air temperature and the largest diurnal range have been recorded in the dry air of the desert where vegetation-free ground quickly gives up the heat of the sun. Minimum levels of precipitation and humidity are found not only in the vast continental interior deserts but also in coastal desert areas. Winds in the desert are not as strong as those in other regions but, when they entrain sand and dust, their effects are as severe as those of any natural phenomenon.

Arid and semiarid climates have a deficiency of rainy days and, at least during the driest part of the year, a deficiency of residual ground moisture. When rain does occur, it often comes in heavy showers and thunderstorms which produce dangerous flooding, particularly in deep, narrow channels which are usually dry and thus attractive for protection. Caution is necessary when thunderstorms or heavy showers are anywhere in the general vicinity because flash flooding occurs at considerable distances from where precipitation falls.

When soils have a high clay content or are salt-encrusted as on some extensive flats and playa lake depressions, a relatively small amount of rainfall turns the surface into a slimy plain on which travel is difficult. Soils that are predominantly sand hold essentially no moisture in the upper portion of the ground, and small and even moderate rainfall frequently will improve trafficability for at least a short time by firming the sand.

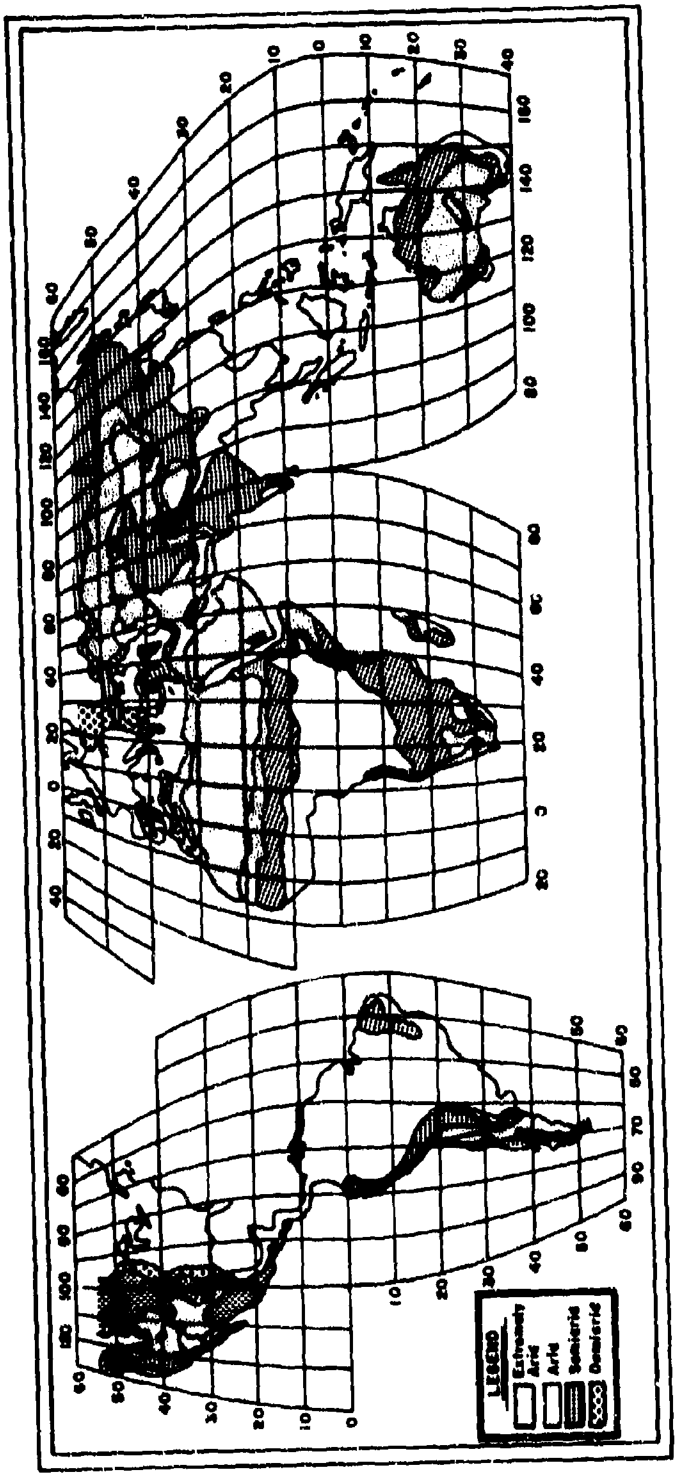


Figure 2-26. Global Distribution of Dry Climatic Types (Ref. 11)

Arid and semiarid climates usually have a concentration of rainy days in the hotter part of the year on the equatorward side of the aridity core and in the colder part of the year on the poleward side. In the summer, rainy days often have very heavy showers and thundershowers; in the winter, rainy days are more likely to be associated with extratropical cyclones and, thus, the rain is not as heavy and is of longer duration. Especially in high latitude desert climates, snowstorms, drifting snow, and persistent snow cover can become severe problems.

Low daytime relative humidity is a climatic characteristic of much of the arid and semiarid areas of the earth. Throughout a major portion of the very hot and extremely hot regions, midday relative humidity ranges between 10 and 25 percent during the hottest and driest part of the year.

Salt fog is not a problem in desert areas, of course, and solid salt as airborne particulates usually is associated with proximity to maritime areas. There are several exceptions, however, in which airborne salt concentrations can become quite high. Arid land is one of those exceptions. Salt can be picked up from dry playas and salt lakes as a result of wind or the combined effect of vehicle passage and wind so that local areas may experience rather heavy saltfall, particularly if the relative humidity is high enough. As a result, airborne salt particulates could be in rather high concentration around salt lake and dry playas, particularly when vehicular activity and high winds occur concurrently.

Solar radiation is a very important factor in desert climates. The highest annual radiation levels—more than 2.93×10^{-2} W cm^{-2}—are observed in the Sahara Desert in northeastern Africa. Desert environments have higher solar radiation than other climates of equal latitude because few clouds are present in the atmosphere and the amount of water vapor present is very low. The result is that incident solar radiation reaches the surface of the earth a significantly larger portion of the time during daylight hours and with a significantly higher intensity than that experienced in very humid climates of the same latitude. Levels of 2.66×10^{-2} W cm^{-2} or more are observed in three principal desert areas of the world: the Sahara, the Arabian, and the Thar in India. The interrelationship between solar radiation received at the surface and the aridity of the climate clearly is reflected in Fig. 2-17 which depicts the mean monthly global solar radiation. Isolines of solar radiation are drawn with units measured in gram calories per square centimeter per day. Those areas in which the mean monthly solar radiation is higher than 500 gcal cm^{-2} day^{-1} clearly are identified with the great desert regions of the world: the southwestern desert of the United States and Mexico, the Sahara Desert of North Africa, the Arabian Desert of the Arabian Peninsula, and the Australian Desert (Ref. 9).

Another related factor in desert areas is the loss of heat by longwave terrestrial radiation. This factor is generally less variable than is the incident radiation; however, the large mean annual terrestrial radiation rates are observed in tropical desert areas. This results from the much greater warming of the surface in deserts relative to the air temperature. The increased loss of terrestrial radiation in the desert is reflected in the relatively cooler nights in the desert compared to those of similar latitude in tropical or temperate climates.

2-5.2 DESERT TERRAIN

Landscapes in areas with arid climates are noticeably different from those that develop in areas having surface water. Features created by erosional agents are often steeper and seem to have been cut out of the overall landscape rather than to be an integral part of it. These include entrenched streams, dry stream channels (wadis), buttes, and barchans (isolated crescent dunes). In these and in other land features, change of slope can be abrupt, a characteristic that might be of more adverse influence on mobility than the slope itself. Landscape features created by deposition have a tendency to contrast with the rest of the terrain rather than to blend with it. Outstanding among these are alluvial fans, where mountain streams merge onto plains, and sand dunes.

Sparse vegetation and, in wide areas, lack of any vegetation leaves the land vulnerable to eroding agents, and the surface is often bare rock, stones, or sand, each of which may present special problems. Fig. 2-27 illustrates several desert terrain types. Wind is an important factor in creating the residual land surface in arid areas, and its actions contrast sharply with that of water. Exposed rock is weathered much more slowly; thus, individual elements from small fragments to escarpments and mountain cliffs frequently have more angular shape. Relatively flat surfaces lose the finer particles and are left with stones and rock-strewn plains, varying from gravel and desert pavement to boulder fields. On the other hand, some depositional features provide the smoothest, firmest surface to be found in the deserts—the dry salt flats and playa depressions that collect silt and minerals from evaporating waters of infrequent, temporary lakes.

Regions with semiarid climates have landscape types transitional between those asso-

Figure 2-27. Types of Desert Terrain (Ref. 13)

Figure 2-27 (Continued). Types of Desert Terrain (Ref. 13)

ciated with aridity and those with more or less permanent wetness, to the extent that climate is related to the development of land forms. A relatively short period with adequate rainfall and above-freezing temperatures can support enough vegetation to reduce drastically the vulnerability of the ground surface to erosion. Individual terrain characteristics of importance are relief, surface materials, and slope.

The term "relief" popularly refers to the height of hills and mountains on the landscape while more technical usage refers to the depth that valleys are cut into the prevailing upper surface. In any case, large relief is a characteristic of mountains and high plateaus. Rugged mountain terrain presents numerous operational difficulties, resulting especially from limitation of movement in the often narrow, winding, and steep-sided valleys. Arid mountains usually have the added unfavorable condition of lack of protective vegetation. Except where roads have been built, mountain valleys are likely to be impassible for wheeled or tracked vehicles because of the many large rocks that litter the surface. Deep gashes in the otherwise flat surfaces may measure hundreds, even thousands of feet to the bottom. The surface material in the extremely arid regions is typically bare rock, broken rock, or sand. Parts of open sandy deserts are subject to pockets of fine powdery sand while others consist of dune fields with individual dunes 50 to 300 ft high and little or no space between them. Sand dunes often have a packed crust a few inches thick on

Figure 2-27 (Continued). Types of Desert Terrain (Ref. 13)

the windward slope while other dune areas have rocks and ledges concealed by sand. Traction is best in sandy areas during the early morning when relative humidity is highest and the temperature lowest.

Dry salt flats and playa depressions, which have a hard smooth surface, are found often in arid and semiarid regions. The calcium carbonate or calcium sulfate crust may be as thick as 6 ft and is usually rock hard. A surface layer of dust sometimes covers the playa depressions and any movement raises clouds of the fine materials. Fig. 2-28 shows the dust raised by vehicle passage on dry earth. Unlike the sand surface, salt crust rapidly deteriorates when rain wets the surface and makes it slimy.

The hydrology features of the arid and semiarid regions of the earth are functions of the contributing environmental influences not only within the regions themselves but also in adjacent regions. Surface water in arid regions and to some extent in semiarid regions frequently has higher suspended particle and mineral counts than those in wetter portions of the world. Underground water on the other hand may be cleaner because of extensive mechanical filtering, although its mineral content may also be high.

Lesser and little known intermittent and ephemeral streams are present and are subject to flash floods in otherwise dry washes, wadis, and arroyos. Hydrologic

Figure 2-28. Vehicle Passage at 15-mph Speed on a Typical Well-maintained Unpaved Road (Ref. 14)

features are relatively less significant in arid and semiarid regions than are other features of the environment.

The color, density, size, and durability of natural vegetation are closely related to the degree of aridity. Vegetation may be completely absent in regions qualifying as extremely arid and very sparse in arid regions. The density and variety increase through the semiarid and demiarid climates. However, even nearest the wet climates, a closed canopy usually does not exist and where there are trees, open stands are most common. More common are thickets of low shrubs which have thick, spined leaves and very sharp, stiff thorns. In semiarid areas, incomplete ground covers of tufted grass are common.

Cultural features of the arid regions of the earth are significantly different from those of temperate climates. A large proportion of the arid area is uninhabited. Prominent transportation routes and communication lines are almost nonexistent. The few that have been established link large areas by a relatively simple system that can be easily disrupted. Populations of arid regions are basically of two types: mobile and sedentary. The mobile tribes migrate in constant search of pasture lands for their limited herds. Some major cities have grown in arid regions, usually at the fringes and on seacoasts or on navigable rivers. Semiarid regions are considerably more habitable than arid regions. Particularly outside of the Tropics, they may be quite comfortable places to live and can support extensive agriculture and industrial developments.

2-6 THE ARCTIC ENVIRONMENT

The arctic climate corresponds to the extreme cold and cold climatic categories defined in AR 70-38 (Ref. 1). For purposes of this discussion, only those regions of the earth that are in the Northern Hemisphere and that exhibit the arctic climate are discussed. This eliminates the Antarctic and the extreme southern tip of South America, both of which are largely uninhabited and at

TABLE 2-8.
ARCTIC TEMPERATURE EXTREMES (Ref. 8)

Conditions	Temperatures
Low temperature, driving snow, icedust	Arctic, exposed: Extreme -70°C (-94°F) Common -40°C (-40°F) Subarctic: Common -25°C (-13°F)

present of little military importance. The temperature extremes of the Arctic are given in Table 2-8.

While the Arctic is defined geographically as that region within the Arctic Circle, this is not synonymous with the arctic climate. As may be seen on the maps of Figs. 2-29 and 2-30, regions that exhibit temperatures below −25°F for 1 percent or more of the time in the month of December extend well below the Arctic Circle, which is at latitude 66 deg 32 min N. Arctic climate thus encompasses most of Alaska, northern and central Canada, most of Greenland, and a large part of the central and northern Asian landmass. However, this is not the only definition of arctic climate that is employed, and a larger or smaller region may be defined for particular purposes. In addition, it is found that arctic climates will penetrate farther to the south on a seasonal basis.

The principal characteristics of the climate of the Arctic are (Ref. 15):

(1) The radiational regime results in a net heat loss caused by low sun angles and long periods of continuous daylight or continuous darkness. Fig. 2-31 shows the alternation of daylight and darkness for three arctic locations.

(2) Surface weather systems are associated with a large scale, cold cored, circumpolar, cyclonic vortex that, because of its position north of the main tracks of the prevailing westerlies, has a generally sluggish circulation.

(3) A snow-ice cover is perennial over much of the Arctic and almost total in winter (see Fig. 2-32). The effect of this surface cover is to reflect most (up to 80 percent) of the incoming solar radiation and to maintain low surface temperatures. The presence of a snow-ice cover also greatly affects the airmasses crossing the arctic basin. Cyclones depend on temperature contrast; therefore, as a rule their frequency and intensity are greatest at contacts between the snow-ice surface and open water, and least over continuous snow-ice surfaces. Precipitation and fog usually are associated with open water leads in the ice pack or along the coast. Clouds in the Arctic are generally thin and the relatively cold conditions produce no clouds of great vertical development. Precipitation is low in absolute amounts but occurs frequently.

(4) The strong radiational cooling associated with the arctic winter results in temperature inversions with depths of 1 to 2 km.

Arctic surface weather is affected greatly by the static-stability of the lower atmosphere and has two marked seasons, winter and summer. In winter, when stability is

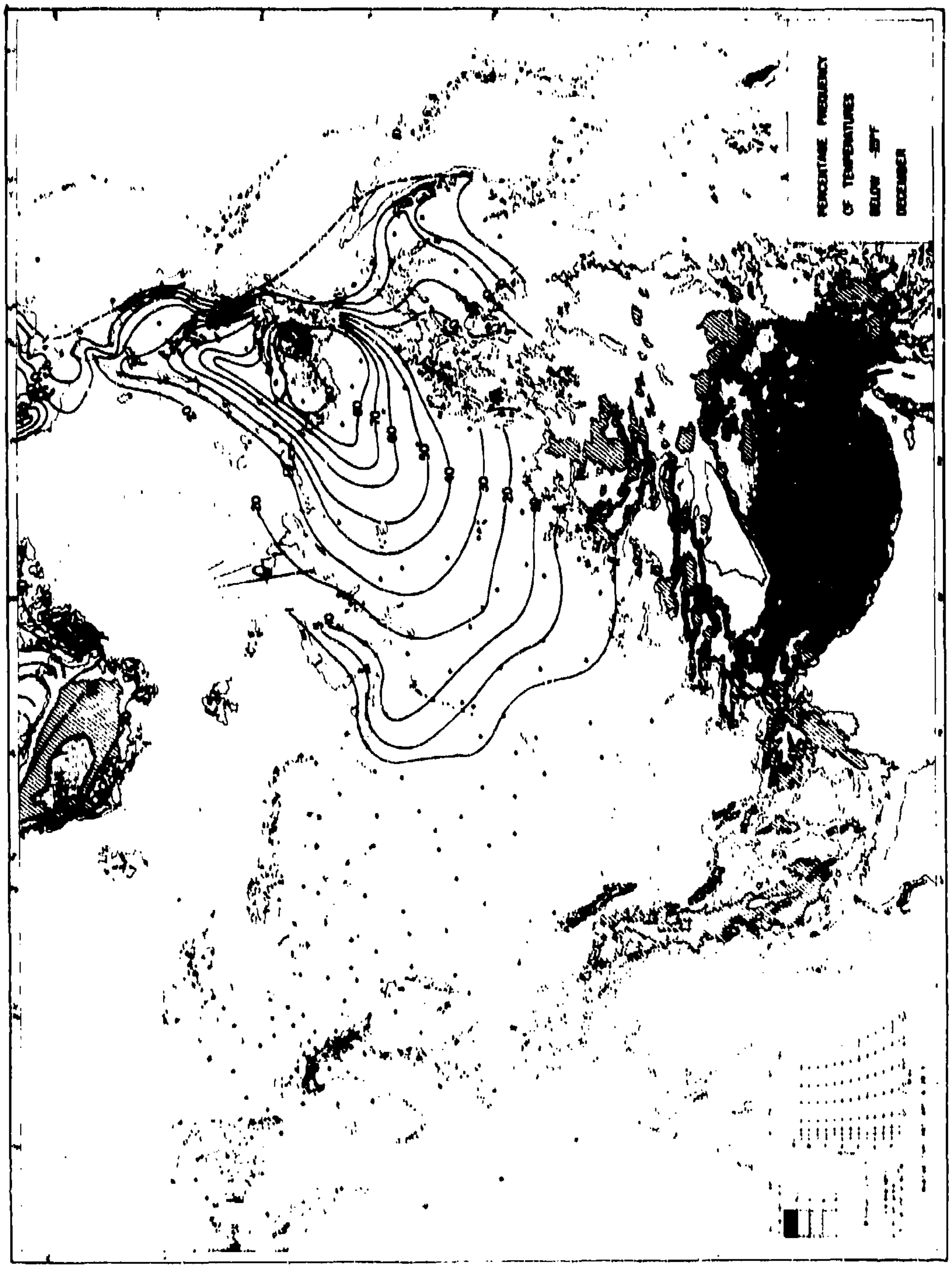


Figure 2-29. Percentage Frequency of Temperatures Below −25°F, December, Eurasia (Ref. 16)

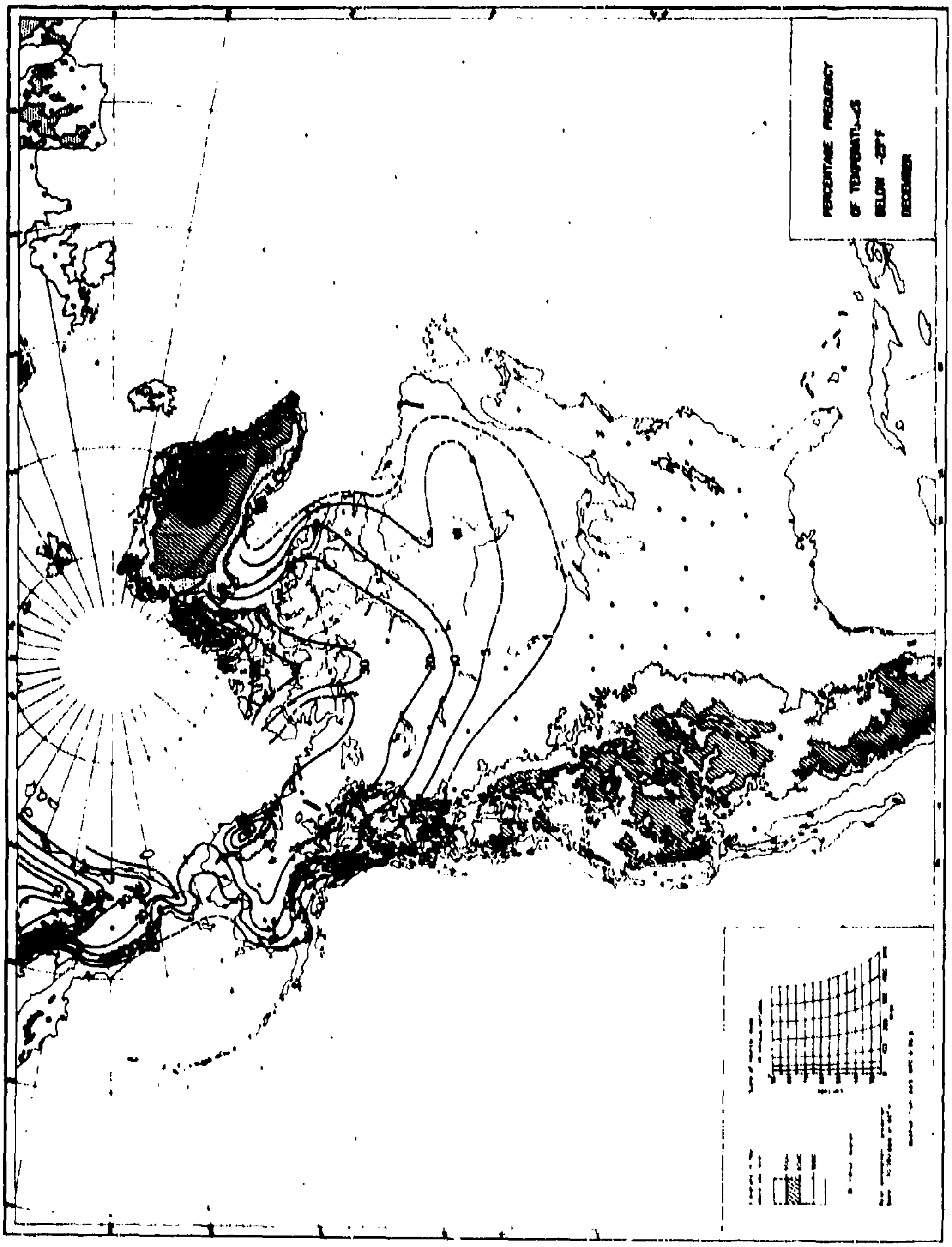


Figure 2-30. Percentage Frequency of Temperatures Below −25°F, December, North America (Ref. 17)

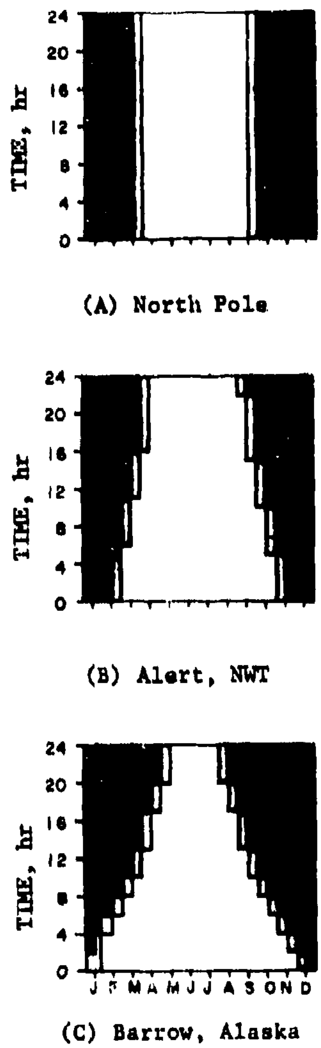


Figure 2-31. Duration of Daylight, Twilight, and Darkness in the Arctic (Ref. 11)

greatest, atmospheric conditions are generally calm and clear. Very low surface temperatures are maintained. Visibility is normally good, although cultural activity (men and materiel) or small open water leads in the sea ice may give rise to fogs. Occasional cyclonic disturbances cause warming, high winds, precipitation, and blowing snow. After the passage of these disturbances, the temperature inversion is reestablished quickly.

In summer, the increase in the areas of open water and bare land weakens surface inversions, and, consequently, the passage of airmasses becomes more effective in influencing surface conditions. The peripheral areas of the arctic basin commonly are subjected to considerable cloudiness and fog during summer. The strong thermal contrast formed at coastlines produces vigorous frontal activity, which accounts for most of the precipitation.

In the paragraph that follows, specific climatic factors are discussed in more detail.

2-6.1 ARCTIC CLIMATIC FACTORS

The climatic factors involved in the arctic climate include extremely low temperatures, blowing snow and snow cover, long periods of darkness during the winter months, long hours of daylight and the dust of summer, and the mud and morass of the arctic muskeg. The effects of these factors are accentuated by the large distances and relative isolation of the region. In the paragraphs that follow, only a brief introduction is given to each of these climatic factors in order to portray the arctic climate. Complete information is to be found in Parts Two and Three of the Environmental Series of Engineering Design Handbooks, in particular in Chaps. 3 and 8 of Part Two, which deal with temperature and solid precipitation, respectively.

2-6.1.1 Temperature

The arctic climate is characterized by persistently low surface temperatures. In Alaska, temperatures of −61.1°C (−78°F) have been reported; at Ft. Yukon, at Alert in Canada, −40°F temperatures have persisted up to 6 days; in Greenland, a −70°C (−94°F) temperature has been reported at Northice; and in Siberia, temperatures lower than −90°F have been reported at several loca-

(A) (B)

Figure 2-32. Two Views of a Rectangular Hummock Field Observed at the Arctic Circle in the Chukchi Sea North of the Bering Strait (The ridges in the field reached heights of up to 7 m) (Ref. 15) tions. Nearly 100 weather stations near the Arctic Circle in Siberia record minimum temperatures of −76°F or lower each year. In contrast, the long periods of summer sunshine result in temperatures frequently exceeding 70°F in the summer months throughout the regions of arctic climate.

2-6.1.2 Atmospheric Moisture and Precipitation

Because of the cold atmospheric temperatures, the water vapor content of arctic air is small, even less than that of hot desert air. At the same time the relative humidity is high--approaching saturation--and reductions in temperature can readily result in the deposition of water from the air in various forms. However, total amounts of precipitation in the Arctic are low. The mean annual precipitation at Barrow in Alaska is 4.11 in., of which just slightly more than one-half occurs as snow. Maximum precipitation occurs during the warmer months, and it is not at all unusual for a single storm to represent a very high proportion of the annual precipitation.

The frequency of precipitation, despite low absolute amounts, is high. Low intensity falls of snow and ice crystals occur frequently and, during the summer, long periods of drizzle are not at all uncommon. The rates of precipitation are low; the maximum accumulation at Pt. Barrow, Alaska, is equivalent to 1.5 in. of water.

2-6.1.3 Wind

Despite the popular notion that the Arctic is raked continually by strong winds, mean windspeeds are low. The few higher winds that do occur are associated with storm passages. For most of the arctic region, the largest frequency class of windspeed is 4-12 mph, accounting for 50 to 60 percent of all occurrences. Gust windspeeds in excess of 100 mph are estimated to have return periods in excess of 30 yr in most of the arctic region.

2-6.1.4 Visibility

Poor visibility is a common operating condition in the Arctic. In the summer, fog is the dominant cause of reduced visibility and in the winter, ice fog and blowing snow prevail. In both cases, the thickness of the obscuring layer may exceed 100 ft.

2-6.1.5 Terrain

The Arctic is characterized by a diversity of terrain, including mountains, foothills, and plains. The northern slope of Alaska contains all three of these physiographic features and serves as an excellent example of arctic terrain.

Much of the Arctic is in a continuous permafrost zone and contains perennially frozen ground to depths in excess of 1,000 ft. In the far northern extremes, the only places where permafrost may be absent are beneath major rivers and under lakes deeper than 6 ft. The thickness of the seasonally frozen surface zone depends primarily upon soil texture and is generally less than 2 ft. In addition to the long, snowy winter and the snow-free summer, it is sometimes useful to recognize the season of ice breakup as illustrated in Fig. 2-33. During this period, terrain is considerably different from that in either of the two seasons the surface strength of this snow cover is lost and runoff begins; the ground becomes saturated with water; all depressions are ponded; and the river ice gradually breaks up and is swept downstream.

In the snow covered winter period, which varies in duration among the various regions of the Arctic, the terrain has its lowest relief since the drifting snow cover tends to subdue many of the more prominent features. The snow cover has a windswept uninterrupted appearance and consists of a hard sastruga-sculptured, windpacked layer, usually overlying a coarse low density layer. Fig. 2-34(A) and (B) show typical snow-covered rubble ice fields over water as may be found on rivers and ocean surfaces.

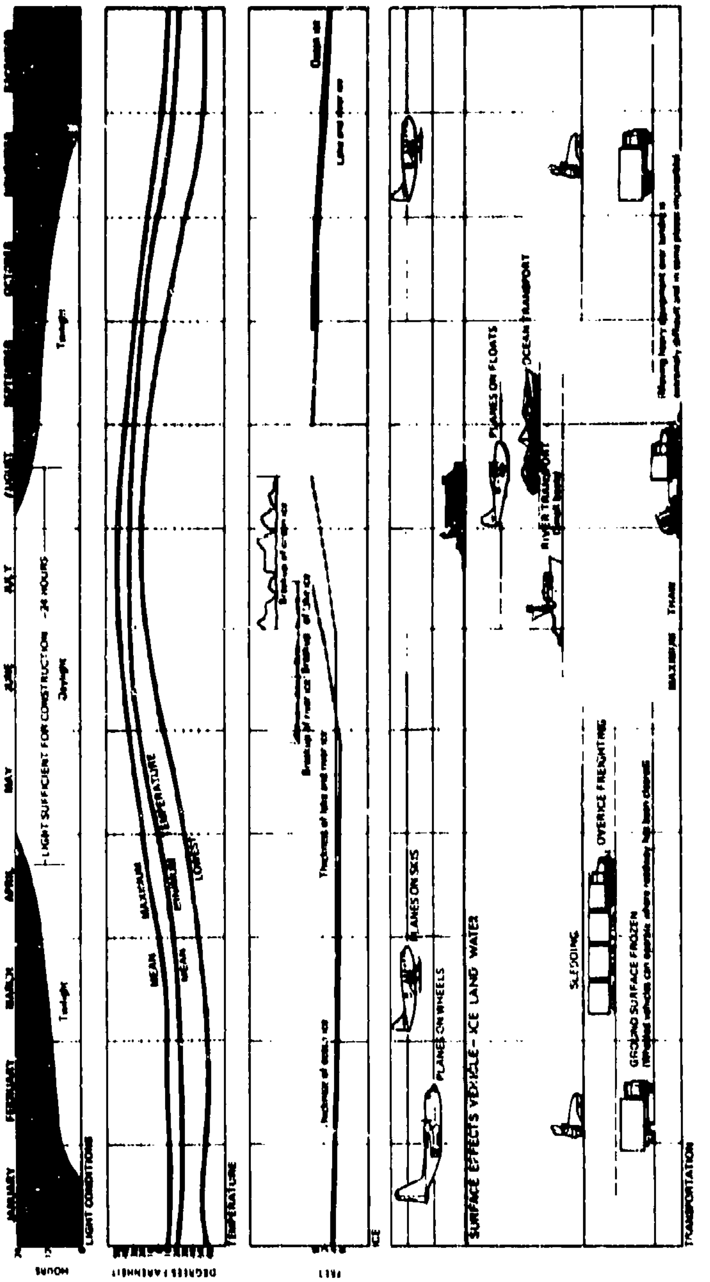
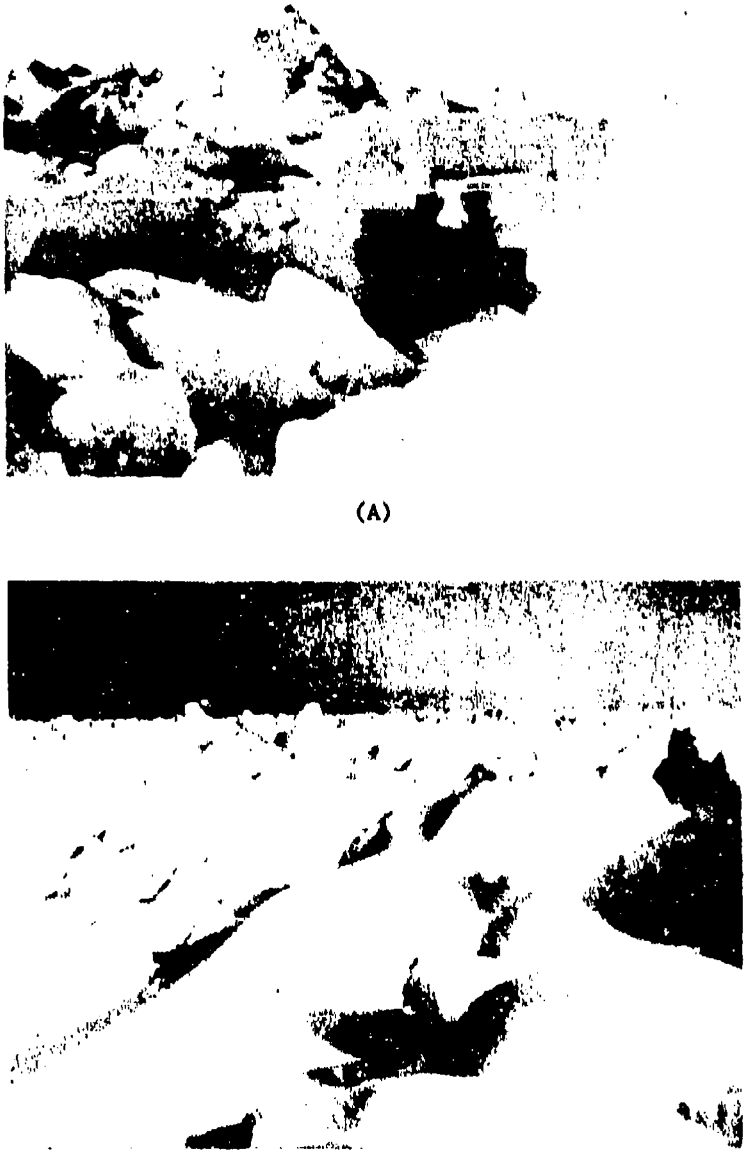


Figure 2-33. Seasonal Variations and Operations in the Arctic. (Ref. 15)



(A)

(B)

Figure 2-34. Two Views of Snow-covered Ice-rubble Fields (Ref. 15)

Ground strength is naturally extremely variable and is controlled by variations in snow properties as well as by the properties of the underlying soil.

A striking feature of many regions of the Arctic, typified by the coastal plains in Northern Alaska, are the many bodies of water which have a pronounced orientation of their long axes. These ponds and lakes range in length from a few feet to several miles and are as much as 20 ft deep.

2-6.2 REPRESENTATIVE ARCTIC CLIMATE*

The US Army Arctic Test Center is located at Ft. Greely, Alaska, about 50 mi south of Fairbanks near Big Delta. The climate at this location is in the cold category defined by AR 70-38 in that the temperature never reaches the -70°F required for the extreme cold category but does reach a minimum of -25°F for greater than 1 percent of the days in the coldest months. This type of climate sometimes is referred to as subarctic rather than arctic and is common in much of the higher latitude zones of North America and northern Eurasia. Because Ft. Greely is the site of the Arctic Test Center, much environmental data have been obtained at this site. Terrain features of sufficient variety exist so that it generally is representative of a large region of arctic climates.

2-6.2.1 Terrain

The terrain at Ft. Greely includes highland (elevation of 2,500 ft or higher), lowland and flat surfaces (elevations less than 1,500 ft), and low hills and lakes at intermediate elevations. These terrain features are a result of glacier action which deposited coarse sandy soils with high permeability and good bearing strength. In lower, poorly drained depressions, the fine-grained organic and mineral soils comprising muskeg are found. Hundreds of small lakes and swampy stream beds are scattered throughout large sections, and sandbars and other alluvial materials are found on the flood plains (see Fig. 2-35). Large areas of broken rock fragments cover the steepest slopes and summits, and the streams generally have gentle gradients and flow in tree-lined narrow channels. Stream flow results primarily from snow and ice runoff in the spring and summer. A summary of these terrain features is given in Table 2-9.

At Ft. Greely, the lakes freeze over in early November and ice reaches a thickness of between 30 and 38 in. by the time of the spring breakup. Snowfall affects the nature of the ice. With little snowfall the ice is black in color and has good transparency but, when the snow is thick, the ice is thin and becomes inhomogeneous. Ice formed under snow is weak and hazardous.

The Ft. Greely area lies in a discontinuous permafrost zone. A permanently frozen layer of soil is found beneath most of the glacial deposits where the top of the permafrost may be 25 ft below the surface. In areas where soil is more than 3 ft thick, however, the permafrost may be as close as 2 to 4 ft from the surface. In the winter, of course, the soil is frozen from the surface to depths of 3 to 10 ft except where sometimes protected by heavy snow cover.

The vegetation characteristics of the Ft Greely area are summarized in Table 2-10. Little or no vegetation is found in areas where permafrost occurs near the surface but spruce forests cover large parts of the area. Vegetation is influenced very much by forest fires; the spruce is replaced by birch-aspen forests after a fire. In low areas, alder, birch, aspen, and willow form heavy clumps of vegetation (see Fig. 2-36). Grasses cover much of the lowlands of the area including the old lake areas that have been filled with peat (see Fig. 2-36(B) and (C)). In such areas, mosquitoes and black flies are a prevalent problem in the summer. The tundra areas are covered with mosses and lichens as well as scattered sedges, heath

*A general reference for this paragraph is Ref. 9.

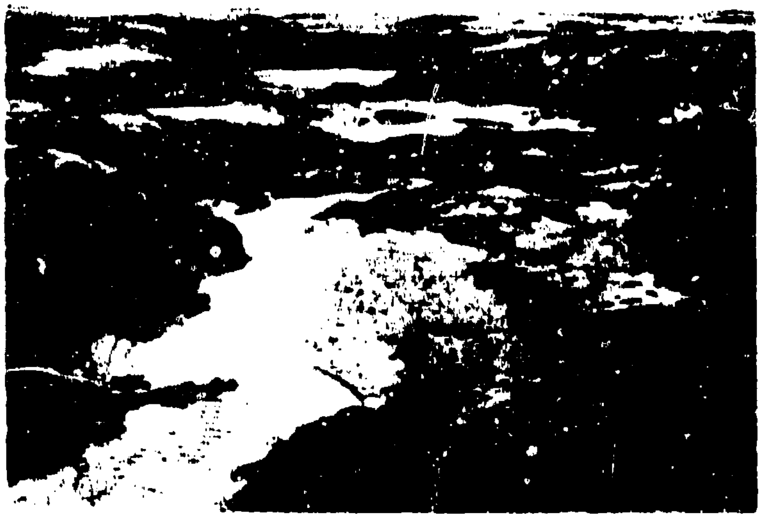


Figure 2-35. A Typical Small Stream on the Arctic Coastal Plain (Ref. 15)

plants, and occasional small trees. This type of vegetation generally is found below the 2,000-ft elevation.

2-6.2.2 Temperature

Weather records show that −25°F temperatures are recorded from November to late in March. In a given winter, the number of days with −25°F temperatures or less range from 13 to 44.

2-6.2.3 Solar Radiation

Fig. 2-37 shows the annual cycle of daily solar illumination. In winter when the sun is low on the southern horizon, the glare from snow-covered surfaces restricts visibility, particularly when haze or ice fog are present. The twilights are long and provide useful illumination well past sunset.

2-6.2.4 Snow

Wind action on the light snow at Ft. Greely results in many open areas being nearly clear of snow throughout the winter. In forested areas, however, snow forms a lasting cover that undergoes little loss from either wind or evaporation. Because the snow is generally light and fine, the water equivalent of 20 in. of snow is about 1 in. of water. Snowfall usually occurs in the early morning hours, and very rarely is any form of liquid precipitation found in the winter months. Snow falls on an average of 8.1 days in January which is the snowiest month with a total accumulation amounting to about 7 in. The snowfall is about one-half this amount in November, December, and February.

2-6.2.5 Visibility Restrictions

Visibility at Ft. Greely is commonly reduced by ice fog and blowing snow. In January, 2.5 percent of all hours experience ice fog but blowing snow is less common. When the blowing snow does occur, it is usually within 2 m of the ground and occurs even in the presence of light winds.

Whiteout occurs during the most severe instances of fog and blowing snow. In these situations, visual references are obscured by the uniform light reflectance from the sky and ground with a loss of orientation and depth perception.

TABLE 2-9.
SURFACE AND TERRAIN FEATURES IN THE FT. GREELY, ALASKA, TEST AREA (Ref. 19)

Terrain type	Elevation & average slopes	Surface material	Drainage	Vegetation	Remarks
Highlands	2,500 ft and above- 20% to 40%	Granite and schist bedrock outcrops at higher elevations. Slopes covered with rock fragments.	Good all year	Tundra mosses and lichens, blueberry cranberry, crowberry, mossberry, labrador tea, small sedges, willow and scattered birch. Spruce, usually black, and aspen on slopes and hilltops.	The only highland section within the Test Area is Donnelly Dome and the surrounding area. Rising to such slight elevation, the section affords little opportunity for mountain testing; mountain areas may be found in the Alaskan Range 40 to 50 mi south.
Flat surfaces	Below 1,500 ft 2% to 8%	Flood plains have layers of silt and gravels. Layers of peat have formed over the glacier gravels of this section.	Flood plains are flat and often flooded in the spring. Gravel plains are better drained.	Willow, alder, birch aspen, and scattered spruce with thick undergrowth of sedge and heath. Also areas of swamp with sedges. Thick young stands of forest dominate burned areas.	Flood plains within the test area are wide, flat, and braided. Spring and early summer flooding occurs along the valleys. Level plains away from rivers are better drained and have been burned over.
Kame-kettle (knobs and lakes)	1,500 to 2,500 ft 20% to 25%	Coarse glacial-deposited gravels covered by layers of peat. Old lake bottoms filled with thick layers of peat. Hilltops have gravel material at surface.	Poor in lowland areas; good at all seasons on steep slopes and hilltops.	Lowlands covered with swamp grasses and sedges in both tussock and meadow formations. On better drained slopes dwarf willow, alder, and heath show up. Hilltops often bare except for mosses and lichens.	Consists of moraine materials deposited by glacier. In the older deposit the sharp features have been eroded and lakes have been filled until they are meadow-like swamp areas. In more recent deposits lakes and steeper hills are present. Summer transportation is difficult.

TABLE 2-10.
PERENNIAL VEGETATION IN THE FT. GREELY, ALASKA, TEST AREA (Ref. 18)

General type	Habitat(s)	Principal species	Remarks
Tall forest	High moraine deposits	White and black spruce with scattered birch, aspen, and willow.	Occupies higher area between lakes. Density hinders transportation.
Mixed short forest	Drier, gently sloping gravel plains that have been burned over.	Aspen and birch with scattered clumps of young spruce.	Young trees replaced spruce forest after forest fires. Cover is very dense and foot travel is difficult.
Mixed scrub	Usually on low poorly drained areas but sometimes found on slopes.	Alder, birch, and spruce with heath undergrowth	Travel in winter easier than in mixed short forest
Sedge-tussock	Lowlands and bare hilltops.	Sedges on lowlands; mosses and lichens on hilltops.	One of the more accessible sections with roads and trails. Good for winter travel.
Tundra	Areas above 2,500 ft	Tundra mosses, cranberry, blueberry, mossberry, small sedges and willows, labrador tea, and scattered alder and birch.	Steeper slopes show signs of solifluction and in places bare bedrock is exposed.

Three types of fog are encountered during the cold weather season:

(1) Warm fog consisting of water droplets suspended in the atmosphere at temperatures above 32°F

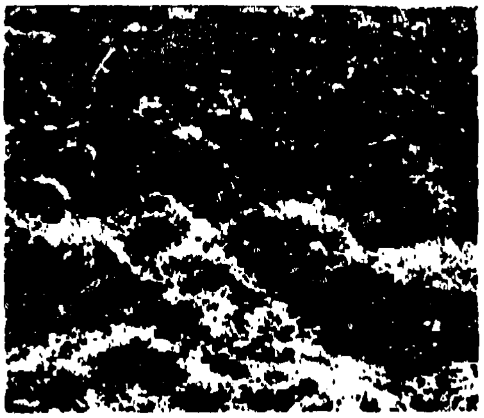
(2) Supercooled fog consisting of liquid droplets suspended in the atmosphere at temperatures below 32°F

(3) Ice fog consisting of minute airborne ice particles.

(A) Typical dense alder stands along rivers and lakes

(B) View showing common distribution and size

Figure 2-36. Vegetation Characteristics of the Ft. Greely, Alaska, Test Area (Ref. 15)



(C) Peat mound hummocks

Figure 2-36 (Continued). Vegetation Characteristics of the Ft. Greely, Alaska, Test Area (Ref. 15)

Warm fog is rare during the cold weather season but cold or supercooled fog can occur when the air temperature is between 32° and -30°F. This latter type of fog can be dissipated by heat sources. During periods of supercooled fog, frost or rime gathers on exposed surfaces and can be thick in the presence of wind.

Ice fog is a frequent occurrence in extremely cold temperatures and is correlated with human activity. Although natural sources of ice fog exist, its most prevalent source is the water vapor injected into the atmosphere from combustion sources, cooling ponds, or other activities. The firing of an artillery piece, for example, creates a small ice fog cloud which can envelope the firing position.

2-7 REGULATORY FACTOR VALUES

In the preceding paragraphs of this chapter, the various climates of the world have been considered, and extreme values for the various environmental factors involved in climate have been given. The extreme environments—desert, tropical, and arctic—are described at greater length but the greater portion of the earth remains after these severe climate regions have been excepted the so-called temperate regions. Most materiel is used in the temperate regions; thus, this climate is often the norm for materiel design.

It is necessary to examine the criteria for materiel that are established by regulations relative to the climates described. The climatic factors under which materiel is expected to operate in the various regions is outlined in AR 70-38, *Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions* (Ref. 1), and in MIL-STD-210, *Climatic Extremes for Military Equipment* (Ref. 5).

The eight climatic categories of AR 70-38 are listed in Table 2-1, and Table 2-11 gives the diurnal extremes of temperature, relative humidity, and solar radiation values for each climate and for both operational and storage-transit conditions. These factor values are those to which military materiel might be subjected. Operational conditions are stated in terms of ambient temperature and humidity measured under standard conditions of ventilation and radiation shielding in a meteorological shelter at a height of 4 to 6 ft above the ground. Temperature of materiel may vary from the ambient air temperature because of the effects of incoming and outgoing radiation and internal sources of heat as influenced by the thermal mass and heat transfer characteristics of the materiel.

Storage and transit conditions reflect the air temperature and humidity conditions to which materiel might be subjected in storage and transit: e.g., inside an unventilated field storage shelter, under tarpaulins, in tents, or in railway boxcars.

The conditions given in Table 2-11 do not represent the absolute extremes that may be encountered in the various climatic locations. AR 70-38 states that Army materiel will not be designed, developed, and tested to withstand the absolute extreme climatic conditions that occur in an area. Materiel is

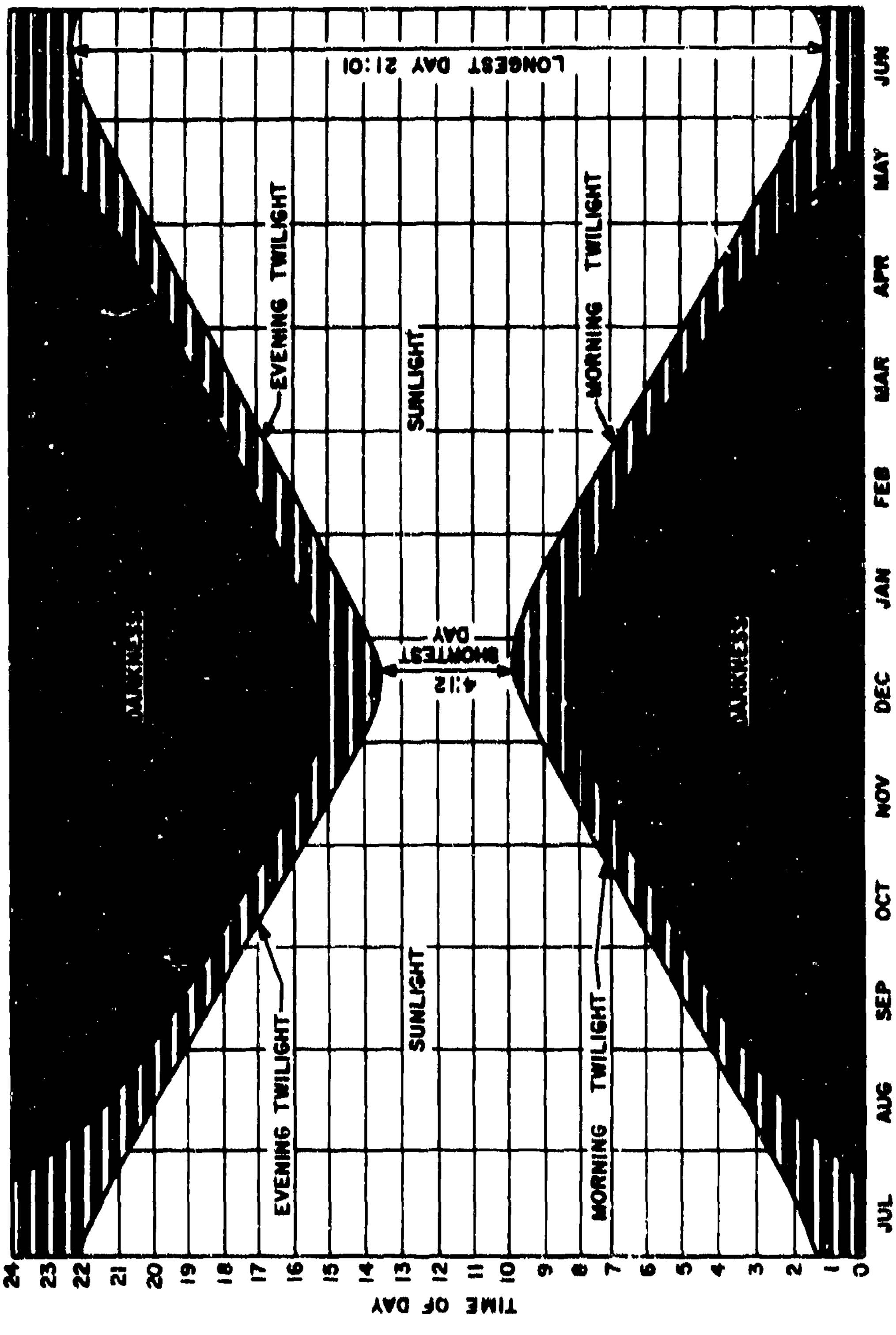


Figure 2-37. Sunlight-Darkness Durations for Ft. Greely, Alaska (Ref. 18)

TABLE 2-11.
TEMPERATURE, SOLAR RADIATION, AND RELATIVE HUMIDITY DIURNAL EXTREMES (Ref. 1)

Climatic Category	Operational conditions			Storage and transit conditions	
	Ambient air temperature, °F	Solar radiation, Btu ft^{-2} hr^{-1}	Ambient relative humidity, %	Induced air temperature, °F	Induced relative humidity, %
1 Wet-warm	Nearly constant 75	Negligible	95 to 100	Nearly constant 80	95 to 100
2 Wet-hot	78 to 95	0 to 360	74 to 100	90 to 160	10 to 85
3 Humid-hot coastal desert	85 to 100	0 to 360	63 to 90	90 to 160	10 to 85
4 Hot-dry	90 to 125	0 to 360	5 to 20	90 to 160	2 to 50
5 Intermediate hot-dry	70 to 110	0 to 360	20 to 85	70 to 145	5 to 50
6 Intermediate hot-cold cold	-5 to -25	Negligible	Tending toward saturation	-10 to -30	Tending toward saturation
7 Cold	-35 to -50	Negligible	Tending toward saturation	-35 to -50	Tending toward saturation
8 Extreme cold	-60 to -70	Negligible	Tending toward saturation	-60 to -70	Tending toward saturation

TABLE 2-12
CLIMATIC EXTREMES FOR MILITARY EQUIPMENT (Ref. 5)

Extreme stress conditions		Environmental factors	Operation: Ground, exposed: Worldwide				Arctic winter	Moist tropics				Hot desert	Shipboard (worldwide)				Short-term storage and transit, land-sea-air (worldwide)			
Thermal	Hot	Duration, hr Air temperature, °F Radiation, W ft^{-2} UV < 4000 Å, % IR > 7000 Å, % Windspeed, mph	10 90 0 0 0 7	5 ↗ ↗ 6 50 7	4 125 105 6 50 7	5 ↘ ↘ 6 50 7		10 75 0 0 0 4	5 ↗ ↗ 4.5 51 4	4 95 90 4.5 51 4	5 ↘ ↘ 4.5 51 4	W	10 90 0 0 0 6	5 ↗ ↗ 4.5 81 6	4 100 90 4.5 51 6	5 ↘ ↘ 4.5 51 6	10 90 0 0 0 0	5 ↗ 0 0 0 0	4 160 0 0 0 0	5 ↘ 0 0 0 0
Thermal	Cold	Duration, hr Air temperature, °F Sky temperature, °F Windspeed	Equilibrium -40		72 -65 -80 5 mph		W					W	24 -20 -45 40 kt				Equilibrium -40 0		24 -80 0	
Humidity	High	ABS Humid, gr ft^{-3}	13				2.1	W				W	W				W			
Humidity	High	Duration, hr Relative humidity, % Air temperature, °F	20 93 to 97 80 to 85		4 100 w/cond 75 to 80		98 to 100 before freezing	W					W				P			
Humidity	Low	ABS Humid, gr ft^{-3}	0.01				W					0.5	0.17				P			
Humidity	Low	Duration, hr Relative humidity, % Air temperature, °F	10 15 90	5 ↘ ↗	4 5 125	5 ↗ ↘						W					10 15 90	5 ↘ ↗	4 2 160	5 ↗ ↘
Precipitation	Rain	Duration, hr: min Amount, in. Drop diam. {Mean, mm; Std. Dev., mm} Air and water temp., °F Wind, mph	11:55 12 2.25 0.77 70	00:05 2 4.00 1.08 70	11:00 11 2.25 0.77 70 40	01:00 7 3.20 1.10 70		W					W				P			
Precipitation	Snow	Expectancy, days Snow load, lb ft^{-2}	1 10	3 20	150 40		W													
Wind	10 ft above surface	Expectancy, yr Ordinary {Steady, mph; Gusts, mph} Exceptional {Steady, mph; Gusts, mph}	2 40 60 60 90	5 50 75 70 105	25 65 100 80 120		W	W				W	85 (75 kt) 115 (100 kt)				P			
Penetration and abrasion	Blowing snow	Flake diameter, mm Wind, mph Air temperature, °F	1 to 3 40 0				W						W				P			
Penetration and abrasion	Blowing sand	Grain diameter, mm Wind at 5 ft, mph Air temperature, °F	0.18 to 0.30 40 100									W	W				P			
Penetration and abrasion	Blowing dust	Grain diameter, mm Density, gr cm^{-3} Wind at 5 ft, mph Air temperature, °F	0.0001 to 0.01 6 × 10[illegible] 40 70									W	W				P			
Pressure	Maximum		1,060 mb = 31.30 in. Hg 15.40 lb in.$^{-2}$				W	W				W	W				P			
Pressure	Minimum		505 mb = 14.94 in. Hg 7.35 lb in.$^{-2}$				W	844 mb=24.85 in. Hg=12.20 lb in.$^{-2}$				844 mb	887 mb = 26.18 in. = 12.90 lb in.$^{-2}$				375 mb = 11.1 in. Hg 5.45 lb in.$^{-2}$			

W = same as ground, worldwide
P = same as ground, worldwide, for packaging only
↘ = decrease at uniform rate
↗ = increase at uniform rate

expected to withstand climatic conditions that are exceeded only one percent of the time (hours) in the most extreme month in the most extreme parts of the appropriate climatic areas. This 1-percent risk policy is accepted in view of the cost and complexity of designing for the absolute extreme conditions that might occur in any given area.

Different climatic extremes for military equipment are given in MIL-STD-210 as in Table 2-12. Climatic extremes are differentiated by the categories worldwide, arctic winter, moist tropics, and hot desert; and the marine environment has been indicated by the title "shipboard worldwide". Values also are given for short-term storage and transport by worldwide land, sea, and air transport. These factor values are determined by scientific judgment and are not expected to be exceeded on more than 10 percent of the most extreme month and are thus called probable extremes.

REFERENCES

1. AR 70-38, *Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions.*
2. AMCP 706-121, Engineering Design Handbook, *Packaging and Pack Engineering.*
3. *Climates of the World*, Environmental Data Service, U S Department of Commerce, January 1969.
4. H. L. Crutcher and O. M. Davis, *Marine Climatic Atlas of the World*, Vol. VIII, *The World*, NAVAIR 50-IC-54, National Weather Records Center, Asheville, N.C., March 1969.
5. MIL-STD-210, *Climatic Extremes for Military Equipment.*
6. P. Riordan, *Weather Extremes Around the World*, ETL-TR-74-5 U S Army Engineer Topographic Laboratories, Ft. Belvoir, VA 1974.
7. G. D. Atkinson, *Forecasters' Guide to Tropical Meteorology*, TR 240, Air Weather Service, U S Air Force, Scott Air Force Base, Ill., 1 April 1971.
8. AMCP 706-134, Engineering Design Handbook, *Maintainability Guide for Design.*
9. D. Ashbel, *New World Maps of Global Solar Radiation During I.G.Y.*, The Hebrew University, Jerusalem, Israel, 1961
10. J. V. Chambers, *Representative Tropical Days*, Special Report S-5, U S Army Natick Laboratories, Natick, Mass., November 1964.
11. G. H. Howe et al., *Classification of World Desert Areas*, TR 69-38-ES, U S Army Natick Laboratories, Natick, Mass., December 1968.
12. R. E. Huschke, Ed., *Glossary of Meteorology*, American Meteorological Society, Boston, 1959.
13. J. A. Millet and H. F. Barnett, *Surface Materials and Terrain Features of Yuma Proving Ground*, TR 71-56-ES, U S Army Natick Laboratories Natick, Mass., June 1971.
14. E. Kuletz and H. C. Schafer, *Survey and Study on Sand and Dirt*, NWC TP 5170, Naval Weapons Center, China Lake, Calif., August 1971.
15. *SEV Arctic Environment Data Package*, U S Army Cold Regions Research and Engineering Laboratory, Hanover, N.H., November 1970.

16. J. N. Rayner, *Atlas of Surface Temperature Frequencies for Eurasia*, Publication in Meteorology No. 39, Arctic Meteorology Research Group, McGill University, Montreal, Quebec, 1961.

17. J. N. Rayner, *Atlas of Surface Temperature Frequencies for North America and Greenland*, Publication in Meteorology No. 33, Arctic Meteorology Research Group, McGill University, Montreal, Quebec, (U S Army Contract No. DA-19-129-QM-1447), January 1961.

18. R. D. Sands et al., *Environmental Guide for Arctic Testing Activities at Fort Greely, Alaska*, TR 70-54-ES, U S Army Natick Laboratories, Natick, Mass., May 1971.

CHAPTER 3

EFFECTS OF ENVIRONMENT

3-1 INTRODUCTION

This chapter provides information on the combined effects of environment on materiel. Whereas in Parts Two and Three of the Environmental Series of Engineering Design Handbooks the effects of single factors are discussed, the organization of this chapter is directed toward the identification of important classes of effects—interference, mobility degradation, material degradation, and the combinations of environmental factors producing these effects. For comparison, an example of single-factor analysis is given in par. 3-6 and two-factor combinations are discussed in par. 3-7.

This chapter provides additional supporting information preparatory to the discussion of the life-cycle environments in Chaps. 4 and 5. Just as Chap. 2 described the important types of climates encountered in the life cycle of materiel, this chapter describes the important classes of effects.

It is important to note the emphasis on material degradation in this chapter. Material degradation is characteristically slow acting, causing materiel impairment over time periods of days, months, or years. These degradative effects are of most importance in the logistic portion of the life cycle, rather than in the operational portion. The effects of environment in the operational environment are more immediate, consisting of functional interference with materiel performance.

Every environmental factor is, at some time and place, part of the life-cycle environment of military materiel. A discussion of all possible combinations of environment would be too cumbersome to include in this handbook. The combinations of environmental factors that occur naturally, plus the concurrence of certain induced factors, are discussed as they seem appropriate to the three extreme climatic environments—desert, tropical, and arctic. The fact that a number of environmental factors are not discussed specifically should not be interpreted to mean that these factors can be ignored or that they are unimportant. This reflects the fact that multifactor analysis of the environment at the present state of the art has been concerned primarily with climatic factors. Although all environmental factors, induced or natural, have been discussed separately, many of the synergisms that occur have not been investigated. At the same time, since some of the factors are basically independent of other factors, they can more easily be considered separately. For all these reasons, the basic approach of this volume has been to explore the multifactor environment, which can be characterized by the extreme climatic types.

Ideally, military materiel should function when and where it is needed regardless of environment. Environment, however, can and does interfere with the functioning of men and materiel in several ways. First, the environment can inhibit availability of the materiel at the time when it is needed. If materiel cannot be delivered to the user when it is needed, then its intended function goes undone as surely as if the materiel had been destroyed. It overshadows performance and reliability considerations and frequently is a devastating fact of the military environment.

Second, materiel can be delivered to operational personnel and still not be able to perform its function although the equipment itself is functional. For example, the environment can deny visibility to the operators of equipment so that it cannot be employed effectively. Reduction of visibility also affects mobility and can result in damage to materiel if movement is attempted when visibility is inadequate. It also affects the use of materiel if it is necessary for operating personnel to see in order to use the materiel. For example, a rifle or other weapon is of little value if the enemy or target cannot be located or identified because of fog or rain, or a perfectly functional tank is of little value if the operators are unable to maneuver it or to direct the firing of its weapons as a result of visibility impairment.

Third, materiel can deteriorate or be damaged to the extent that it cannot function properly as a result of environmental factors. Basically, only two general types of damage can occur to materiel: (1) damage by physical processes, and (2) damage by chemical processes. These processes are not exclusive since mechanical damage is frequently necessary to permit the exposure to environmental factors that cause chemical damage. In addition, the processes of chemical reaction produce physical damage in many cases. Rust, rot, mold, electrical short circuits, and prematurely wornout truck tires are examples.

A special case occurs when an item of materiel is rendered inoperable by the environment although no permanent damage may occur to the materiel. For example, sometimes an environmental extreme may modify operation of the item of materiel so that *continued* use would so shorten the materiel lifetime that operation is not practicable under the extreme condition; e.g., overheating of vehicles in extremely hot climates, and overheating of brakes because of steep terrain.

In Table 3-1 the general effects of environment on materiel are tabulated. Typical environmental factors involved are listed and, in some cases, the sources of these factors are identified.

3-2 INTERFERENCE

3-2.1 OPTICAL

Optical, electromagnetic, and acoustic radiation constitute important sources of interference with the proper operation of materiel and performance of personnel.

Optical interference affects visibility as well as the instruments that rely upon optical radiation for their operation. Such equipments include lasers, optical ranging devices, optical rangefinders, solar cells, optical navigation equipment, and tracking devices such as theodolites, survey instruments, and fire direction equipment.

The most common forms of optical interference result from the suspension of particles in the atmosphere. These include moisture as in clouds, fog, and salt fog; ice and snow particles in ice fog and snow storms; dust in dust storms; atmospheric pollutants; and rain. Also, optical interference effects are produced as a result of differing indexes of refraction of layers of the atmosphere, as in mirages. Very bright reflections can also interfere with visual performance.

In some cases, water is a form of optical interference, particularly when terrain is covered by water to the extent that it is not possible to determine the shape of the terrain underneath the water. This is particularly important in fording operations or in operations in flooded areas. Vegetation restricts visibility to varying degrees, depending upon the nature and quantity of the vegetation present. In many areas, irregular terrain with high relief features is the major limitation on visibility. Finally, it should be noted that darkness is a factor that, although not necessarily considered a form of optical interference, is extremely effective in reducing performance, particularly the

TABLE 3-1.
EFFECT OF ENVIRONMENTAL FACTORS

Major effect	Causes
Interference	
Optical (reduction of visibility, loss of communications)	Fog, ice fog, salt fog, whiteout, rain, snow, mirages, darkness, terrain, clouds, duststorms, vegetation, water (covering terrain), countermeasures
Electromagnetic (nonoptical)	Lightning, terrain, auroral phenomena, rotating machinery, electromagnetic pulses from nuclear weapons, electrostatic discharge, communication (radio and television) sources, microwave sources, transmission lines, industrial equipment
Audio	Gunfire, explosions, rotating machinery, vibration of materiel, impact or shock of materiel, thunder, wave impact, animal noise, traffic, construction, exhaust noise from engines
Mobility reduction (embedment, trapping, loss of traction)	Ice, snow, mud, wet salt flats, swamp, sand, relief (due to shape of terrain), rocks and boulders, vegetation, grade, water, step function interfaces in the terrain
Mechanical damage (deformation, fracture, fatigue, loss of strength, change of state, change of viscosity for liquids)	Temperature, humidity, fog, water, rain, water pressure, wind loading and air pressure, ice and snow loads, blowing sand and dust, terrain (shock, vibration, impact), macrobiological organisms, shock, vibration, acceleration, solar radiation
Chemical damage (deterioration, corrosion, spoilage)	Temperature, humidity, fog, salt fog, salt water and spray, rain, ozone, air pollutants, microbiological organisms

visual performance of human beings. Whether or not a visibility factor is considered an aid or an interference depends on whether the objective is concealment or observation.

3-2.2 ELECTROMAGNETIC

Electromagnetic interference at nonoptical wavelengths is present in a wide variety of phenomena. Electromagnetic interference produces signals that interfere with communication equipment, radar equipment, and other types of electronic equipment that depend for their operation upon the reception of electromagnetic signals. In addition, the presence of strong electromagnetic interference can induce damaging voltages in electronic and control equipment such as computers that do not depend on the propagation of electromagnetic energy in free space.

Natural sources of electromagnetic interference include lightning, ionospheric disturbances, and auroral phenomena. In addition, for those high frequency devices that depend upon line-of-sight for their function, terrain features interposed between two communication sites or between radar set and target can degrade or prevent operation. Vegetation interposed between a transmitter and receiver or between receiver and target can absorb or scatter electromagnetic energy to such an extent that operation becomes marginal. Even flying birds and insect clouds have on occasion appeared as false targets in high frequency radar systems.

The sources of manmade electromagnetic interference are numerous. They include industrial equipment, microwave ovens and other microwave sources, communications (both radio and television sources), transmission lines, rotating machinery, and electrostatic discharges of various types.

3-2.3 ACOUSTIC

Audio or acoustic interference can produce several effects. First, audio interference can interfere with critical communications between individuals Audio interference also distracts and irritates personnel, often reducing performance when the noise level reaches a certain point, particularly when the task to be performed involves mental processes. Further, a common experience has been for the presence of even small noises to become a source of severe irritation, which is reflected in performance degradation or loss of sleep. A classic example is the loss of sleep caused by a single mosquito buzzing in a room. The severity of the irritation produced under these circumstances varies with individuals, but it can be severe. Noise can also be a negative factor when concealment is desired. Finally, loud noises and blast effects are known to produce both temporary and permanent hearing damage in man.

Natural sources of acoustic energy include thunder, wind noise in vegetation, and wave impact. Manmade sources of audio interference are extremely varied; e.g., explosions and gunfire, jet engine and other engine exhaust noises, traffic, construction, rotating machinery, plus vibration, impact, and shock of materiel.

3-3 MOBILITY DEGRADATION

Mobility, both vehicular and personnel, can be affected by a variety of mechanisms. Vehicles can become embedded in soft snow, mud, or sand to such an extent that the power transmission system of the vehicle is no longer effective in producing the traction sufficient to move the vehicle forward. This usually occurs when the amount of material that must be pushed aside in front of the vehicle become sufficient to prevent its forward motion with the traction provided by the contact of the wheels with the terrain. Loss of traction can occur without embedment as a result of the slipperiness of ice, wet salt flats, wet and oil-coated pavements, packed snow, and thin layers of mud over dry or otherwise more tractive material. Mobility also can be lost by trapping, as occurs when fixed parts of the vehicle come in contact with the ground, thus preventing motion of the vehicle. This particular mode of immobility occurs as a result of attempted traverse of ditches and hillocks or humps.

Other natural obstacles, such as rocks and boulder fields, also prevent vehicle motion by trapping. Mature forests prevent passage of vehicles; many waterways, because of depth and currents, are often impassible; and step function interfaces in the terrain such as cliffs, steep stream beds, and ditches prevent vehicle movements. Finally, a vehicle can traverse a maximum slope (which differs for various vehicles according to their weight, power, and configuration), beyond which traction is insufficient to produce forward progress. In other cases, the limiting parameters are not traction and power but rather the stability of the vehicle. This is particularly applicable in lateral movement along steep slopes because for most vehicles the wheelbase is longer than the track width.

3-4 MECHANICAL AND CHEMICAL DAMAGE TO MATERIALS

The deterioration of materials as a result of exposure to various environmental factors is discussed in this paragraph. First, particular types of materials are discussed with respect to those environmental factors most likely to result in deterioration. Thus, if one is working with or considering a particular material, the primary environmental pitfalls can be identified easily. Second, a number of environmental factors are presented along with their principal effects and the typical kinds of failures that the environmental factor produces. This may be useful when it is desired to evaluate the importance of a particular environmental factor.

Emphasis is placed on the effects of environmental factors on materials. Discussion of multifactor, environmentally induced problems encountered by operational materiel (which in reality are assemblages of items constructed of various materials) will be deferred to Chap. 4. The paragraphs that follow delineate the basic types of material, identify the agents of deterioration, and enumerate the effects of deterioration for each material type.

In considering the deterioration of any item, the target materials may be divided into two broad headings—inorganic and organic. The fundamental material types and the primary deteriorative agents or effects for each material type are listed in Table 3-2.

Table 3-3 lists the commonly occurring environmental factors that are most significant from the standpoint of deterioration. With each are listed the principal effects caused and some typical failure modes induced by the factor.

To provide some insight into the kinds of deterioration that can occur, deterioration of various classes of material is discussed in the paragraphs that follow (Ref. 3).

3-4.1 METALS

Except for physical changes brought about by low temperatures, the primary deterioration of metals is in the form of corrosion. Corrosion of metals is related closely to the environment. Basically, moisture, chemical action, electrochemical action, and temperature are the elements that contribute to the deterioration of metal. Moisture in the form of water or water vapor is essential, with the rate of corrosion being influenced by the manner in which the moisture is applied. Alternate wetting and drying, as by a spray, causes rapid corrosion; whereas wetting, as by condensation, with a thin water layer is even more destructive. A high relative humidity results in an 80-percent increase in the corrosion rate of steel and a significant increase in the corrosion rate of zinc over that in dry air.

Corrosion of metals by reaction with trace chemicals in the environment occurs under a variety of circumstances, each generally requiring moisture. Atmospheric pollutants

TABLE 3-2.
MATERIAL DETERIORATION AGENTS (Ref. 1)

Material	Agent
Inorganic	
Metals	Chemically induced corrosion Electrolytic processes Age hardening Stress deterioration
Glasses	Actinic processes Physical and chemical weathering Microbiological attack
Organic	
Rubber	Oxidation (ozone) Loss of plasticizer High temperature (continued vulcanization) Microbiological attack Stress deterioration
Plastics	Chemical attack (solvent vapors) Actinic processes Microbiological attack Mechanical stresses
Oils and greases	Oxidation Chemical dissociation Microbiological attack Evaporation
Wood (cellulose)	Biological attack Imbalance of moisture
Fabric	Biological attack Actinic processes Thermal deterioration

are an important source of trace chemicals and, in some areas subject to fog, produce much metallic corrosion. The salts in soils and water are the most widely distributed and troublesome of corrosive chemical agents. Natural salts causing the greatest damage are the chlorides—particularly sodium chloride because it is most frequently encountered—but the nitrates, sulfates, phosphates, and, occasionally, carbonates are also active agents. Salts in solution or in a moist environment hydrolize, causing corrosion of metals either by direct chemical action or by electrochemical action.

TABLE 3-3.
SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Ref. 2)

Environmental factor	Principal effects	Typical failures induced
High temperature	Thermal aging:	Insulation failure
	Oxidation	Alteration of electrical properties
	Structural change	
	Chemical reaction	
	Softening, melting, and sublimation	Structural failure
	Viscosity reduction and evaporation	Loss of lubrication properties
	Physical expansion	Structural failure
		Increased mechanical stress
		Increased wear on moving parts
Low temperature	Increased viscosity and solidification	Loss of lubrication properties
	Ice formation	Alteration of electrical properties
	Embrittlement	Loss of mechanical strength
		Cracking, fracture
	Physical contraction	Structural failure
		Increased wear on moving parts
High relative humidity	Moisture absorption	Swelling, rupture of container
		Physical breakdown
		Loss of electrical strength
	Chemical reaction:	Loss of mechanical strength
	Corrosion	Interference with function
	Electrolysis	Loss of electrical properties
		Increased conductivity of insulators
Low relative humidity	Desiccation:	Loss of mechanical strength
	Embrittlement	Structural collapse
	Granulation	Alteration of electrical properties
		"Dusting"
High pressure	Compression	Structural collapse
		Seal penetration
		Interference with function

TABLE 3-3 (Continued).
SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Ref. 2)

Environmental factors	Principal effects	Typical failures induced
Low pressure	Expansion	Fracture of container
		Explosive expansion
	Outgassing	Alteration of electrical properties
		Loss of mechanical strength
	Reduced dielectric strength of air	Insulation breakdown and arc-over
		Corona and ozone formation
Solar radiation	Actinic and physicochemical reactions:	Surface deterioration
	Embrittlement	Alteration of electrical properties
		Discoloration of materials
		Ozone formation
Sand and dust	Abrasion	Increased wear
	Clogging	Interference with function
		Alteration of electrical properties
Salt spray	Chemical reactions:	Increased wear
	Corrosion	Loss of mechanical strength
		Alteration of electrical properties
		Interference with function
	Electrolysis	Surface deterioration
		Structural weakening
		Increased conductivity
Wind	Force application	Structural collapse
		Interference with function
		Loss of mechanical strength
	Deposition of materials	Mechanical interference and clogging
		Abrasion accelerated
	Heat loss (low velocity)	Accelerated low-temperature effects
	Heat gain (high velocity)	Accelerated high-temperature effects
Rain	Physical stress	Structural collapse
	Water absorption and immersion	Increase in weight
		Structural weakening
		Accelerates cooling
		Electrical failure

TABLE 3-3 (Continued).
SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Ref. 2)

Environmental factors	Principal effects	Typical failures induced
Rain (cont)	Erosion	Removes protective coatings Structural weakening Surface deterioration
	Corrosion	Enhances chemical reactions
Water immersion	Corrosion of metals	Structural weakness, seizure of parts, contamination of products
	Chemical deterioration	Dissolving out and changing of materials
	High pressures (13 lb at 30-ft depth)	Mechanical damage
Insects and bacteria	Penetration into equipment	Blockage of small parts, meters, etc.
	Nibbling by termites	Damage to plastic cables or other organic insulating materials, causing shorts
Fungi	Growth of molds, hyphae	Damage to optical equipment; leakage paths in high impedance circuits; blockage of small parts, meters, etc.; breakdown of mechanical strength of all organic materials
Temperature shock	Mechanical stress	Structural collapse or weakening Seal damage
High speed particles (nuclear irradiation)	Heating	Thermal aging Oxidation
	Transmutation and ionization	Alteration of chemical, physical, and electrical properties Production of gases and secondary particles
Ozone	Chemical reactions:	Rapid oxidation
	Crazing, cracking	Alteration of chemical, physical, and electrical properties
	Embrittlement	Loss of mechanical strength
	Granulation	Interference with function
	Reduced dielectric strength of air	Insulation breakdown and arc-over
Explosive decompression	Severe mechanical stress	Rupture and cracking Structural collapse

TABLE 3-3 (Continued).
SUMMARY OF ENVIRONMENTAL EFFECTS (Ref. 2)

Environmental factors	Principal effects	Typical failures induced
Dissociated gases	Chemical reactions;	Alteration of physical and electrical properties
	Contamination	
	Reduced dielectric strength	Insulation breakdown and arcover
Acceleration	Mechanical stress	Structural collapse
Vibration	Mechanical stress	Loss of mechanical strength
		Interference with function
		Increased wear
		Structural collapse
Magnetic fields	Induced magnetization	Interference with function
		Alteration of electrical properties
		Induced heating

Because of their high activity, free acids and bases are rarely encountered in the natural environment. An important exception, however, is the high acid concentration in some atmospheric pollutants found in industrial emissions. Sulfur dioxide and carbon dioxide in the air form sulfurous acid and carbonic acid in the presence of water vapor.

Electrochemical (or galvanic) processes account for more destruction of metals than any of the other forms of corrosion. The deterioration process operates in the following manner. When two dissimilar metals are in contact and exposed to an electrolyte, a galvanic cell is formed and current flows. The rate of current flow depends on the potential difference, which in turn depends on the electrochemical dissimilarity of the metals. Table 3-4 gives the relative electromotive potential of various metals.

Galvanic action causes the progressive corrosion of the more positive of the two metals forming the cell, with the action continuing as long as an electrolyte is present. Sufficient differences usually exist between adjacent crystals of a metal for this action to take place, even on an apparently homogeneous metal, but, when different metals such as aluminum and steel are coupled, the potential difference is greater and the corrosion is accelerated.

At low temperatures most metals undergo transient changes in properties that make them susceptible to failure in areas of high stress concentration. At low temperatures, metals become stronger and stiffer but also more brittle and subject to fracture as a result of suddenly applied loads. This low-temperature, brittle-fracture phenomenon can occur in some metals at temperatures as high as 32°F.

TABLE 3-4.
ELECTROCHEMICAL SERIES (Ref. 3)

Anodic (Positive) End	
Lithium	
Rubidium	
Potassium	
Calcium	
Sodium	
Strontium	
Barium	
Magnesium	
Beryllium	
Aluminum	
Manganese	
Zinc	
Chromium	
Gadolinium	
Iron (Fe^{++})	
Cadmium	
Indium	
Tellurium	
Cobalt	
Nickel	
Tin	
Lead	
Iron (Fe^{+++})	
Hydrogen	(neutral)
Antimony	
Bismuth	
Arsenic	
Copper	
Iodine	
Silver	
Palladium	
Mercury	
Platinum	
Gold	
Cathodic (Negative) End	

3-4.2 WOOD AND CELLULOSIC PRODUCTS

Wood and cellulosic products are subject to deterioration by the factors of climate, physical forces, chemical agents, and biological agents. The latter, microbes and insects, are without doubt the prime cause of failure in wood and wood products. Wood in contact with the ground is susceptible to fungi and molds, particularly in a moist and warm environment. Most such organisms cause decay and drastically reduce the structural strength of wood, whereas others do not damage the wood but quickly deteriorate certain plywood glues. Under humid conditions fungi and molds can stain wood in a few days, even if the wood is supported off the ground, and can eventually cause decay.

Wood in contact with the ground is also subject to attack by many insects, in particular termites and powder post beetles. Wood supported above the ground and kept dry is subject to attack by these insects to a much lesser degree. In the case of wood supported above ground, the subterranean termites have to build tubes up from the ground to reach the wood. Insect damage to crates supported above the ground is due primarily to powder post beetles and drywood termites.

Abrasion, weathering, and high temperatures also cause deterioration of wood products. Abrasion occurs during shipment and handling. Long exposure to high temperatures causes gradual loss of strength, the rate of loss increasing with temperature. Similar results occur when unfinished wood is exposed to the weather for any extended period of time. Alternate periods of rainfall and hot, dry weather produce cracks, splits, and general erosion of wood, eventually resulting in loss of structural properties. In extreme conditions where long life must be assured, wood products should be protected from the elements.

Wood products are readily destroyed by chemical concentrations and industrial waste.

For a discussion of the various effects of different types of chemicals on some common woods, the reader is referred to Ref. 4.

Cellulosic paper products are subject to the same deteriorating agents that affect wood. When ordinary paper becomes wet, it loses its structural strength because the moisture dissolves and softens the gelatinous binder that holds the fibers together. Wet strength papers are available where this is a problem.

Under proper conditions of moisture and warmth, microbiological attack of paper, paperboard, and fiberboard can be severe. Mildew, bacteria, and fungi are the chief offenders. Some microbes merely deface or stain paper, but serious damage occurs when the cellulose content of paper is consumed.

Insects damage paper because they use it as a food. Termites consume paper for its prime structural component, cellulose. Silverfish, on the other hand, destroy paper by eating the starchy materials, such as glue and sizing. Cockroaches feed on many materials, eating both bindings and paper. The cellulose-eating insects (termites and cockroaches) will attack sheetboard, pasteboard, composition board, fiberboard, labels, paper boxes, insulating paper, and tar paper.

Rodents damage paper products while gnawing in their search for food. Since the paper particles are not swallowed, toxic agents on the paper are useless. The most effective preventive has been setting out a poison bait. Table 3-5 describes the range and habits of several common small rodents.

Continued exposure to sunlight causes deterioration of cellulose; rate and severity are dependent upon the kind of cellulose used in the paper and the impurities present therein. Basically, however, sunlight is a minor problem.

Heat alone can weaken paper by altering its chemical structure, but the main role of heat under normal circumstances is that of a catalyst in decay caused by microbes and moisture.

Most chemical deterioration of paper is due to the sulfur dioxide gas present in industrial atmospheres. Acids formed from sulfur dioxide attack the gel-like portion of the fibers but have a minor effect on the cellulose content. Deterioration varies according to the type of paper.

3-4.3 PLASTICS

In general, most plastics have good resistance to corrosion and chemical action. Chemical deterioration of plastics can result in loss of strength, erosion, warpage, cracking, and loss of transparency. Most of these physical changes are caused by loss of plasticizer. The acrylic plastics have relatively high resistance to various chemical solutions. Most plastics are not susceptible to microbiological attack. Generally, because of the wide variety of plastics, a plastic that will resist deteriorative processes can be chosen for a particular application. For example, a number of plastics, e.g., polyethylene and Teflon, remain flexible and retain their strength at low temperatures (−30° to −50°F).

3-4.4 RUBBER

Rubber is subject to deterioration by chemical, biological, and physical agents often working in concert. The most serious cause of deterioration in rubber is the ozone present in the atmosphere. Ozone causes rubber to become brittle and may produce fissures over its surface. The severity of attack varies greatly according to the type of rubber. Oxygen has a similar but much slower effect. Natural rubbers swell when in contact with liquid hydrocarbons such as oil, gasoline, and benzene. Disintegration or aging occurs from prolonged contact.

Rubbers, particularly carbon-based rubbers, lose their flexibility and become brittle at low temperatures. Failure by shattering as

TABLE 3-5.
COMMON TYPES OF SMALL RODENTS (Ref. 3)

Type	Range	Habits
Norway rat	Universal distribution throughout the world	Burrowing rodent; lives close to man; omnivorous
Roof rat	Warm climates, particularly along sea-coasts and rivers throughout the world	Adept climber, lives in trees and upper portions of buildings; prefers fruits and vegetables
House mouse	Universal distribution throughout the world	Capable of adaptation to wide variety of conditions; lives close to man; almost omnivorous
Wood rat	Mountainous regions of eastern and western North America and Gulf States	Frequents cabins and camps; prefers green vegetation; seldom destructive
Field mouse	Universal throughout grassland areas of the world	Inhabits meadows and semiswampy grassy areas; constructs distinct trails; feeds on green vegetation and tree roots
Woodland mouse	Practically all North America; similar forms in other countries	Lives in semiwooded areas; primarily a seed eater
Ground squirrel	Present in semiopen areas of western North America and other countries	Burrowing rodent; food includes grains, green vegetation, and insects

TABLE 3-6.
DEGRADATION OF RUBBER BY HIGH TEMPERATURES (Ref. 3)

Type of rubber	Highest usable temperature	
	°C	°F
Silicone	260	500
Polyacrylic	177	350
Buna-N	171	340
Neoprene	157	315
Butyl	149	300
Buna-S	138	280
Natural	127	260
Thiokol	121	250

a result of suddenly applied loads thus becomes more probable at low temperatures. Changes are reversible, however, and the material, if not mechanically damaged, recovers its original properties as temperatures return to normal. At high temperatures both natural and synthetic rubbers become gummy, take on a permanent set, and decrease in tensile strength. Table 3-6 shows the temperatures above which various types of rubber become unusable.

Certain rubber compounds are susceptible to microbiological deterioration. The reaction is rather slow and requires an environment containing moisture and warmth. Decomposition of rubber by sunlight is due mainly to the blue and ultraviolet wavelengths. These rays cause the rubber to liberate gases as the rubber decomposes. The surface of rubber undergoing actinic deterioration exhibits resinification of the surface and an irregular pattern of very fine cracks.

3-4.5 TEXTILES

Textiles are subject to deterioration principally by weather and biological agents. They are particularly susceptible to destruction by microbes since some of the material, being of vegetable or animal origin, serves as food. Warmth and wetness facilitate the development of a flourishing and diversified collection of bacteria, fungi, and molds that destroy materials of vegetable or animal origin. Fabrics of cotton, linen, and some rayons are attacked vigorously. Microbiological deterioration causes odors, spotting, loss of water repellency, loss of strength, and a decrease in flexibility. The growth of microbes on textiles invariably is preceded by contact with soil or other moist substances that harbor them.

Moisture generally is considered an agent of deterioration. Ordinarily, the more moisture available, the more rapid the degradation. However, an unusual feature worth noting in the deterioration of textiles, is that moisture contributes to the breakdown of some textiles (they become very brittle) by its absence. An optimum moisture content is required for the maintenance of useful properties. Textiles that have lost their properties through lack of moisture can be restored by exposure to the proper humidity.

TABLE 3-7.
RESISTANCE OF FIBERS TO OUTDOOR EXPOSURE (Ref. 3)

Fiber	Resistance to outdoor exposure
Viscose rayon	Yellows slightly
Cuprammonium rayon	Good
Acetate	Loses strength somewhat
Nylon	Excellent
Vinyon N or Dynel (Union Carbide)	Excellent
Saran (Dow) or Velon (Firestone)	Excellent
Orlon (Dow) and Chemstrand (Monsanto)	Excellent
Dacron (du Pont) or Terylene (Imperial)	Excellent
Acrilan (Monsanto)	Excellent
Glass	Excellent

Sunlight is responsible for most of the nonbiological deterioration of textiles. It changes the cellulose content of the textile fiber by photochemical processes. Certain dyes reduce the deleterious effects of sunlight. Deterioration by sunlight sometimes is accelerated by the effects of other climatic elements. Table 3-7 gives a qualitative indication of the resistance of various types of fibers to outdoor exposure.

3-4.6 RATIONS

An important supply item subject to deterioration is food. Problems with deterioration are probably more severe for food than for any other single, large-quantity military item. Food is absolutely necessary, is required in large quantities on a continuing basis, and is very difficult to protect from deterioration for any long period of time.

The most serious types of food spoilage can be classified as chemical and biological. The latter includes insect infestation, which renders food inedible from an esthetic point of view, and the growth of fungi and molds, which spoil food. Chemical deterioration includes a number of types of spoilages. Examples of chemical spoilage that occur during storage of subsistence items are (Ref. 5):

(1) *Browning reaction.* This type of spoilage results in darkening or "browning" of the product, loss of flavor decrease in certain nutrients, and undesirable changes in taste. The natural flavors disappear and off-tastes develop. In addition, undesirable

changes in texture and even the production of toxic substances may develop. Some of the commodities that undergo this type of deterioration are dried fruits and vegetables, powdered eggs and milk, fruit juice concentrates, certain beverages, jams, jellies, canned bread, certain canned vegetables, meat items, and a variety of other foods.

(2) *Fat deterioration.* Fats undergo changes resulting in the production of off-odors and tastes, loss of nutritive value, and perhaps the production of toxic substances. A few items so affected are biscuits, cookies, prepared mixes, ice cream powder, and dried whole milk.

(3) *Changes in texture.* Several types of chemical changes may take place to cause texture changes. In dried cranberries, changes in the pectin molecule may occur. In other cases, the product may toughen; e.g., dried apricots sometimes become brittle.

(4) *Color changes.* The natural colors of many food items undergo undesirable changes during storage. The reddish pigments of strawberry jam gradually disappear with storage. At the same time, browning takes place with the result that the jam becomes brown or black rather than red. Many canned items such as berries, prunes, and beets undergo color changes during adverse storage conditions.

(5) *Staling reaction.* The mechanism of this reaction is not well understood but it results in an undesirable change in the texture of items such as canned bread.

(6) *Vitamin changes.* Frequently, a gradual loss of vitamins occurs during storage. This is true in practically all foods that have been studied.

All foods, except salt and perhaps sugar, are perishable. Consequently, regardless of how fresh a food may be, it can be ruined by improper storage and handling. Large amounts of research have shown conclusively that temperature is generally the most important single factor influencing the life of food items.

3-5 EFFECTS ON PERSONNEL

In addition to affecting materiel, the environment also affects man. Although this handbook is oriented toward effects on materiel, when personnel are affected by environmental factors, the result is usually that new or modified materiel requirements are created. The design engineer must be alert and knowledgeable with respect to such requirements. In the discussion of visibility and mobility effects, it is pointed out that when man is the operator of materiel that requires use of vision for successful operation, a variety of environmental factors can hamper his operational effectiveness and in turn the operational effectiveness of the materiel operated by man; e.g., night vision equipment was developed to partially remove visibility limitations imposed by darkness.

In any discussion of man in the operational environment, it is important to make the distinction between discomfort and impairment of function. Many circumstances in the operational environment cause discomfort to man, yet in most cases he is able to remain operationally effective. Discomfort factors include temperature, both cool and hot; high and excessively low humidities; solar radiation; rain and solid precipitants; macrobiological organisms; and, particularly, the biting and stinging insects. Experience has demonstrated that, except in unusual circumstances, microbiological factors cause little problem in the operational environment. A certain percentage of personnel is on sick call, virtually independent of the circumstances. Pollutants and sand and dust in the atmosphere can cause discomfort to the individual as well as impairment of visual function.

Impairment of personnel performance can be produced by several environmental factors, including electromagnetic radiation,

TABLE 3-8.
EXPECTED SHORT-TERM EFFECTS FROM ACUTE WHOLE-BODY NUCLEAR RADIATION (Ref. 6)

Dose in rads	Probable effect
10-50	No obvious effect, except, probably, minor blood changes.
50-100	Vomiting and nausea for about 1 day in 5 to 10% of exposed personnel. Fatigue, but no serious disability. Transient reduction in lymphocytes and neutrophils.
100-200	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25 to 50% of personnel. No deaths anticipated. A reduction of approximately 50% in lymphocytes and neutrophils will occur.
200-350	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness; e.g., loss of appetite, diarrhea, minor hemorrhage. About 20% deaths within 2 to 6 wk after exposure; survivors convalescent for about 3 mo, although many have second wave of symptoms at about 3 wk. Up to 75% reduction in all circulating blood elements.
350-550	Vomiting and nausea in most personnel on first day, followed by other symptoms of radiation sickness; e.g., fever, hemorrhage, diarrhea, emaciation. About 50% deaths within 1 mo; survivors convalescent for about 6 mo.
550-750	Vomiting and nausea, or at least nausea, in all personnel within 4 hr from exposure, followed by severe symptoms of radiation sickness, as above. Up to 100% deaths; the few survivors convalesce for about 6 mo.
1,000	Vomiting and nausea in all personnel within 1 to 2 hr. All dead within days.
5,000	Incapacitation almost immediately (minutes to hours). All personnel will be fatalities within 1 wk.

terrain and precipitation, shock and vibration, and acoustic energy, plus the visibility impairment factors already discussed. Electromagnetic and nuclear radiation effects are sufficiently slow acting for nominal exposures that personnel so exposed are not impaired in operational effectiveness. The effects of long-term exposure to nominal doses have not been completely determined. Table 3-8 presents expected short-term effects from acute whole-body exposure to high-energy nuclear radiation.

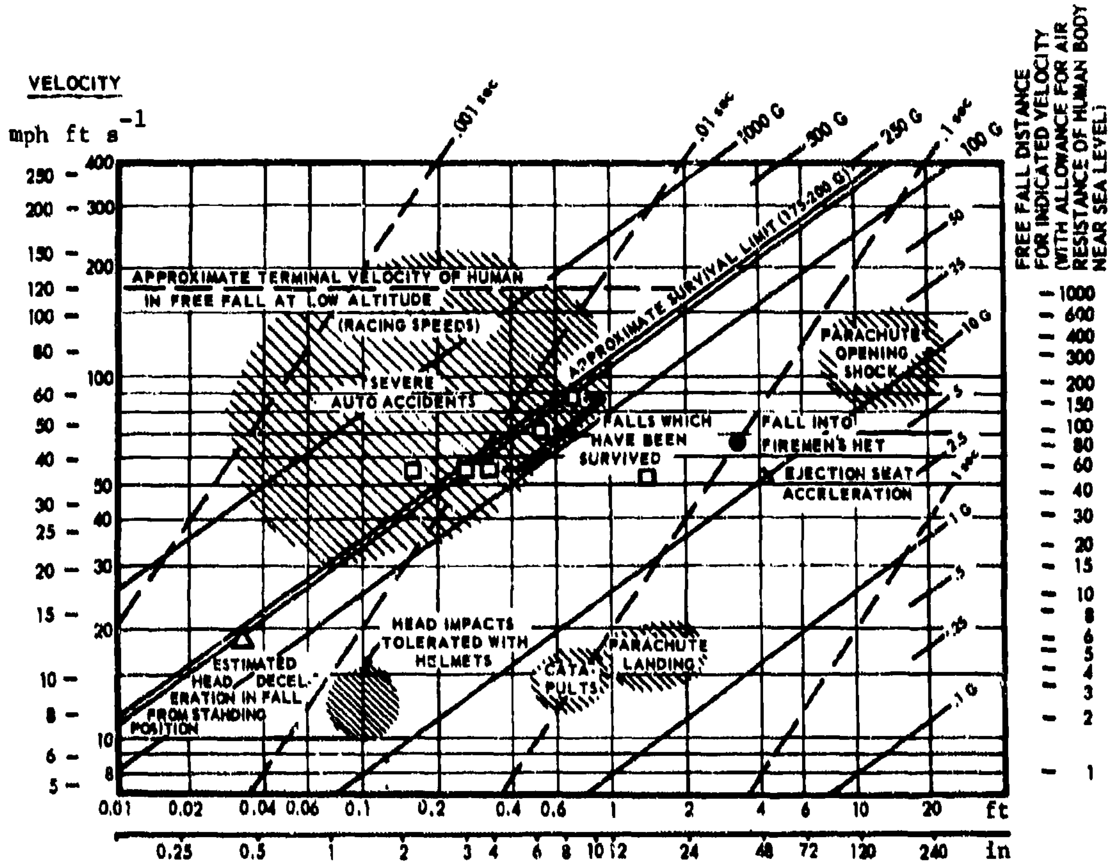


Figure 3-1. Impact Documentation (Ref. 6)

Personnel, particularly individual foot soldiers, are faced with the same mobility problems involving terrain and precipitation as already have been discussed with respect to materiel. Rugged mountainous terrain, certain terrain coverings such as ice, snow, and vegetation, and sandy or swampy areas significantly reduce the mobility of the individual soldier. Shock, vibration, and acceleration can affect the performance of personnel, particularly in those tasks that require hand-eye coordination, and can, if sufficiently severe, cause injury and death to personnel. Fig. 3-1 indicates survival limits and the ranges of selected typical events. Velocity and deceleration distance are shown on common axes, with magnitude of force and deceleration time shown on secondary scales. Hollow squares mark selected, well-documented, free-fall survivals for which impact forces have been calculated. Acoustic levels of significantly high magnitude can produce interference with mental processes so that concentration is interrupted, while, at very high levels, hearing impairment can occur. Table 3-9 presents human responses to noise exposure.

The effects of temperature on human performance are not understood completely, but it is known that temperature extremes are detrimental to work efficiency. As

TABLE 3-9.
REPRESENTATIVE SUBJECTIVE AND BEHAVIORAL RESPONSES TO NOISE EXPOSURE (Ref. 6)

Conditions of Exposure			Reported Disturbances
SPL (dB)	Spectrum	Duration	
150*	1 - 100 Hz	2 min	Reduced visual acuity; chest wall vibrations; gag sensations; respiratory rhythm changes
120	Broadband	-	Reduced ability to balance on a thin rail
110	Machinery noise	8 hr	Chronic fatigue
105	Aircraft engine noise	-	Reduced visual acuity, stereoscopic acuity, near-point accommodation
90	Broadband	Continuous	Vigilance decrement; altered thought processes; interference with mental work
85	1/3-octave at 16 kHz	Continuous	Fatigue, nausea, headache
75	Background noise in spacecraft	10-30 days	Degraded astronauts' performance
60	STOL aircraft	80 s hr^{-1}	Annoyance reactions in 50% of community residents

*In this study subjects wore protective devices to prevent hearing loss.

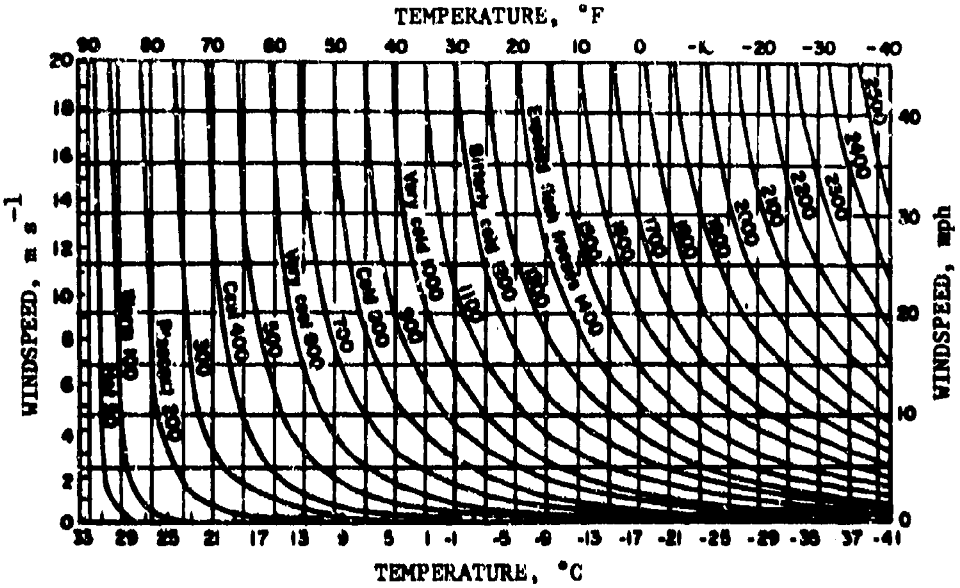
TABLE 3-10.
TOLERABLE LIMITS OF TEMPERATURE (Ref. 2)

Condition	Temperature, °F
Comfort zone, summer	56 to 75
Comfort zone, winter, light work	63 to 71
Comfort zone, winter, heavy work	55 to 60
Physiological limits, at rest, heat	156 for 30 min at 10% humidity 107 for 30 min at 90% humidity 500 for 2 min, air absolutely dry 200 for 35 min, air absolutely dry 122 for 120 min, air absolutely dry
Physiological limits, at rest, cold	38 for 5 hr at 3 mph airspeed 44 for 4 hr at 9 mph airspeed
Physical stiffness of extremities begins	50 and under
Physical fatigue begins	75 and over
Mental activities and complex performance begins to deteriorate	85 and over

temperature increases above the comfort zone, mental processes slow down, motor response is slower, and error likelihood increases. As the temperature is lowered, physical fatigue and stiffening of the extremities begin. The tolerable limits of heat and cold for normally clothed personnel are given in Table 3-10. The heat factor is probably the most important fact in reducing the operational efficiency of personnel. Between 86° and 95°F, the errors made by personnel as a result of temperature begin to increase precipitously. Errors are also a function of humidity with fewer errors occurring in dry air than in humid air. Incapacition can also occur as a result of heat. Table 3-11 classifies these incapacitating effects.

TABLE 3-11.
DEBILITATING EFFECTS OF HEAT (Ref. 6)

Disorder	Cause	Symptoms	Prevention	First aid
Heat cramps	Excessive loss of salt in sweating with inadequate replacement	Pain and muscle spasm; pupillary constriction with each spasm. Body temperature normal or below normal.	Normal diet and fluid intake	Rest, administer salt and water
Heat exhaustion	Cardiovascular inadequacy; dehydration	Giddiness, headache; fainting; rapid and weak pulse, vomiting; cold, pale, clammy skin; small rise in body temperature.	Frequent and early replacement of water, frequent pauses.	Rest in shade in recumbent position. Administer fluids.
Heat stroke	Failure of temperature regulatory center, due to excessively high body temperature.	High body temperature; irritability, prostration, delirium; hot, dry, flushed skin. Sweating diminished or absent.	Adequate pacing of activity, avoidance of severe effort by unacclimatized men in hot environment.	Alcohol spray bath or immersion in cold water. Medical emergency requiring a physician.



Numbers on curves represent windchill in
kg-cal m^{-2} hr^{-2}.

Figure 3-2. Windchill Chart (Ref. 2)

In cold regions, in spite of the best arctic clothing, it has been found that personal suffering increases rapidly as the temperature drops below −10°F. Personnel may need all of their energy to use tools of any kind in the open. Without shelter and heat, most adjustments are impossible, and with heavy gloves worn out in the open, even the simple task of removing or inserting screws becomes extremely difficult.

A properly dressed worker can perform tasks at temperatures between 32° and 0°F for 30 min without interference from the cold itself. Fig. 3-2 is a windchill chart that can be used as a guide to the severity of exposure conditions for personnel who are appropriately dressed and not wearing heated garments. For more detailed discussion of the effects of individual environmental factors on personnel, the reader is referred to the appropriate chapters of Parts Two and Three of this Environmental Series.

3-6 SINGLE-FACTOR ENVIRONMENTAL ANALYSIS

One approach to analysis of the effects of environment on materiel has been to consider the effect of individual environmental factors separately. To illustrate this single-factor analysis method and its application, an example is given in Table 3-12. In this table, effects of individual environmental factors are given. The environmental factors so tabulated are vibration, shock, temperature, humidity, and salt spray.

3-7 TWO-FACTOR ENVIRONMENTAL COMBINATIONS

Environmental factors do not occur individually in any actual environment. Inherent properties of the atmosphere, such as temperature, humidity, and pressure, are present at all times and interact with each

TABLE 3-12.
FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 2)

Component	Vibration effects	Shock effects	Temperature effects	Humidity effects	Salt spray effects
Blowers	Brinelling of bearings	-	Shorts; lubricant deterioration	Corrosion	Corrosion
Capacitors:					
Ceramic	Increased lead breakage; piezoelectric effect; body and seal breakage	Lead breakage; piezoelectric effect, body and seal breakage	Changes in dielectric constant and capacitance; lowered insulation resistance with high temperature	-	Corrosion; shorts
Electrolytic	Increased lead breakage; seal damage; current surges	Lead breakage; seal damage; current surges	Increased electrolyte leakage; shortened life; increased current leakage; large change in capacitance; increased series resistance with low temperature	Decreased insulation resistance; increased dielectric breakdown; increase in shorts	Corrosion shorts
Mica	Lead breakage	Lead breakage	Increased insulation resistance; silver ion migration; drift	Silver migration	Shorts
Paper	Increase in opens and shorts; lead breakage	Opens; increased dielectric breakdown; shorts; lead breakage	Changes in capacitance; increased oil leakage; decreased insulation resistance; increased power factor	Decreased insulation resistance; increased power factor	Shorts
Tantalum	Opens; shorts; current surges; lead breakage	Opens; lead breakage	Electrolyte leakage; change in capacitance; insulation resistance; series resistance	Decreased insulation resistance; increased dielectric breakdown; increase in shorts	Corrosion

TABLE 3-12 (Continued)
FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 2)

Component	Vibration effects	Shock effects	Temperature effects	Humidity effects	Salt spray effects
Transformers	Shorts; opens; modulation of output	Shorts; opens; modulation of output	Reduced dielectric; opens; shorts; hot spots; malformation	Corrosion; fungus; shorts; opens	Corrosion; shorts; opens
Transistors	Opens; functional disintegration	Opens; seal breakage	Increased leakage current; changes in gain; increases in opens and shorts	Increased leakage current; decreased current gain. If sealed, no effect	Increased leakage current; decreased current gain. If sealed, no effect
Tubes, electron	Opens; shorts; microphonics; loosening of elements; changes in characteristics	Opens; shorts; changes in characteristics	Shorts; temporary change in characteristics; formation of leakage paths; increased contact potential; shorting of heater life, gassiness; bulb puncture	Change in characteristics; leakage path; arcing	Shorts; corrosion; leakage path; arcing
Vibrators	Intermittent	Intermittent	Lag	Case corrosion	Case corrosion

TABLE 3-12 (Continued).
FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 2)

Component	Vibration effects	Shock effects	Temperature effects	Humidity effects	Salt spray effects
Choppers	Increase in phase angle and dwell time	Contacts open; change in phase angle and dwell time	Decrease in phase angle; variation in dwell time	-	Corrosion
Circuit breakers	Premature activation	Premature close or open	Failure to function; premature function	Corrosion	Corrosion
Clutches, magnetic	Creep	Intermittent operation	Hot spots in coil	Falloff in torque	Binding
Coils	Loss of sensitivity; detuning; breaking of parts, leads, and connectors	Lead breakage; detuning; loss of sensitivity	Warping, melting; instability; change in dielectric properties	Electrolysis; corrosion	Corrosion; electrolysis
Connectors:					
Standard	Separation of plugs and receptacles; insert cracks; opening of contacts	Opening of contacts	Flashover, dielectric damage	Shorts; fungus; corrosion of contacts; lowered insulation resistance	Corrosion
Interstage	Insert cracks; opening of contacts	Opening of contacts	Flashover, dielectric damage	Shorts; fungus; corrosion of contacts; lowered insulation resistance	Corrosion
Crystals	Opens	Opens	Drift; microphonic	Drift	-
Crystal holders	Intermittent contact	Intermittent contact	-	Change of capacity	-
Diodes	Opens	Opens	Change in voltage breakdown; increased current leakage; increase in opens and shorts	Increased current leakage	Corrosion of lead and case

TABLE 3-12 (Continued).
FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 2)

Component	Vibration effects	Shock effects	Temperature effects	Humidity effects	Salt spray effects
Gyros	Drift	Drift; leaks	Drift	-	-
Insulators	Cracking; elongation	Cracking	Epoxy cracking; ferrite separation (arcing); moisture condensation (insertion loss)	Moisture condensation (insertion loss); reduction in dielectric strength and insulation resistance	Reduction in dielectric strength and insulation resistance
Joints, solder	Cracking; opens	Cracking; opens	Loss of strength	Fungus	Corrosion
Magnetrons	Arcing; "FM"-ing	Seal breakage		Arcing	Corrosion
Motors	Brinelling of bearings; loosening of hardware	-	Shorts; opens; deterioration of lubricants	Binding of bearings; shorting of windings; corrosion	Corrosion; binding of bearings
Potentiometers	Increased noise; change in torque and linearity; wiper brush bounce; open circuit	Increased noise; change in torque, linearity, and resistance; open circuit	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance with high temperature	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance	Decreased insulation resistance; increased corrosion; binding
Relays	Contact chatter	Contact opening or closing	Open or shorts; decreased insulation resistance with high temperature	Decreased insulation resistance	Corrosion of pins

TABLE 3-12 (Continued).
FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 2)

Component	Vibration effects	Shock effects	Temperature effects	Humidity effects	Salt spray effects
Resistors	Lead breakage; cracking	Cracking; opens	Increased resistance; opens; shorts	Increased resistance; shorts; opens	Change in resistance; shorts; opens
Resolvers	Intermittent brush operation; brinelling of bearings; cracking of terminal board; loosening of hardware	Intermittent brush operation; cracking of terminal board; loosening of hardware	High breakaway voltage; shift in electrical axis; opens; shorts; deterioration of lubricants	Corrosion that causes expansion and blistering of potting compound; shorting of winding; pinion corrosion	Corrosion that causes rotor binding;
Servos	Brinelling of bearings; loosening of hardware; cracking of terminal board	Loosening of hardware; cracking of terminal board	Oil throw-out, breakdown of grease; high breakaway voltage	Corrosion that causes blistering of potting compound; shortting of winding; pinion corrosion	Corrosion that causes rotor binding; salt crystals in bearings and on motor
Switches	Contact chatter	Contact opening	Oxidation of contacts	Pitted contacts; arcing	Oxidation and corrosion; pitted contacts
Synchros	Intermittent brush operation; cracking of terminal board, brinelling of bearings; loosening of hardware	Intermittent brush operation; cracking of terminal board; brinelling of bearings; loosening of hardware	High breakaway voltage	Corrosion that causes expansion and blistering of potting compound; shorting of winding; pinion corrosion	Corrosion
Thermistors	Lead breakage; case cracking; open circuit	Lead breakage; case cracking; open circuit	Increased shorts and opens	Change in resistance	Lead corrosion; change in resistance

other as well as with other factors that may be present. As a result, when the effects of environment on materiel are to be considered, the manner in which each environmental factor alters the effects of the others must be taken into account. One of the easier ways to analyze combinations of environmental factors is to examine environmental pairs. Some combinations of natural environmental factors and the manner in which each combination may intensify, neutralize, or add nothing to the effects of the individual factors are listed as follows (Refs. 2,7):

(1) *High temperature and humidity.* High temperature tends to increase the rate of moisture penetration. The general deterioration effects of humidity are increased by high temperatures.

(2) *High temperature and low pressure.* These environmental factors produce effects that are dependent on each factor. For example, as pressure decreases, outgassing of constituents of materials increases, and, as temperature increases, the rate of outgassing increases. As a result both factors together tend to intensify the rate of outgassing.

(3) *High temperature and solar radiation.* This is a natural combination that causes increasing effects on organic materials.

(4) *High temperature and salt spray.* High temperature tends to increase the rate of corrosion caused by salt spray.

(5) *High temperature and fungi.* A temperature of 70°F is necessary for most fungi to flourish, but above 160°F they cannot develop. As a result of this temperature dependence, unless a proper range of temperature is present, fungi do not grow.

(6) *High temperature and sand and dust.* The erosion rate of windblown sand and dust may be accelerated by high temperature. However, high temperatures reduce sand and dust penetration.

(7) *High temperature and ozone.* Starting at about 300°F, ozone concentrations decrease with increasing temperatures. Above about 520°F, ozone cannot exist at pressures normally encountered. For normal climatic temperatures, reduction of ozone is thus unaffected. High temperature increases chemical reaction rates, thus increasing reaction rates of ozone up to 300°F.

(8) *Low temperature and shock and vibration.* Low temperature tends to intensify the effects of shock and vibration. However, it is a significant consideration only at very low temperatures.

(9) *Low temperature and acceleration.* This combination produces the same effect as low temperature and shock and vibration.

(10) *Low temperature and explosive atmosphere.* Temperature has very little effect on the ignition of an explosive atmosphere. It does, however, affect the air-vapor ratio, which is an important consideration.

(11) *Low temperature and humidity.* Humidity decreases with temperature, but low temperature induces moisture condensation, and, if the temperature is low enough, frost or ice occurs.

(12) *Low temperature and low pressure.* This combination can accelerate leakage through seals.

(13) *Low temperature and salt spray.* Low temperature reduces the corrosion rate of salt spray.

(14) *Low temperature and solar radiation.* Low temperature will tend to reduce the effects of solar radiation and vice versa.

(15) *Low temperature and sand and dust.* Low temperature increases dust penetration.

(16) *Low temperature and fungi.* Low temperature reduces fungous growth. At subzero temperatures, fungi will remain in suspended animation.

(17) *Low temperatures and ozone*. Ozone effects are reduced at lower temperatures, but ozone concentration increases with lower temperatures.

(18) *High humidity and low pressure*. Humidity increases the effects of low pressure, particularly in relation to electronic or electrical equipment. However, the actual effectiveness of this combination is determined largely by the temperature of the environment.

(19) *High humidity and salt spray*. High humidity may dilute the salt concentration, but it has no other bearing on the corrosive action of the salt.

(20) *High humidity and fungi*. High humidity helps the growth of fungi.

(21) *High humidity and sand and dust*. Sand and dust have a natural affinity for water, so this combination increases deterioration, but the incidence of windblown sand and dust is low at high humidity.

(22) *High humidity and solar radiation*. Humidity intensifies the deteriorating effects of solar radiation on organic materials.

(23) *High humidity and ozone*. Ozone reacts with moisture to form hydrogen peroxide, which has a greater deteriorating effect on plastics and elastomers than the additive effects of moisture and ozone alone.

(24) *High humidity and vibration*. This combination tends to increase the rate of breakdown of electrical materiel.

(25) *High humidity and shock and acceleration*. The periods of shock and acceleration are considered too short for these environments to be affected by humidity.

(26) *High humidity and explosive atmosphere*. Humidity has no effect on the ignition of an explosive atmosphere, but a high humidity will reduce the pressure of an explosion.

(27) *Low pressure and salt spray*. This combination is not expected to occur.

(28) *Low pressure and fungi*. This combination adds nothing to the overall effects.

(29) *Low pressure and sand and dust*. This combination can occur only in extreme storms, during which small dust particles are carried to high altitudes.

(30) *Low pressure and vibration*. This combination intensifies effects in all equipment categories, but mostly with electronic and electrical equipment.

(31) *Low pressure and shock or acceleration*. These combinations become important only at the extreme environmental levels, in combination with high temperature.

(32) *Low pressure and explosive atmosphere*. At low pressures, an electrical discharge is easier to develop, but the explosive atmosphere is harder to ignite.

(33) *Salt spray and fungi*. This is considered an incompatible combination.

(34) *Salt spray and sand and dust*. This will have the same combined effect as humidity and sand and dust.

(35) *Salt spray and vibration*. This will have the same combined effect as humidity and vibration.

(36) *Salt spray and shock or acceleration*. These combinations will produce no added effects.

(37) *Salt spray and explosive atmosphere*. This is considered an incompatible combination.

(38) *Salt spray and ozone*. These environments have the same combined effect as humidity and ozone.

(39) *Solar radiation and vibration*. Under vibration conditions, solar radiation deterio-

rates plastics, elastomers, oils, etc., at a higher rate.

(40) *Solar radiation and shock or acceleration.* These combinations produce no added effects.

(41) *Solar radiation and explosive atmosphere.* This combination probably produces no added effects.

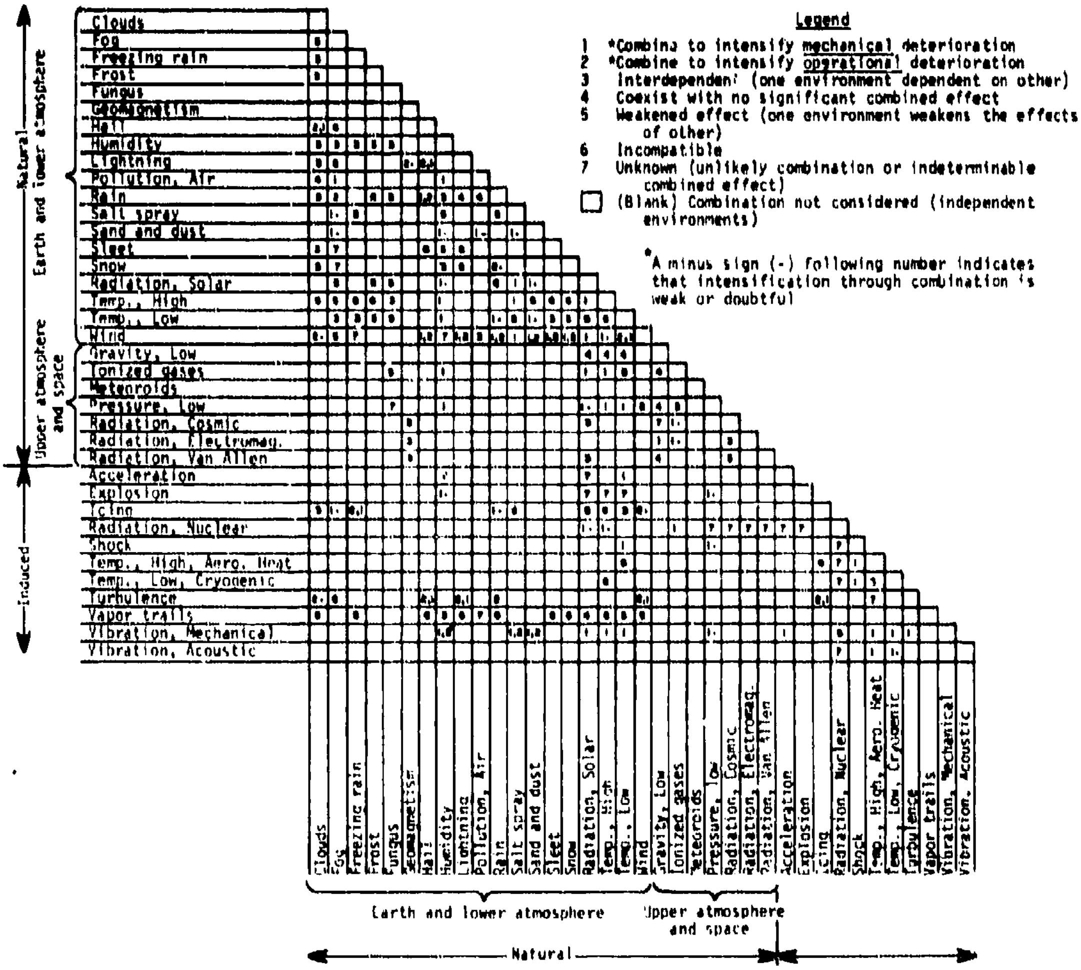
(42) *Solar radiation and low pressure.* This combination adds nothing to the overall effects.

(43) *Solar radiation and fungi.* Because of the heat from solar radiation, this combination probably produces the same combined effect as high temperature and fungi. However, the ultraviolet in unfiltered radiation is an effective fungicide.

(44) *Solar radiation and ozone.* This combination increases the rate of oxidation of materials.

(45) *Fungi and ozone.* Fungi are destroyed by ozone.

TABLE 3-13.
COMBINATIONS OF ENVIRONMENTAL FACTORS (Ref. 8)



(46) *Sand and dust and vibration.* Vibration may increase the wearing effects of sand and dust.

(47) *Shock and vibration.* This combination produces no added effects.

(48) *Vibration and acceleration.* This combination produces increased effects when accompanied by high temperatures and low pressures in the extreme environment ranges.

Terrain is a very important factor in the surface transportation of materiel since it affects mobility. Difficult terrain, when combined with certain climatic factors (such as high wind, heavy snow, ice, blowing sand and dust, rain, and/or fog), effectively can reduce mobility to zero. Thus, the interaction or combination of particular types of terrain in concert with various climatic factors can have a very significant effect on mobility.

Because of their interlocking nature, extreme values of some factors (e.g., humidity and rain; pressure gradient and wind; wind and blowing dust, sand, or snow; solar radiation and temperature) are likely to occur simultaneously (Ref. 8). Conversely, in most combinations, the extremes of one factor do not occur together with the extremes of another. Table 3-13 summarizes the qualitative relationships between pairs of environmental factors.

The illustrations given in these paragraphs are not intended to be complete in scope but are included to remind the reader of the complexity of the operational environment and to promote the use of caution in arriving at environmental decisions based on the consideration of individual environmental factors separately.

REFERENCES

1. TM 38-230, *Preservation, Packaging, and Packing of Military Supplies and Equipment*, Headquarters, Department of the Army, January 1957.
2. AMCP 706-134, Engineering Design Handbook, *Maintainability Guide for Design*.
3. AMCP 706-121, Engineering Design Handbook, *Packaging and Pack Engineering*.
4. G. A. Greathouse and C. J. Wessel, Eds., *Deterioration of Materials*, Reinhold Publishin[illegible] N.Y 1954.
5. [illegible] *...n Conditions for* [illegible] *ng of Semi-Perishable* [illegible] Office of Quartermaster General, Department of the Army, March 1955.
6. SP 3006, *Bioastronautics Data Book*, National Aeronautics and Space Administration, Washington DC, 1964 (N65-15594).
7. E. C. Theiss et al., *Handbook of Environmental Engineering*, Air Force Systems Command, U S Air Force, Wright-Patterson Air Force Base, Ohio, 1961.
8. G. F. Arthur, *An Investigation of the Concurrence of Environmental Factors*, Engineering Test Division, Wright Air Development Center (now part of Air Force Systems Command, Wright-Patterson Air Force Base, Ohio), September 1960.

Chapter 4

OPERATIONAL ENVIRONMENT

4-1 INTRODUCTION

The operational environment of the Army potentially encompasses all regions of the earth (except for Antarctica which is excluded by international treaty). To describe this environment in terms of climate or geography would not be accurate since major determinants of the environment are the unique operational and materiel requirements of a military activity. In fact, descriptions of climate and geography are available in other chapters of this handbook and in other handbooks in the Environmental Series. The operational environment is described in many documents—histories of war, Army analyses of past operations, and detailed descriptions of performance of specific materiel types. In this chapter, the approach is to describe the operational environment in terms of such experience—gained both in actual military operations and in field test exercises—wherein the complex environment is created by interactions of personnel, materiel, climate, terrain, and operations. This description is not coherent since the operational environment is always changing—personnel are better trained; each new generation of materiel is different; the location of operations changes; and operations are greatly modified. Each individual experience gained on the operational environment contributes to an improved capability in future operations, if that experience is used. This chapter, which describes the operational environment, is directed toward increased use of such experience by design engineers.

Environmental effects on materiel are extremely important in Army operations. Although insufficient data are available to quantify the importance of environmental effects in the operational environment, it is amply demonstrated by Army experience that:

(1) A large percentage of operational failures are caused by environmental effects—more than result from direct military action by an enemy; and

(2) Materiel impairment wherein capabilities are decreased in effectiveness constitutes a second large category of environmental effects—these effects are countered by increased resupply and maintenance or by accepting lower levels of capability.

The history of warfare is replete with examples of military catastrophes caused by the environment. Usually, these were a direct result of materiel and personnel not properly prepared to fight under the environmental conditions encountered. Russia's victory over the German Army in World War II is credited to the German Army's lack of mobility in the Russian winter. The same winter environment played a major role in the defeat of Napoleon on the Russian front. One example of the difficulty experienced by Germany in coping with the severe environment of the Russian winter involved their JU-87B dive bombers. In the extreme cold of the Russian winter, the engines of these bombers could not be started, causing loss of air support. The German designers provided an engine heater to solve these problems, but often the heater itself could not be started in the cold of the Russian winter (Ref. 1).

The military operations involving the United States (in Southeast Asia) have provided other examples of operational problems resulting from the environment. Some typical examples are:

(1) When modern, large electronic equipment was installed near Saigon, the weight of the equipment caused the floor of a new building housing the equipment to sink into the marshy earth (Ref. 2).

(2) In the central highlands of Vietnam, man-packed, short-range voice radios were ineffective because the dense jungle undergrowth absorbed the transmitted energy (Ref. 2).

(3) Two ammunition companies and one quartermaster field depot company were deployed in Vietnam with a large number of commercial forklifts. The terrain and climate were such that the forklifts were inoperable for approximately one-half of each year (Ref. 3).

(4) Nonperishable canned subsistence items shipped to Japan in the early stages of the Vietnam buildup were stored in the open in commercial cardboard boxes. The cartons soon disintegrated and the cans rusted, causing the food to be wasted (Ref. 3).

(5) Vehicle-mounted electronic communications equipment in Vietnam was parked at communication sites and interconnected to power and signal cables for extended periods of time. The brakes and drive trains of the vehicles frequently rusted and became frozen.

(6) During the dry season in Vietnam, sand and dust caused major problems by clogging ventilating ducts, causing wear on rotating parts, and producing erratic malfunctions of switches and relay contacts.

(7) A more unusual environmental effect occurred during the Gulf of Tonkin incident in August 1964. During this time, the long-distance, high frequency radio links between Saigon and Washington were hampered by severe sunspot activity (Ref. 2).

This list of environmental influences could be continued indefinitely, varying in significance from almost trivial effects to major losses of materiel. In spite of these countless examples, the environment affects military operations in only two basic ways.

First, the environment produces direct and immediate effects on the success of an operation or the ability of a military force to carry out an operation. Most military operations are relatively large-scale affairs involving large numbers of men and materiel. Therefore, in order to have any significant effect on an operation, the environment must simultaneously (i.e., in a relatively short span of time with respect to duration of the operation) affect a significant portion of a particular type of materiel. In addition, that materiel type must be vital to the success of the operation. This class of effects is labeled "impairment of operation execution" in this chapter.

Second, exposure to the environment over a long period of time can affect military materiel. Such effects are generally of little significance within the time scale of any given operation. They are important, however, in that they affect the operational readiness of materiel. Materiel that has severely deteriorated, either in the logistic phase or as a result of inaction or storage after having been delivered to operational units, cannot be mobilized for the execution or support of an operation. If 1 or 2 percent of the materiel of a given type fails as a result of the action of long-term (long-acting) environmental factors during a given operation, it is of little concern to the operations commander since such failures would have an inconsequential effect on the outcome of the operation. The processes of deterioration--particularly chemical processes--generally must take place over too long a time scale to be of significance within the context of a given operation. Yet, environmental factors that cause materiel deterioration are not absent in the operational environment. In fact, not only is the range of deteriorative environmental factors wider in the operational environment than in the relatively better regulated logistic environment, but the severity of the factors is also generally greater. They do not, however, assume primary importance (contribute to mission success or failure) because a given operation usually is completed before the relatively slow-acting deteriorative processes can disable the materiel. Both categories have significance in the operational environment, but, once an operation has begun, the first considerations overshadow normal deteriorative processes. The class of effects that are slow-acting and deteriorative in nature are labeled "impairment of operational readiness" in this chapter.

These two ways of viewing the operational effects of environment result in two almost distinct sets of environmental factors. From the standpoint of mission execution (after operations have begun), only two major sets of environmental factors have real significance—the terrain factors and the rapid, direct-acting (damage or inhibition produced by the factor directly and immediately, without long-term deterioration) climatic factors. From the standpoint of operational readiness, however, the environmental factors that are generally more significant are the slow-acting, long-term deteriorative chemical and physical processes.

Because of this duality in environmental effects, the important set of environmental factors depends on whether the concern is with operational readiness or with operation execution. This dichotomy is illustrated interestingly in the literature by the relative emphasis on one or the other of these considerations in discussion of extreme climatic environments. An extremely large body of literature concerns the environmental effects of the arctic and subarctic environments. By any means of comparison, the great majority of this literature emphasizes the importance of the rapid, direct-acting factors that produce failure and impairment of materiel. Inability of men and materiel to function normally without special preparation is characteristic of the arctic regions.

Deterioration of materiel in the arctic environment is less of a problem. The low temperatures retard spoilage and other forms of deterioration and inhibit the growth of micro-organisms (microbes), and very little free moisture is available to foster deteriorative processes. The literature reflects this relatively minor impact of the long-term deteriorative processes on materiel in the arctic environment.

On the other hand, the exact opposite is true with respect to the tropical environment. Again, a large body of literature concerns the effects of the tropical environment on personnel and materiel. Problems associated with terrain and the rapid, direct-acting climatic factors in the tropical environment are treated; however, discussion of the effects of deteriorative processes on materiel comprises a significant and major portion of the literature. This is true, of course, because deteriorative processes caused by environmental factors are of significantly greater variety and impact in the tropical environment than in any of the other environments. The discussion in this chapter will reflect this characteristic of the literature; i.e., in the discussion of the impairment of operation execution, emphasis is placed on the cold environments, while, in the discussion of the operational readiness of materiel as affected by deteriorative processes, emphasis is placed on the tropical environment.

In life cycle environments, a gray area exists (at least from the environmental standpoint) in the portion of the life cycle that occurs after materiel has been delivered to the using unit and before the materiel is actually placed in use. Materiel in this portion of the life cycle is no longer, in the strictest sense, part of the logistic cycle, yet it has not yet been placed in use. Generally, it is a temporary storage situation involving various types of handling. In most cases the storage is not as protective nor is the handling as well regulated as in the reasonably well-controlled logistic cycle. Further, protective packaging may or may not be removed from the materiel.

Most of the time that materiel is in the hands of the operational unit (final user) is spent in this special handling or storage environment, which is defined here as operational storage. Because the environment during "operational storage" is, in many cases, as poorly controlled and as severe as the "operational environment", it is considered to be part of the operational environment.

In this chapter the effects of the operational environment on materiel are discussed. Primary emphasis is on the effects of climatic factors and terrain in the three extreme environments (cold, tropical, and desert). Par. 4-2 discusses a number of examples of the impairment of operation execution caused by environmental influences. A summary of a large-scale study of 9,203 incidents of operation impairment resulting from environmental effects during World War II in the European theater of operations is given. The types of impacts, the geographic correlations of various environmental influences, the seasonal effects, and the relationships between the various types of military operations and environmental factors are discussed. Pars. 4-3, 4-4, and 4-5 present examples of impairment of operation execution for the three extreme climatic regions. Par. 4-2.1 discusses those environmental factors that produce impairment of operational readiness of materiel. Again, examples from the literature on the effects of the three extreme climatic types are given. Attention is also directed in par. 4-2.5 to the temperate or intermediate climate and its effects on operation execution and operational readiness.

4-2 IMPAIRMENT OF OPERATION EXECUTION—TEMPERATE CLIMATE

This and the next three paragraphs contain descriptions of those environmental effects in the operational environment which detract from the ability of a unit to carry out a mission. Most of these effects remain part of the operational environment despite a maximum engineering effort. As long as an army must move cross-country, then rain, mud, and rivers will inhibit mobility. The engineer's efforts may lessen such effects but not eliminate them.

The strong correlation of climate with effects in the operational environment as well as the nature of the operations from which experience has been derived makes it convenient to subdivide the discussion of environmental effects that impair operation execution into those occurring in temperate, cold-wet, arctic, desert, and tropical climates. This paragraph applies to the temperate climate.

The operations of the Army in the Mediterranean and European theaters during World War II and in Korea typify operations in temperate zones. A comprehensive study of 9,203 incidents of environmental effects on military operations in those theaters provides much insight into the nature and relative importance of such effects (Ref. 4). These incidents were associated with 82 environmental factors, of which only 22 included more than 100 incidents. These 22 factors, however, comprised 83 percent of the total number of incidents. Of the 82 factors, 20 are related to the atmosphere and, among the most important factors, 11 are associated with the atmosphere. These 11 natural climatic factors represent almost one-half (47.5 percent) of the total number of incidents. The second most significant category of factors is that related to terrain (33.2 percent of the incidents), and the third, to water features (12.3 percent of the incidents).. From these data, natural climatic factors (primarily variations in visibility conditions) and terrain (land and water features) are most important in the operational environment.

Thirty-nine factors were reported fewer than 20 times. Among these were some factors that might have been expected to have greater incidence--such as insects, microbes, and human disease. Table 4-1 lists the various environmental factors and the number of incidents with which they are associated.

4-2.1 ENVIRONMENTAL EFFECTS

The 31 more important environmental factors and the effects they produced on military operations are listed in Table 4-2. The entries in the table indicate the fraction of time that the factor produced a given environmental effect during the operation. The total of all of the fractions for a given environmental element should equal 1.00 but does not because of rounding-off error. Of the nine most important environmental effects shown in Table 4-2, three involve effects on materiel, two involve effects on personnel, and four are combined effects. Effects involving movement and observation account for 75 percent of the cases of environmental impact recorded in the table. A wider variety of things affect movement than any of the other categories.

The general patterns revealed by these data are:

(1) *Movement*. All factors that produce inhibition or prevention of movement can be categorized according to whether the movement they affect involves the land surface, water surface, or air.

(a) Land surface movement is restricted by (i) low traction surfaces, which include mud, snow cover, ice, combined snow and ice, swamps, and sand (other surfaces not included in the table, which occurred in a very small number of incidents, were frozen bodies of water, cultivated fields, rice paddies, and beach terrain); (ii) steep surfaces, including slopes, stream channels, beach gradients, and mountain passes; (iii) obstacled surfaces, including forests, underbrush, landslides, orchards, cultivated crops, boulder surfaces, urban patterns, and avalanches; and (iv) other obstructions and combinations, including narrow rivers, artificial water courses, wide rivers, steep slopes with forest, steep slopes with snow and ice cover, steep slopes with mud, steep slopes in road systems, steep slopes with snow cover and forest, steep slopes with underbrush, and steep slopes with angular rocks and/or gravel.

(b) Water surface movement is restricted by currents, waves, tides, swells, and off-shore features.

(c) Air movement is affected by wind and turbulence.

(2) *Observation*. All elements affecting observation can be included in the following classes:

(a) Precipitation, including rain, snowfall, precipitation/condensation phenomena, hail, and sleet

(b) Condensation, including fog, clouds/overcast, and combined condensation phenomena

(c) Noncondensation atmospheric obstructions, including blowing sand and dust, haze, glare, and shadow

(d) Vegetation, including underbrush, forests, and orchards

(e) Terrain obstacles such as hills

(3) *Minor factors*. In Table 4-2 only five environmental factors--low temperature, moonlight, barren land, high slopes, and low temperature/humidity--do not produce their major effects in the movement and observation categories. They may be classified as follows:

(a) Exposure. The major effect pro-

TABLE 4-1.
DISTRIBUTION OF INCIDENTS AMONG ENVIRONMENTAL FACTORS (Ref. 4)

Factors	Count
Mud	1280
Fog	869
Steep slopes	591
Rain	502
Snow cover	486
Precipitation and condensation phenomena	462
Haze	393
Clouds and/or overcast	337
Floods	379
Snowfall	331
Currents, water	277
Forest	218
Low temperature	198
Road system	197
Ice	192
Wind	169
Waves/swells	168
Water depth	123
Moonlight	121
Barren land	112
Combined condensation phenomena	111
Blowing sand/dust	104
High slopes	97
Snow and ice	97
Underbrush	90
Steep slopes and forest	83
Steep slopes/snow cover/ice	80
Swamps	80
Narrow rivers	68
Steep slopes and mud	62
Low temperature/rain/humidity	58
High temperature	57
Electrical disturbances	56
Sand	56
Frozen ground	50
Steep slopes/road systems	40
Stream channels	42
Artificial watercourses	42
Offshore features	36
Hard ground	35
Ice formation	24
Wild rivers	23
Steep slopes/snow cover/forest	21
Steep slopes/underbrush	20
Snow cover/forest	20
Ice	20
Landslides	19
Local water supply	19
Angular rocks/gravel	16
Tides	16
Cultivated fields	15
Glare	15
Salt spray	13
Orchards	11
Cultivated crops	10
Beach terrain	10
Turbulence	9
Insects	9
Steep slopes/angular rocks/gravel	8
Shelter	7
Humidity	7
Hail and sleet	7
Magnetic ore deposits	7
Boulder surface	7
Beach gradients	6
Caves	5
Passes	5
Micro-organisms	5
Local materiel supply	5
Urban patterns	5
Avalanches	4
Dry vegetation	4
Field grasses	4
Shadow	3
Disease	3
Potable water	3
Rice paddies	3
Aridity	2
Mirage	2
Animals	2
Railway system	2
Local food supply	1

duced by moonlight and by barren land relate to exposure—over 90 percent of the incidents involving these factors are classified under exposure. The use of the word exposure in this particular instance refers to lack of cover, making observation by the enemy possible.

(b) Extreme temperature. Low temperatures produce two major effects: mechanical or nonmechanical malfunction, and chilling. Incidents involving high temperature were reported only 57 times and were not significantly concentrated in any one kind of effect on either materiel or personnel.

(c) Barrier. High slopes prevented normal firing of artillery pieces and mortars, were barriers to the use of small planes with relatively low ceilings, and acted as barriers to radio communications. The environmental factors associated with effects on various classes of materiel are given in Table 4-3.

Because of the nature of the operations involved in these particular military theaters,

TABLE 4-2.
ENVIRONMENTAL FACTORS INVOLVED IN OPERATIONAL INCIDENTS (Ref. 4)

Environmental factor	Effect								
	Movement inhibition	Observation interference	Movement prevention	Function inhibition: effects on operating personnel	Mechanical or nonmechanical malfunction	Function inhibition: external environmental influence	Exposure	Exposure prevention	Chilling
Mud	68*	--	29	--	2	3	--	--	--
Fog	--	73	--	18	--	1	--	8	--
Steep slopes	74	4	16	1	1	2	1	2	--
Rain	7	60	4	19	4	1	--	1	3
Snow cover	67	3	24	--	1	4	1	--	1
Precipitation & condensation	2	67	--	30	--	--	--	1	--
Haze	--	78	1	18	--	1	--	3	--
Clouds overcast	--	66	--	30	--	3	--	1	--
Floods	32	--	32	--	32	4	--	--	--
Snowfall	4	69	1	23	1	1	--	2	--
Currents, water	47	--	29	--	20	3	--	--	--
Forest	25	46	3	2	--	9	1	15	--
Road system	80	1	15	1	2	1	1	1	--
Low temperature	2	--	--	--	58	3	--	--	37
Ice	78	1	10	1	7	3	1	--	--
Waves/swells	31	--	29	--	28	12	--	--	--
Wind	28	5	11	1	24	27	1	1	4
Water depth	32	1	35	--	22	5	1	--	5
Moonlight	1	1	1	--	--	1	95	--	--
Barren land	1	--	2	1	1	3	92	--	--
Combined condensation	--	69	--	26	--	2	--	4	--
Blowing sand and dust	2	61	4	23	4	6	--	1	--
High slopes	11	7	1	1	1	66	12	1	--
Snow and ice	82	1	6	1	4	4	1	--	--
Underbrush	46	35	2	5	--	2	--	10	--
Steep slopes and forest	71	15	2	--	--	8	--	4	--
Steep slopes/snow cover/ice	92	--	6	--	1	--	--	--	--
Swamps	73	1	23	--	1	1	--	--	--
Narrow rivers	50	--	47	--	3	--	--	--	--
Low temperature/rain/humidity	6	11	6	--	3	--	--	--	75
Sand	48	2	31	--	19	--	--	--	--

*The numbers indicate the percent time that a factor produced a given environmental effect during the operation.

some of the categories bear explanation. For example, the category "ships and other water craft" refer more to rubber boats for river crossing than to naval vessels and the currents are largely river currents. Many of the prefabricated structures are bridges, which explains the relationship to currents. The effect of high slopes on communication equipment is to interfere with transmission of field radios. The effect of wind on ammunition and explosives has to do largely with smoke screening.

TABLE 4-3.
EFFECTS OF ENVIRONMENTAL FACTORS ON VARIOUS CLASSES OF MATERIAL (Ref. 4)

Class of materiel (no. of incidents)	Factors	Incidents, %
Weapons (449)	Mud	25
	Fog	14
	Clouds/overcast	6
Ammunition and Explosives (44)	Wind	23
	Low temperature	16
	Floods	11
	Mud	5
	Rain	5
Aircraft (595)	Clouds/overcast	18
	Rain/condensation phenomena	18
	Rain	14
	Fog	12
Ships and other watercraft (217)	Currents	60
	Floods	6
Motor vehicles (2372)	Mud	41
	Snow cover	11
	Steep slopes	8
	Road systems	7
Prefabricated structures (71)	Floods	65
	Currents	24
Communications equipment (121)	High slopes	41
	Floods	8
	Wind	7
Electric wire, and power and distribution equipment (31)	Low temperatures	29
	Floods	23
	Snow cover	10
Live animals (73)	Steep slopes	60
	Mud	12
	Rain	5

The class of materiel most often affected was vehicles. Fifty-five percent of all materiel effects concern vehicles and movement. Some of the factors are relatively specialized in their effect while others are not. For example, mud is almost entirely a movement factor (95 percent of the reported incidents involving mud also involve movement) and only affects land surface movement. Mud is very effective in limiting movement by itself and is even more effective when combined with steep slopes. On the other hand, it does not occur usually in combination with any movement factor other than steep slopes. Examples of vehicles in mud are shown in Figs. 4-1 and 4-2. Moonlight and bare ground are also essentially single-effect elements; i.e., permitting exposure to enemy observations. Such elements as wind, waves and swells, and underbrush, however, produce several different kinds of effects, depending upon the nature of the military activity.

Table 4-4 indicates the effects of the various environmental factors on personnel. The most prevalent was observation inhibition, accounting for approximately 54 percent of all effects on personnel.

4-2.2 GEOGRAPHIC CORRELATIONS

The reported environmental incidents originated in the following geographic locations: Morocco, Algeria, Tunisia, Libya, Egypt, Italy, Yugoslavia, Hungary, Greece, southern France, northern France, Switzerland, Austria, southern Germany, northern European lowlands, northern Norway, and Korea. The most frequently reported elements of

Figure 4-1. Operation of Howitzer in Mud (Ref. 5)

Figure 4-2. Tanker Traversing Mud (Ref. 6)

the environment in terms of first, second or third highest percentage of reports by number of countries are presented in Table 4-5. The military importance of mud is obvious.

Various types of military operations occurred in the different countries. The factor most often reported in Morocco and Algeria was waves and swells because a landing operation was involved, while in Tunisia a more normal land campaign occurred and mud was most important. In Korea, fog and rain were reported more frequently than was mud, indicating the patrol action nature of the operation. The factor most often reported in Libya and Egypt was blowing sand and dust. Snow cover was a significant element in Yugoslavia, Hungary, Austria, the northern European lowlands, and northern Norway. Steep slopes were significant elements in Italy, Greece, southern France, and Austria.

Table 4-6 indicates the types of operations involving environmental incidents reported in the various countries. The relatively high percentages categorizing the bottom row of the table--the nonweapons operation "Transportation"--clearly indicate the mo-

TABLE 4-4.
EFFECTS OF ENVIRONMENTAL FACTORS ON PERSONNEL (Ref. 4)

Factor	Number of incidents	Incidents, %
Fog	689	16
Rain	352	8
Precipitation/condensation phenomena	318	7
Haze	314	7
Steep slopes	307	7
Clouds/overcast	255	6
Snowfall	243	6
Snow cover	169	4

TABLE 4-6.
RELATIVE IMPORTANCE OF ENVIRONMENTAL FACTORS (Ref. 4)

Environmental factor	Number of countries in which a factor had the rating shown		
	First	Second	Third
Mud	8	2	2
Fog	2	2	2
Waves and swells	2	0	1
Snowcover	1	2	1
Blowing sand and dust	2	1	0
Rain	0	2	1
Snowfall	0	1	3

bile character of military activities. While weapon operations more often are influenced by environment than are nonweapon operations, transportation is overwhelmingly the nonweapon operation most subject to environmental impact. It was important in every location.

Table 4-7 lists factors associated with environmentally related incidents as reported in the various countries. Primary deterrents to land movement were low traction surfaces and steep slopes. Low traction was a significant problem in Tunisia, Yugoslavia, Hungary, Greece, Austria, the northern European lowlands, and northern Norway. Steep slopes had relatively high impact in Libya, Italy, Greece, and Austria. The importance of amphibious landings is reflected in the sea surface movement incidents in Morocco, Algeria, and the northern European lowlands (Normandy).

The factors—flood, currents, water depth, and sand—that tend to inhibit movement and at the same time bring about malfunction of materiel were especially typical of Morocco, Libya, Egypt, southern France, and Korea. Blowing sand and dust (listed as other atmospheric factors) were recorded frequently in Tunisia, Libya, and Egypt, whereas, in the other areas, condensation or precipitation are far more important.

4-2.3 SEASONAL INFLUENCES

In much of the world, climatic factors change significantly during various seasons of the year. Those factors that produced impacts on military operations occur most frequently in winter. The most important months are January, February, November, December, and October in that order, with January incidents being most numerous. The data confirm that military operations, by their nature, encounter a wider variety and greater intensity of environmental impact in winter—a fact that has been observed in military operations throughout history.

Table 4-8 lists the factors involved in environmental incidents according to the month in which they were reported. Certain factors are clearly seasonal. Snow cover, snowfall, ice, low temperatures, and combinations of these are winter elements. In addition, condensation and precipitation phenomena that affect visibility are more frequent in winter months than in summer months. Rain, however, is distributed seasonally in no particular pattern in these areas. Part of the explanation may lie in the fact

TABLE 4-6.
TYPES OF OPERATIONS INVOLVING ENVIRONMENTAL INCIDENTS (by percentage of reported incidents) (Ref.4)

Type of operation	Area															
	Morocco	Algeria	Tunisia	Libya	Egypt	Italy	Yugoslavia	Greece	S. France	N. France	Switzerland and Austria	S. Germany	Lowlands and N. Germany	N. Norway	Korea	Average
Aircraft	1		13	10	14	9	3		4	14	7	16	14		16	8.3
Armored	2		7	2	2	5	1		1	6	11	7	9		7	4.0
Heavy weapons	2		14	2	9	14	6	4	13	14	24	16	14		16	9.8
Small arms	3	2	9	7		18	11	2	16	10	4	17	14		17	8.6
Complex*	2	2	14	26	21	14	25	47	20	20	20	13	19		9	16.8
Amphibious	65	24				3		6	6	5	2	1	1			7.5
Engineering		2	1	11	5	2	3		6	3	6	4	3	7	2	3.6
General & Individual	6	14	4	2		2	1			1	2	1	1	7	1	2.8
Medical		16	4			5	2	2		2		1	1	2	1	2.4
Signal	2	2	4	1	7	2	7	4	6	2	2	3	2	7	4	3.6
Transportation	11	21	18	22	12	18	30	29	19	16	20	15	15	71	15	22.1

*A complex operation is a land operation utilizing a combination of small arms (infantry), heavy weapons (artillery), and armored units working in conjunction.

(Low frequency rows have been omitted; therefore, the columns do not total 100%.)

TABLE 4-7.
FACTORS AFFECTING MILITARY OPERATIONS IN VARIOUS LOCATIONS (Ref. 4)
(By percentage of reported incidents)

Effect	Factor	Location															
		Morocco	Algeria	Tunisia	Libya	Egypt	Italy	Yugoslavia and Hungary	Greece	S. France	N. France	Austria	S. Germany	N. European lowlands	N. Norway	Korea	Average
Limitations on land movement	Low traction	7	18	30	19	17	24	44	42	27	24	33	24	31	37	14	29
	Steep slopes	2	4	10	12	8	15	9	28	11	5	15	3	2	3	8	9
	Movement restricted to roads		2	3	1		3		2	2	2	5	3	2	10	3	2
	Steep slopes combined with snow, rivers, etc.			1			1	4	2	4	2	4	2	2		2	2
	Snow cover with ice, wind, etc.							2		2	2		1	2	3	1	1
Limitations on sea movement	Waves, tides, and winds	37	34	1	3		3			5	4			10			6
Limitations on air movement	Wind, obscuration, etc.	3	10	3	1		2			5	2		2	2		1	2
Combination of movement limitation and equipment malfunction	Sand, dust, rocky terrain, etc.	34	8	5	27	17	9	11	2	15	8	2	13	8	8	15	12
Limitations on observation	Precipitation	95	18	9	4	3	13	9		13	17	13	19	16	20	20	12
	Condensation	4	2	18	2	8	13	15	5	5	21	13	16	16	5	23	11
	Other atmosphere		2	16	24	47	6		5	5	5	2	6	5		3	8
Combination of movement limitations and observation limitations	Forests, fog, etc.		2	3			2	5		3	7	5	6	6		3	3

TABLE 4-8.
DISTRIBUTION OF INCIDENTS BY MONTH AND FACTOR (Ref. 4)
(Percentage of reported incidents)

Environmental factor	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Mud	4	15	7	8	3	3	2	2	10	15	19	10
Fog	11	15	7	4	3	7	2	3	10	16	8	15
Steep slopes	5	3	8	12	9	7	9	11	9	10	9	6
Rain	4	9	7	13	6	4	6	6	10	8	18	8
Snow cover	73	10	1	1	4						4	6
Precipitation and condensation phenomena	23	20	13	5	1	2	3	1	6	7	11	8
Haze	13	15	9	10	5	3	4	5	6	9	6	14
Clouds/overcast	10	9	14	9	7	2	5	3	9	7	8	15
Snowfall	64	5	6	1	5						9	10
Floods	2	21	6	1	2	2	3	19	8	5	5	5
Currents, water	7	52	12	14	1	1	1		1	2	5	4
Forest	19	9	5	9	5	12	3	2	12	11	6	8
Road system	3	5	12	17	12	9	8	7	10	5	7	4
Low temperature	3	4	2	2	1		1	1		1	9	18
Ice	76	4	1		1						2	16
Waves/swells	5	7	1	4	4	20	22	1	3	2	26	5
Wind	23	18	10	9	4	1	3	3	6	5	10	8
Water depth	7	22	1	3	2	9	7	7	2	9	19	12
Moonlight	18	23	27	2	2	1		1	3	7	2	12
Barren land	13	3	8	9	6	13	5	6	11	11	6	8
Combined condensation phenomena	24	25	6	3	1	5	3	2	4	4	10	13
Blowing sand/dust	1	4	9	20	19	10	11	9	11	5	1	1
Snow and ice	66	4	2		1				1		3	23
High slopes	4	2	11	18	10	8	9	8	7	8	8	5
Underbrush	8	6	2	9	12	21	9	3	8	10	3	9
Steep slopes and forest	5	7	18	18	4	5	2		8	14	5	13
Steep slopes/snow cover/ice	79	6	6								1	8
Swamps	2	5	4	8	12	26	4	4	5	13	8	10
Low temperature/rain/humidity	21	5	3		2	2		5	12	16	22	12
Sand	7		2	5	5	25	16	9	2	4	16	9
Narrow rivers	12	18	6	9	6	9		13	4	6	4	13

that, while the major effect of rain is on observation, it also has widely distributed effects of other types. Wind is also primarily a winter phenomenon in the areas studied. Reporting of the effects of moonlight on exposure is primarily a winter phenomenon. Since moonlight is hardly seasonal, the distribution of environmental impacts or effects in winter obviously must arise from the exposure problem. It appears that the combination of snow cover and lack of vegetative cover are winter characteristics that enhance or emphasize exposure due to moonlight. Summer phenomena are underbrush and blowing sand and dust. Mud is primarily a winter phenomenon. Floods are primarily early winter and late winter elements, as is water depth. Currents appear to be most significant in spring. Most of the currents reported are river currents, and spring is the period of maximum river flow. Factors of the environment that show no marked seasonal variation in frequency of occurrence are steep slopes, rain, forest, road systems, barren land, high slopes, steep slopes/forest, and narrow rivers. Figs. 4-3 and 4-4 show the environmental effects on materiel and personnel, respectively, for each month.

The following conclusions are drawn from these data:

(1) The most important effects of environment on the execution of military operations are those that inhibit or prevent movement and observation, and the most important single factors of environment with respect to these effects are mud and fog.

(2) The major differences between two different locations are not so much the overall effects they produce on the average military operation as they are the different effects elicited by different kinds of operations and the varieties of factors that produce these effects.

(3) In general, winter has a greater impact than summer; the rainy season has a greater impact than the dry season.

(4) Since the nature of environmental factors differs with geographic location, the impact of a given factor on a given operation is also a function of location.

4-2.4 CORRELATIONS WITH TYPE OF MILITARY OPERATION

The impact of environment on various types of military operations has been evaluated (Ref. 7), based on the data discussed in the preceding paragraphs (Ref. 4). Table 4-9 lists the 10 environmental factors that had the highest impact on operations. From this table, the very close correspondence of an operation with a particular factor is evident. Five of the factors were associated with a particular operation from 60 to 75 percent of the time: current (small arms), clouds and/or overcast (aircraft), floods (transportation), precipitation/condensation phenomena (aircraft). Rain has the most widely dispersed effects with respect to operations, perhaps because the report "rain" usually implies some associated phenomena. The 10 highest impact factors are associated with all of the weapon operations but with only two of the nonweapon operations.

The data in Table 4-9 refer to those incidents in which the operation was prevented. On occasions, however, environmental elements can delay or obstruct an operation without actually preventing the operation from occurring. When the operation was reported to have been delayed or obstructed, the operations in Table 4-10 were those affected. When operations are delayed or obstructed, the element-operation relationship appears to be more diffuse. Two elements that maintain an extremely high correlation are waves or swells and amphibious operations. It can also be seen from Table 4-10 that a slightly higher percentage of nonweapon operations are affected. This is true because the nonweapon operations are more likely to be delayed than prevented. In general, however, the association of high impact elements and the operations they affect do not differ greatly from those

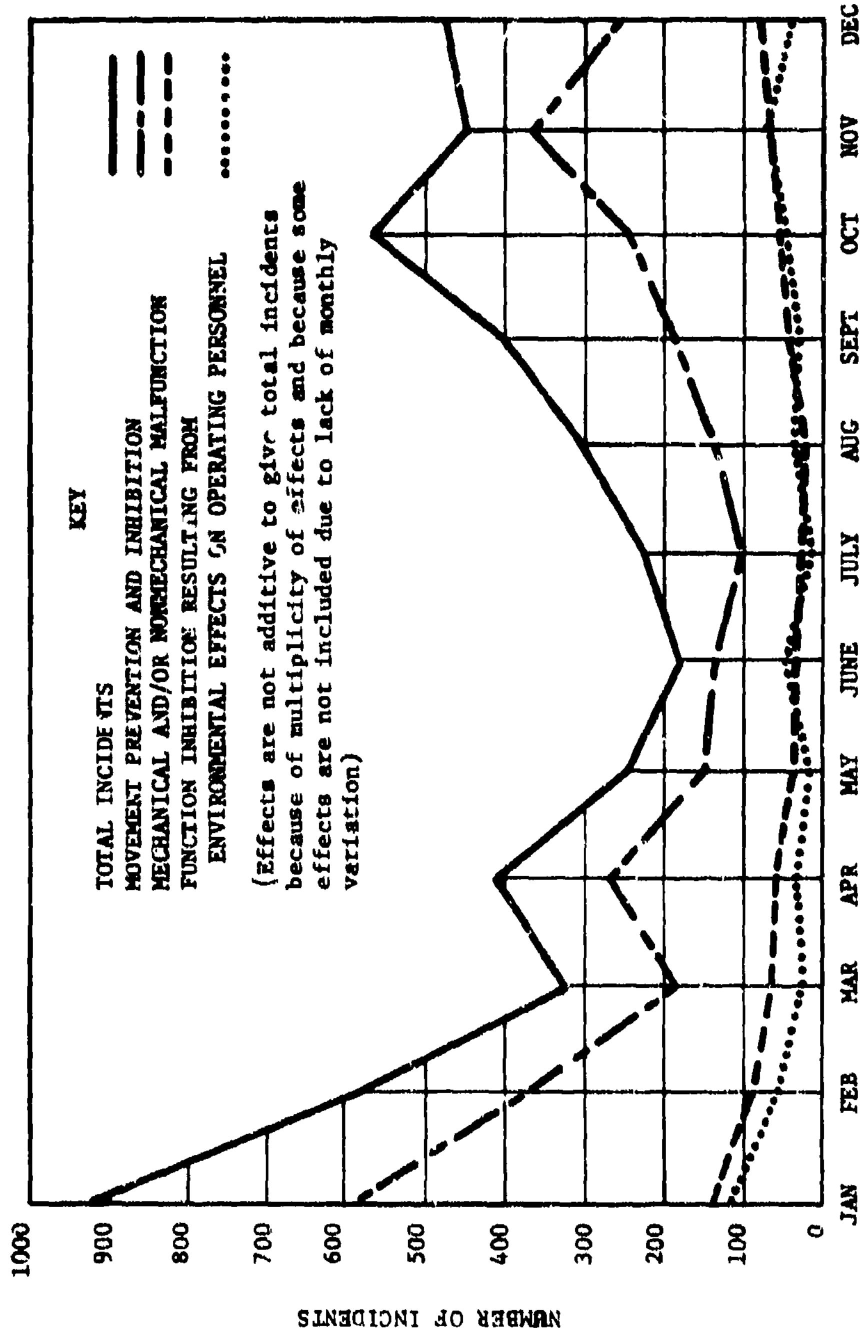


Figure 4-3. Monthly Occurrence of Environmental Incidents Involving Materiel (Ref. 4)

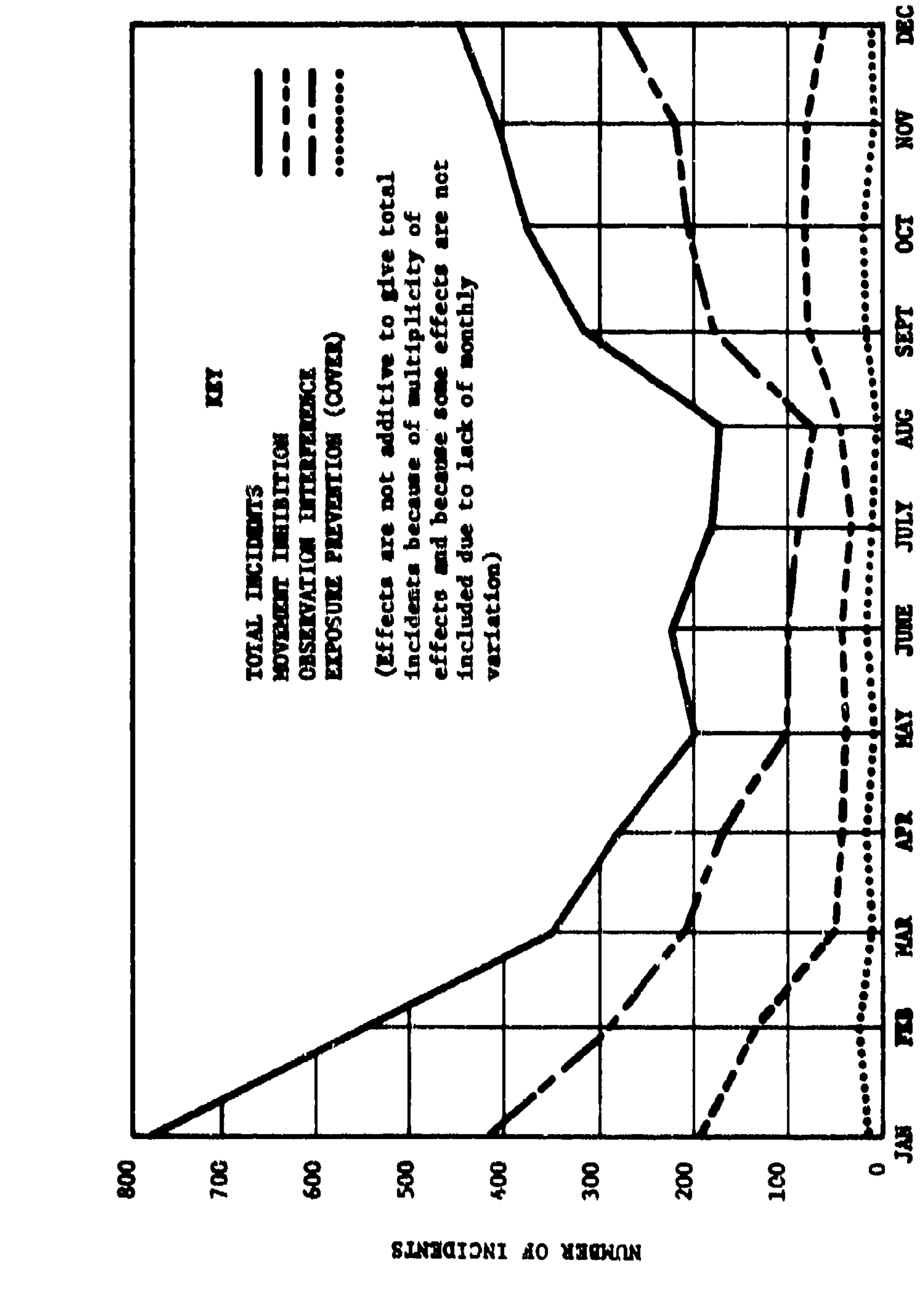


Figure 4-4. Monthly Occurrence of Environmental Incidents Involving Personnel (Ref. 4)

TABLE 4-8.
ASSOCIATION OF ENVIRONMENTAL FACTORS THAT PREVENT EXECUTION WITH TYPES OF OPERATION (Ref. 7)

Factor	Operation	Incidents, %
Currents, water	Small arms	60
	Transportation	18
	Engineering	10
Clouds and/or overcast	Aircraft	70
	Heavy weapons	13
	Complex*	13
Precipitation/ condensation	Aircraft	75
	Heavy weapons	13
	Complex*	9
Snow	Aircraft	55
	Heavy weapons	15
	Small arms	12
Floods	Transportation	4
	Small arms	31
	Engineering	16
Combined condensation phenomena	Aircraft	63
	Heavy weapons	22
Waves or swells	Amphibious	46
	Transportation	41
Rain	Aircraft	51
	Heavy weapons	16
	Complex*	14
	Small arms	9
Narrow rivers	Small arms	48
	Armored	34
Water depth	Small arms	53

*A complex operation is a land operation utilizing a combination of small arms (infantry), heavy weapons (artillery), and armor working in conjunction.

TABLE 4-10.
ASSOCIATION OF ENVIRONMENTAL FACTORS THAT IMPAIR EXECUTION WITH TYPES OF OPERATION (Ref. 7)

Factor	Operation	Incidents, %
Currents	Small arms	36
	Amphibious	29
	Transportation	18
Clouds and/or overcast	Aircraft	61
	Heavy weapons	18
	Complex*	14
Precipitation/ condensation	Heavy weapons	37
	Aircraft	35
	Complex*	15
Snow	Heavy weapons	49
	Small arms	19
Floods	Transportation	36
	Small arms	22
	Complex*	11
Combined condensation phenomena	Heavy weapons	46
	Aircraft	34
Waves or swells	Amphibious	71
	Transportation	16
Rain	Heavy weapons	30
	Aircraft	25
	Small arms	19
	Complex*	13
Narrow rivers	Small arms	41
Water depth	Complex*	26
	Small arms	21

*A complex operation is a land operation utilizing a combination of small arms (infantry), heavy weapons (artillery), and armor working in conjunction.

in Table 4-9. In particular, the following elements are still primarily associated with a single operation: currents, clouds and/or overcast, floods, and waves or swells.

It is concluded that:

(1) Some environmental factors produce more widespread and severe impacts on military operations than others.

(2) Some types of military operations are highly susceptible to environmental impacts (e.g., an aircraft operation is the most susceptible operation with the highest amount of environmental impact, whereas medical operations are the least susceptible to environment).

(3) Some environmental factors are associated primarily with one type of operation.

(4) Weapon operations are affected more adversely by the environment than nonweapon operations.

An additional study based on these data was undertaken to describe environmental effects on specific military operations (Ref. 8). The weapon operations analyzed included aircraft, armor, small arms, and heavy weapons complex; combined arms and amphibious operations; while the nonweapon operations analyzed included engineering, medical, signal, ordnance, and transportation. Seventy-three percent of all incidents were associated with weapon operations as opposed to nonweapon operations. However, transportation—a nonweapon operation—was reported to be affected more often than any other type of operation. For weapon operations, reports of effects on personnel outnumbered reports of effects on materiel, while the reverse was true for nonweapon operations.

The dominant effect on personnel for all operations was observation interference. The dominant effect on materiel was movement restraint. Table 4-11 lists the environmental effects on materiel. Only four effects—three affecting materiel and one affecting personnel—had a greater frequency of occurrence for nonweapon than for weapon operations.

An important effect on materiel in weapon operations is function inhibition resulting from environmental effects on operating personnel. This effect shows up mainly as a subsidiary effect of observation interference—a situation in which the materiel is limited functionally because of the inability of the operating personnel to see. This effect is almost nonexistent in the nonweapon operations.

The effects "mechanical malfunction" and "function limitation due to external environmental influences" are relatively important to the nonweapon operations, accounting for about 23 percent of the total, whereas in weapon operations they account for only 13 percent of the total.

In weapon operations, observation interference produced the single largest effect on personnel—51 percent of the total. Movement limitation was the next most important with about one-half as many cases. The same two effects are also the most significant ones for the nonweapon operation, but in reverse order.

The effect of environmental factors on operations can be classified in a number of ways. One is based on whether the environmental effects are on personnel or on weapons. Aircraft, heavy weapons, and small arms operations are characterized by a dominance of environmental effects on personnel. On the other hand, armor, amphibious, engineer, ordnance, signal, and transportation operations involve environmental effects on materiel in greater than 75 percent of the cases. Two operations, the combined arms and the medical operation, cannot be characterized as either personnel or materiel since the distribution of impact is about equal for both.

There is a further correlation between operations and certain specific effects; i.e.,

TABLE 4-11.
DISTRIBUTION OF ENVIRONMENTAL EFFECTS BETWEEN WEAPON AND NONWEAPON OPERATIONS (Ref. 8)

Effects	Reported incidents involving each effect, %	
	Weapons	Nonweapons
On materiel		
Movement prevention	56	44
Movement restraint	50	50
Mechanical/nonmechanical malfunction	45	55
Function inhibition: external environmental influences	40	60
Function inhibition: effects on operating personnel	95	5
Accelerated wear	24	76
Exposure	80	20
Exposure prevention	76	24
On personnel		
Noninfectious disease	44	56
Fatigue	54	46
Chilling	75	25
Movement prevention	89	11
Movement restraint	81	19
Observation interference	95	5
Observation improvement	80	20
Exposure	95	5
Exposure prevention	95	5

most operations can be characterized by dominant effects. Some operations are susceptible to great impact from a single effect while others are impacted by several significant environmental effects. The following operations are predominantly subject to one kind of effect: armor (movement prevention or limitation), transportation (movement prevention or limitation), aircraft (observation interference), heavy weapons (observation interference). Certain operations are subject to more than one dominant effect from the environment. These multiple-effect operations are small arms, complex, amphibious, ordnance, engineer, and signal. Generally, weapon operations are characterized more by one dominant effect than non-weapon operations. In addition, effects on movement and observation usually have a greater impact on weapon operations. Non-weapon operations have a relatively greater proportion of their effects in the nature of mechanical malfunction and function limitation due to external environmental influences.

4-2.5 OPERATIONS IN TEMPERATE CLIMATE

Although the temperate climate receives little emphasis in Chap. 2, "Operational Climates of the Army", many of the effects of environment on operations occur in that climate because that is where most operations occur. The important terrain factors--high relief, poor load-bearing soils, mud, forests, swamps, and streams--are found in the temperate climates as are damaging factors such as sand and dust, snow, ice, and extreme temperatures and humidities which are more often associated with extreme climates. An example of snow is shown in Fig. 4-5. In temperate climates seasonal snow cover is often greater than in arctic regions. However, most materiel is designed to operate in these temperate conditions and personnel are better acclimated to them.

Examples of the mobility problems that can occur in temperate climates are given in a comparison (Ref. 9) of operational mobility of Army vehicles performed by the U S Army Transportation Board for the U S Army Transportation Engineering Agency, Ft. Eustis, Va. (Ref. 9). Results clearly indicate that operational mobility can be compromised in temperate climates. Substantial problem areas were encountered in off-road-movements through beach sand, tidal mud flats, and gumbo clays. Many of the 36 vehicles were unable to traverse this terrain. Throughout the evaluation, particular emphasis was placed on ascertaining how the use of aggressive tread*, low pressure, oversized tires affect the mobility of vehicles. Vehicles thus equipped were superior to vehicles using standard tires. It was also clearly demonstrated that, in vehicles not designed for such modification, the strain on certain components such as clutch assemblies and driving axles may be increased sufficiently to cause failure.

The capability of a vehicle to cross difficult ditches and descend steep slopes depends on the following characteristics: high horsepower-to-weight ratio, aggressive tires, positive all-wheel drive, an adequate angle of approach and departure, and adequate braking. Successful operations over sand slopes and soft soils require low axle loads. The superiority of tracked vehicles to wheeled vehicles was demonstrated for operation over soft soils and difficult terrains. For example, a 2-1/2-ton cargo truck equipped with oversized tires was immobilized in a swamp area after making only 12 passes, while a 5-1/2-ton tracked vehicle continued to operate after 50 passes. Other examples of immobilization include these. A 5-ton cargo truck was immobilized while crossing a 3-ft ditch as a result of inadequate angle of approach caused by a front-mounted winch. Then a combat tank was immobilized in a 3-ft sand ditch. In the swampy test area, the 2-1/2-ton cargo truck was immobilized before reaching the assigned test range. A 3/4-ton vehicle was disabled on the exit slope of a 5-ft ditch. A truck-tractor system was immobilized during a 5-ft ditch-crossing test. Some articulated vehicles have an inadequate angle of break, which results in high centering and immobilizes the vehicle when traversing small mounds.

4-3 IMPAIRMENT OF OPERATION EXECUTION—COLD CLIMATES

Knowledge of the cold climate (cold and extreme cold categories of AR 70-38, Ref. 10) is derived from number of field training operations in such climates, from the testing performed at the Arctic Test Center, Ft. Greely, Alaska, and by the Cold

*An aggressive tread is one with very large cleats or grousers such as on tires used on construction equipment.

Figure 4-5. Snow Accumulation Problems in the Temperate Climate (Photograph by R. W. Gerdel)

Regions Research and Engineering Laboratory, Hanover, N.H. The cold climates encompass a large portion of the Northern Hemisphere seasonally and the extreme northern regions continually. The cold-wet climate, which seasonally appears in large regions of the north, is particularly notable for its difficult environmental effects.

In this paragraph, general effects of the cold climate on materiel are discussed after which considerable attention is given to the experiences gained in a controlled test operation on Adak Island, Alaska. Additional information is provided from other tests in more extreme conditions. In general, execution of operations is limited or prevented in many cold regions.

4-3.1 GENERAL EFFECTS ON OPERATIONAL MATERIEL

The problems associated with the operation of vehicles are much more numerous in the arctic regions than elsewhere, and are associated with the difficult terrain and the extreme low temperatures encountered. With the exception of inhabited areas, vehicle transportation is uncertain and hazardous because of the absence of roads. Travel from base to base is over rugged terrain covered with either snow and ice or tundra. Wheeled vehicles are confined to roads, and low pressure tracked vehicles such as shown in Fig. 4-6 are indispensable when travel is required cross country. The danger of upset and crash into arctic ice provides an additional environmental hazard for which special provisions must be made.

Most problems with fuels and lubricants, cold starting of engines, and durability and mobility of vehicles have been solved although improvements are desirable. Some difficulty is experienced with heating capacity of automotive and vehicular heaters as well as with batteries and rubber compounds. Provided proper special purpose oils or greases are used, most problems in the area of fuels and lubricants arise as a result of contamination with moisture or fine particulate matter.

Moisture condensation on surfaces, which is encountered when cold equipment is moved into warm enclosed areas, can be a problem. Many arctic areas are subject to dense fog in spring and fall, impairing visibility and causing moisture problems. Photographic equipment is particularly susceptible to the arctic environment. The most frequently encountered difficulties involve stiffness of operation, frosting of lens systems, and icing of mechanical parts, plus operational difficulties, along with the stiffening of film and the altering of processing and developing procedures--all require special techniques and adequate maintenance. It is also important that personnel be specially trained in operation and repair under extreme low temperature conditions.

Shelters are very important for the survival of personnel as well as for the proper and thorough maintenance of equipment, vehicles, and aircraft. The fundamental environmental control requirement in arctic climates is heating. Indeed, if human beings are to survive in the Arctic for any length of time, proper heat-generating equipment must be available.

Wet and dry cell batteries, which are important in electrical power generating equipment and electrically operated materiel, lose their output capacity at extreme low temperatures. Most of the difficulties of the wet cell batteries are due to an increase in internal resistance as the temperature decreases. Deterioration of cells at an accelerated rate is not a problem in the Arctic. Under extremely cold conditions (−40°F and below), wet and dry cell batteries used to power electronic equipment become frozen. Electrical characteristics of circuit components also change to such an extent that frequent readjustments are required. When temperatures fall below 0°F, equipment should be heated and a long warmup period should be provided. If possible, ground equipment should be operated in housing or shelters that are heated continuously to insure maximum reliability.

Table 4-12 presents information on the effect of cold climates on various categories of ground-support equipment. In addition to the difficulties induced by environment, some indication of the remedies that can be employed to overcome or circumvent the problems are included.

4-3.2 OPERATIONS IN THE COLD-WET CLIMATE

Task Force Williwaw (Ref. 12), a composite force of ground troops, tested a wide variety of ground equipment in the cold-wet climate and terrain of Adak Island, Alaska, during winter conditions. Investigations were made of vehicle mobility and personnel exposure problems. The cold-wet climatic conditions encountered were (1) a temperature range of 20° to 40°F, (2) high humidity, rain, fog, and snow, (3) snow remaining on the ground for short periods of

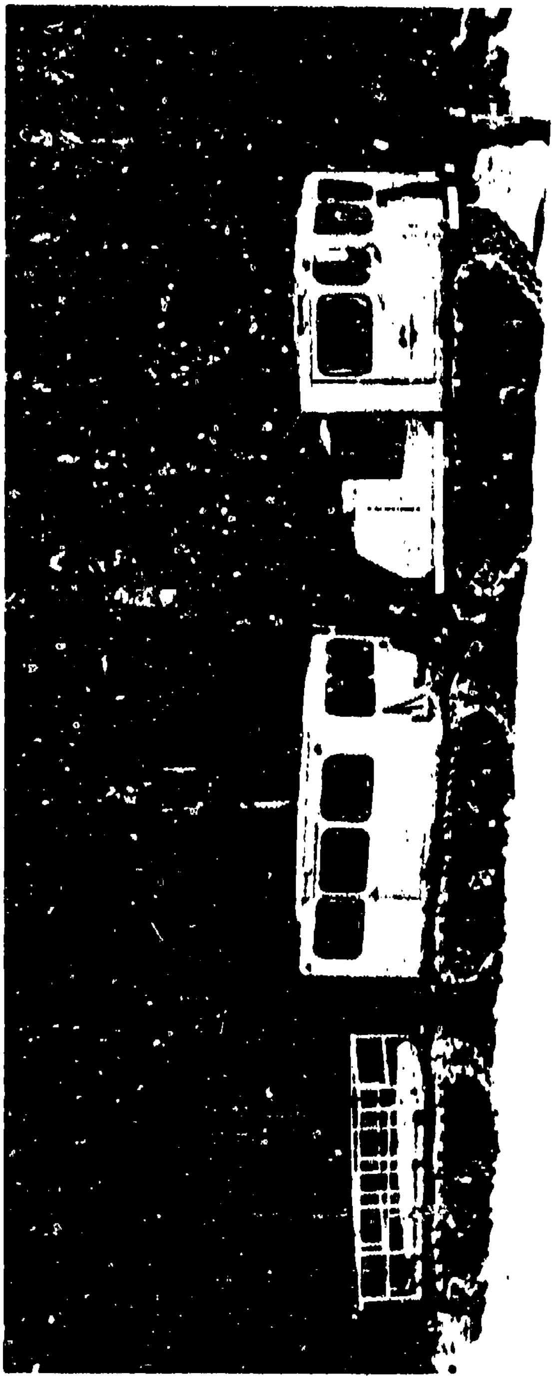


Figure 4-6. Oversnow Tracked Transport (Ref. 11)

TABLE 4-12.
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental Effect	Remedy
Electronic equipment		
General	Difficulties of arctic electronic operation result from the extreme low temperatures (to -60°F); the magnitude of the annual temperature range (from -60° to +100°F); the prevalence of high winds, the nonexistence of good roads; the ruggedness of the tundra terrain, the lack of efficient batteries, heaters and insulation; and the effect of the arctic environment on the operators.	Some improvement in arctic electronic operation can and is being accomplished by reduction of unit weights, providing shock and vibration mountings, sealing units or components against moisture, snow and dirt, increasing battery performance and heater efficiency, correcting insulation and packaging difficulties, and generally, by improving the winterization methods and materials.
	The rugged terrain of the arctic regions causes damage to electronic equipment as the result of vibration and shock.	Vibration damage has been controlled by the use of cast resins, shock mounting and good packaging. Reduction of weights of components by printed circuits and miniaturization of components reduces the probability of shock and vibration damage.
	Moisture results in corrosion and change of dielectric constants due to "breathing" and wind-blown rain, snow, dust, and dirt.	Hermetic sealing of components and units is the best protection. Circulation of warm dry air, careful inspection and maintenance and cleanliness are protective measures. Fibrous resin bonded glass insulation acts as a moisture barrier.
	Insulation of cables and other parts becomes brittle and breaks or loses flexibility	The use of arctic rubber or arctic polymer as cable insulators provides

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	at low temperatures.	flexibility at low temperatures. Heating elements, winterization, and the use of fibrous or silicone glass with resin bonders as insulating materials for units are aids to avoid extreme low temperatures.
	At low temperatures, both wet and dry cell batteries lose power and become useless; e.g., a temperature of -30°F produces a 90% reduction in current capacity of lead-acid storage batteries.	Independent heating units to keep batteries at adequate operating temperatures, good insulation, and winterization practices keep units in operation.
	Inadequate closures allow rain, snow, sand and dust to pass through seals and packing. "Breathing" permits accumulation of frost, causing variation in dielectric constants.	Hermetic seals of small components prevent entrance of foreign matter. Careful cleaning, maintenance, and circulation of clean, dry, warmed air are preventive measures.
	At low temperatures, cables lose flexibility, plugs cannot be readily removed or reinserted in crowded panels, captive type screws cannot be removed, terminals are not watertight and cordage loses its strength and flexibility due to moisture absorption.	Panel arrangement can provide adequate space for the removable plugs. All screw heads should be capable of screwdriver use. Terminals can be protected and made watertight.
Contingent wiring and connectors		
Solder joints	High tin solders having 60% tin content disintegrate at temperatures below -58°F and connections made therewith fall apart.	Solder should not contain more than 35% tin.
Poles, ground rods, and stakes	It is impossible to erect poles or drive ground rods or steel stakes into permafrost. The provision of adequate grounds is a constant	The surface of the ground could be penetrated by building fires and heating but when permafrost was

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	problem.	reached, it could not be penetrated.
Wire	Difficult to dig trenches in snow and ice, and mechanical damage is prevalent to wire laid on the surface.	Overhead installation should be used whenever possible.
Components		
Transformers	Pitch-filled transformers and coils crack due to excessive temperature changes. Subsequent condensation in these cracks causes electrical breakdown of the unit.	Prescribed winterization procedures should be followed to eliminate this condition.
Tubes	Tube envelopes break loose from the base when tubes are placed in service without extended warm-up periods.	Winterization procedures such as keeping filament power on at all times must be followed rigidly.
Capacitors	The effective capacity of electrolytic capacitors is materially reduced when operated in an ambient temperature of -20°C and below.	
Sensitive switches and relays	Formation of ice or frost on the actuating mechanism renders the switches erratic or inoperative.	Great care should be exercised in applying switches under conditions likely to produce an accumulation of ice or frost.
Quartz crystals	Crystals may fail o oscillate at low temperatures because of mechanical changes.	Should be kept as close as possible to normal operating temperatures.
Shelters	Problems are permafrost, insulation, heating, and weight limitation imposed by supply transport. Designing and constructing shelters with these principal factors as parameters are the problem.	

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Building materials and construction	Due to the bleak and barren terrain north of the timber line, building materials necessary for permanent and semipermanent shelters must be imported.	Building materials used are those commonly used in the temperate zone and modified in their manner of application. Structures are primarily prefabricated types that can be transported by air or tractor train, and quickly and easily erected in low temperatures: (1) Quonset huts (2) Cowan huts (3) Pacific huts (4) Jamesway huts (5) Army standard theater of operation huts (6) Stout houses (7) Hangars (8) Nose hangars (9) Wannigans (10) Tents The use of ice and snow for structural purposes has proved feasible, but has not been used to any great extent except in cases of emergency.
	The destructive effects of freezing and thawing are attributed to the presence of surface and ground water which are the most important factors influencing construction in permafrost regions. Moving ground water in construction areas is particularly critical since it conveys heat which is capable of thawing ground and upsetting the thermal regime. In addition, it may undercut foundations by carrying away soil suspension and cause foundation settlement due to the reduction of	Surface and subsurface drainage under the buildings must be adequate in all seasons for conveying surface and ground water away from the site. Areas where surface and ground water are critical should be avoided as construction sites.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	bearing capacity. Heaving of foundation is also possible.	
	Thawing of permafrost under foundations causes settling and possibly damage to foundations and buildings.	To prevent thawing of the permafrost and to preserve the permafrost level, floors must be insulated and ventilated air space must be provided between the floor and ground or an adequate insulating cover placed over the ground. The foundation should be placed over or anchored in the permafrost in accordance with developed arctic techniques.
	Snow drifts can impose severe lateral stresses on building structures, block ventilation, and disrupt communications.	Buildings should never be built on breaches in hillsides where they create troughs into which transverse winds can deposit deep snowdrifts. In areas subject to high winds, inadequate spacing between shelters or locations too close to steep natural features also can cause snowdrifts.
Heating	The major heating problem is air stratification found in heated shelters in subzero regions. Floor-to-ceiling temperature differentials as high as 60 deg F have been observed in shelters heated by space heaters.	Radiant heating has been found to be very effective. Where radiant heating installations are exposed to possible damage from freezing, such as floor areas adjacent to hangars, doors or other comparable conditions, a suitable nonfreezing circulating medium of proper specific heat should be used.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
		Partial solutions to the problem are to use more insulation, installation of space heater as low as possible, and use of fans to increase desired circulation.
Ventilation	Moisture given off by personnel in unventilated shelters will condense on inside surfaces. Subsequent forming of frost may penetrate and destroy effective insulation.	Personnel have a tendency to seal up shelters. The temperature inside a shelter depends largely on suitable insulation. Adequate ventilation is essential not only to overcome the difficulty mentioned, but also to provide fresh air and to remove carbon monoxide gases, if present.
	The combined effects of strong winds and heavy snow and ice loads induce excessively high stresses on roofs.	Roofs must be capable of withstanding the combined effects of strong winds and heavy snow and ice loads. Eaves should not be used in areas with extremely high winds, as the roof may be blown away as a direct result of their use. High-pitched roofs are not too desirable, since they are subject to greater wind loads than flat or low-pitched roofs. They also waste more heat and generally are more expensive.
Doors	Outward opening doors are often blocked by snow and ice and sometimes ripped off by high winds.	All types of doors except those swinging outward are acceptable.
	Handles on doors can be difficult to manipulate by personnel wearing heavy gloves or mittens.	Door handles should be increased in size or shaped suitably.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	The entrance of cold air and snow through doors during use is objectionable.	Vestibules or air locks become a practical necessity during the severe cold winter and always should be installed.
Windows	Windows are generally of small importance. During the winter they transmit no light to the interior. They offer an escape of heat as they have poor insulating values.	
Tentage	Single thickness tents are unsatisfactory. Icing, due to freezing of condensation and melted snow on the canvas, makes it very difficult to strike and refold tents without tearing.	Double thickness tents have overcome this difficulty.
Lubricants		
	Lubricants, including crankcase oils, hydraulic fluids, greases, and gear oils developed for warmer weather use are generally unsatisfactory at very low temperatures, causing channeling; dry gears and bearings; difficult starting and shifting; quick wear and deterioration of engines, engine attachments, and chassis.	Many satisfactory oils, greases and fluids for use at low temperature exist. Use of the recommended lubricant for each specific purpose is required.
Chassis lubrication	Snow and ice at low temperatures cause chassis to require frequent lubrication.	Chassis lubrication at 500-mi intervals is recommended for arctic operations.
Wheel grease	Grease stiffness at temperatures of -35°F and below requires replacement of bogie wheels.	Selection of the latest recommended grease will reduce the difficulty.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Ball bearings	At extreme low temperatures, ball bearing lubrication difficulties are experienced.	Suitable ball bearing grease depends upon the temperature, size, spread and load of the bearings, and the quality of the lubricant. Selection of the proper special purpose grease is most important.
Engine lubricating oil	Congealing of lubricating oil at low temperatures causes excessive wear when cold starting.	Lubricating oil must be kept fluid by continuous heating if necessary
Fire fighting equipment		
Fire extinguishers	At low temperatures, fire extinguishers do not function satisfactorily. The fire is not blanketed, extinguishing materials do not adhere to ceiling or overhead fires, temperature of burning material is not reduced, extinguishing materials do not carry through the air without dangerously high pressure, and, all classes of fires--Class A (Solids), Class B (Liquids), and Class C (Electrical)--cannot be fought with the same extinguisher.	Fluorinated hydrocarbons, dibromodifluoromethane and dibromotetrafluoroethane, are the most effective for all classes of fires at low temperatures to -65°F.
Fire trucks	Low temperatures cause trucks, pumps, and stored water to freeze.	Fire trucks, pumps and stored water should be kept in heated shelters. Pumps operated by the truck engine should circulate the water enroute to the fire and piping should be insulated. Trucks should be winterized and equipped with front

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
		wheel drive, and low pressure mud and snow tires.
Alarms	Insulation in buildings and shelters muffles sound, causing difficulty in sounding fire alarms.	Bells are more effective than gongs. Hand cranked sirens are most effective.
Electrical power generating equipment		
Gasoline and diesel driven generating equipment	The major difficulties of diesel and gasoline power plants, aggravated by the arctic and subarctic climates, are similar to those listed under vehicles, self-propelled.	
Motor generators	Starting is difficult under extreme cold because bearings and journals bind due to dissimilar coefficients of expansion, and because of lack of lubrication resulting from solidification of lubricant.	Proper design and materials eliminate binding; however, if excessive clearances are used, excessive wear occurs during normal operating temperatures. Approved low temperature greases should be used.
	The effect of dry cold air is increased wear of commutators and brushes.	
Vehicles		
Self-propelled	Cold starting of internal combustion engines is a major problem. Difficulty in starting begins at approximately 30°F and becomes progressively worse as the temperature decreases.	
	More engines are ruined by towing to start than by low temperatures.	Extreme caution should be exercised to avoid doing damage both to the towing vehicle and the vehicle being towed.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	The problem with cold weather crankcase lubricants is created by the wide range in temperature through which they must function. Designed with a low viscosity to allow starting, they fail as lubricants when they are brought up to operating temperatures.	
	Gasoline and diesel fuels have the ability to dissolve about 0.1% water. At very low temperatures this water comes out of solution in the form of ice crystals and obstructs fuel systems.	This can be avoided by adding to the fuel small proportions--0.3% or less--of low molecular-weight alcohols. Heavier alcohols are less effective. Alcohol should be added after the fuel is in the tank and not in the fuel containers or storage drums.
		Drain cocks in the fuel tank and settling bowls in the filter housing should be used periodically to remove accumulated water. The use of oversize fuel lines and of fittings smoothly rounded on the inside is an added insurance. Fuel tank should be kept as full as possible and should be full when parked overnight. All snow or ice should be removed from dispensing equipment and from around fuel tank filling cap before removing cap to refuel vehicle.
	Visibility is frequently reduced by ice fog generated by I.C. Engines operating in temperatures between -20° and -60°F. This condition	The use of ice fog suppressors are of some value.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	can be serious enough to restrict operations and bring about hazardous conditions.	
	Conventional coolants and hydraulic fluids congeal at extremely low temperatures. Protection at -80°F, lowest storage temperature, against freezing is inadequate.	Special coolants and hydraulic fluids, fairly satisfactory for use at extremely low temperatures, have been developed.
	Long arctic nights require more than temperate zone lighting capacity.	Larger generators should be installed.
	Operators are handicapped in operating controls with heavy arctic-type gloves.	All control knobs, handles, keys, levers, etc. that the operator uses should be spaced and of suitable shape so that they can be operated while wearing gloves.
Trucks, personnel carriers, tractors, and towing vehicles		
Gasoline engines: trucks and personnel carriers	The primary problem in gasoline engines is cold starting.	Engines should be maintained in good mechanical condition. Arctic lubricating oils must be used with low viscosity and fluidity characteristics. Preheating of engine, using externally applied heat, aids in starting. Frigid-type storage batteries should be used. Gasoline should be sufficiently volatile and should

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
		possess quick starting characteristics. At about -20°F and below starting fluids--highly volatile-at-low-temperatures fuels--will aid cold starting (but their effect is less pronounced than for diesel engines). Starting techniques and procedures should be known and practiced by operators.
	Ignition systems fail if not adjusted or conditioned for cold weather.	The contact points of distributors should be brought closer together than recommended for temperate zone operation. The ignition timing should be retarded from the setting recommended for temperate zone operation.
	Condensers are adversely affected by the cold; excessive pitting of the points results.	The condensers should be replaced with those having lower capacitance.
	Moisture condenses and accumulates on spark plugs forming a coating of ice and causing short circuits.	Keep spark plugs clean and free of ice and moisture.
	At reduced voltages (basically due to the subzero temperature effect on battery) spark plugs set at normal gap setting do not give hot sparks, the normal setting being excessive.	Spark plugs of higher heat range, especially those with smaller electrodes, have better performance characteristics. Spark gap should be reduced.
	The metering characteristics of of some carburetors are seriously changed by low temperatures. This results from contraction of the various parts.	

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Diesel engines: tractors and towing vehicles	The primary problem in diesel engines is cold starting. Once an engine is started, the effects of cold are somewhat reduced.	Engines should be maintained in good mechanical condition. Proper heavy duty arctic lubricating oils must be used with low viscosity and fluidity characteristics. Since diesel engine bearing loads are usually higher than gasoline engines, lubricating oil should not be diluted to ease hard starting. Preheating of engine using externally applied heat will aid materially. At subzero temperatures starting fluids will assist cold starting appreciably. Diesel fuels must have a pour point sufficiently low to allow flow and prevent precipitation of waxes. Using a fuel of 80 octane, which is considered high in ignition qualities, starting can be accomplished only to 0°F. For this reason, starting aids are mandatory. Starting techniques should be known and practiced by operators.
Transmission and differential gearing	Transmissions and differentials are not equipped with devices (and in most cases are not accessible) for keeping them warm during operation. If the lubricant is not sufficiently fluid, gears will run dry. On Task Force Frigid, over 13 transmissions and 13 clutch failures occurred among 96 vehicles, mainly produced by stiff lubricants.	Only approved gear lubricants of low viscosity must be used. Protection is available to -65°F by using special grease prepared from light lubricating oils.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	Shifting of gears becomes progressively more difficult as temperatures decrease. It often is impossible to shift from neutral until the transmission has been heated due to internal friction or applied heat.	Automatic transmissions have operated satisfactorily in field tests.
	Starting motors frequently are fouled by oil dripping from other parts of the engine.	Proper maintenance should remove this difficulty.
	Hardening of the oil at extreme low temperature keeps the gears from meshing and also tends to keep them in mesh after the engine starts.	
Chassis	The formation of ice and snow on chassis parts has an adverse effect. Water vapor condenses within the warm mechanisms and forms ice particles.	Grease chassis frequently; 500 mi is a recommended interval.
	Open cockpits offer little protection for personnel from the elements in [illegible] winter and from insects in s[illegible]r.	Completely enclosed cabs should be used. They should be sufficiently wide to seat men in arctic clothing comfortably. They should have suitable heaters and means for frost removal from all windows, provisions for a quick emergency escape, and should be arranged or constructed to keep out exhaust gases.
Traction		
Wheeled: trucks and personnel carriers	Wheeled vehicles are of little use except on graded roads and fields. Deep soft snow limits their use even on graded roads.	Tracked vehicles are indispensable and should be used.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	Fork-lift type vehicles have difficulties in loading, unloading, and transporting equipment and supplies for comparatively short distances over snow covered ground.	
Tracks: tractors and towing vehicles	Mobility of heavy tracked vehicles is limited over arctic terrain.	Easily detachable aggressive grousers and ice cleats should be provided for use with heavy tracked vehicles.
	Track breakage accounts for a high percentage of operating costs of a weasel.	No practical method has been found to repair broken track; however, in the hands of careful and experienced drivers and proper maintenance, it is capable of dependable and continued service.
Trailers	The major problem involved in the operation of any type trailer is to provide a uniformly comfortable working temperature with the added complication of the requirement for mobility. Uniform temperature distribution is complicated by extreme temperature differentials between inside and outside, and the characteristic air stratification associated therewith. Floor-to-ceiling differentials as high as 60 deg F have been recorded.	Properly designed forced circulation and distribution systems, radiant heaters and adequate insulation will reduce air stratification to a minimum and insure comfortable conditions for personnel.
	The usual cold starting difficulties are associated with engine driven machinery in unheated trailers.	External sources of power can be provided for preheaters. Where this is not available, the self-contained combustion-type heaters must be provided.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Dollies	The primary difficulties involved in handling dollies are those associated with the ability of personnel wearing heavy arctic clothing to maneuver, hook them up, etc.	
Spare parts	Rubber tires, hoses, gaskets, belting and other nonmetallic parts harden, lose their elasticity and compressibility and become brittle at temperatures below -60°F.	Some of the relatively new polymers will insure resilience at much lower temperatures.
	Tire chains wear excessively and cause localized abrasion of the tire treads.	Army standard issue chains provide more tractive effort, are more durable, and cause less abrasion than other types.
	Metering characteristics of some carburetors are seriously changed by contraction of various parts at low temperature.	This can be compensated for by proper cold adjustment and readjusting at running heat.
Sleds	The problems involved are the same as previously discussed under trailers.	
	The principal problems concerning cargo carriers are breakage of runners, hitching-up assemblies, and upset incident to operation over rough terrain.	
Winterization kits	The major difficulty with winterization kits in general is the inadequacy of heaters, the fact that engine compartment blankets absorb moisture and subsequently freeze, thermostat controls become inoperative, window defrosters are inadequate and the combustion type heaters are a fire hazard.	

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Climatic and environmental control equipment		
Air heaters	The difficulties encountered with air heaters used in buildings and other shelters for housing personnel are covered under "Electric Power Generating Equipment." Heaters used for other purposes are covered under "Vehicles."	
Snow, frost, and ice control for parked aircraft	The major difficulty is the removal of ice from aircraft wing and tail surfaces.	The most universal means of removal is the application of external heat, preferably hot air.
Snow, frost, and ice removal	Chemical deicing fluids may be toxic or corrosive. Ice melting effectiveness decreases rapidly with reduced temperatures, but is still quite effective at -15°F and may not freeze down to -40°F.	Toxic, inflammable, and corrosive fluids are to be avoided. A solution of lithium chloride containing a wetting agent and a corrosion inhibitor is preferable
	Water alone may run down and refreeze. Steam may be deflected by wind or overheat metal surfaces.	If ambient temperatures are not too cold, water can be removed from pockets before freezing.
	Water and ice phobic materials are difficult and tedious to apply, are usually inflammable and injurious to human skin and eyes, and do not completely remove ice.	
	External heat application units may not be available, they also require large amounts of fuel or electric power.	

**TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)**

Materiel	Environmental effect	Remedy
Photographic equipment		
Cameras	Moisture will condense on all parts of cold equipment when suddenly exposed to warm air. If returned to cold air moisture will freeze and render the equipment useless.	Cameras intended for operation in extreme cold should be kept at that temperature and not be brought into heated shelters.
Mechanical mechanisms	Mechanical mechanisms become sluggish because some lubricants thicken under extreme cold.	Equipment should be winterized by lubricating with special low temperature oils or operated dry if conditions warrant.
	Cameras tend to bind and stick at low temperatures because of differential skrinkage.	Delicate mechanisms may need fine adjustments because of shrinkage and differential contraction.
	It is very difficult to make fine adjustments when wearing arctic mittens, or to load film magazines and thread film.	
Lens glass	Lens glass exposed to abrupt temperature changes may check or shatter.	Severe thermal shock must be avoided.
Projectors	Projector equipment is usually more permanently installed and much more apt to be adequately sheltered than cameras; however, all the difficulties encountered are the same, if exposed to low temperatures.	Adequate preventive maintenance and careful supervision can insure maximum reliable operation.
Film	Photographic film becomes stiff and brittle on exposure to low temperature, low humidity, or a combination of both.	Where it is not possible to keep the film warm, it is possible to minimize the difficulty by proper handling techniques.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	Covers for wings are too heavy, bulky, and difficult to handle, especially in a high wind, for use with large aircraft. Unheated covers will absorb moisture and upon refreezing will stick to wing surfaces. Heated covers require large amounts of electric power, especially in a high wind.	
Personnel gear	The face, hands, and feet are hard to protect during periods of high windchill or extreme temperature. Protective gear is bulky and may cause excessive perspiration. The mobility and working efficiency of the individual while outdoors may be reduced to 5 - 10 percent of his normal efficiency.	This situation is improving continually with the development of face masks, gloves, mittens, and foot gear.
Electrical systems; permanent and portable field lighting, floodlights, and components		
Portable lighting masts	Telescopic legs and their locks become frozen with ice and inoperative in low temperature areas.	Crowfoot masts are readily transported and set up. They resist high winds and low temperatures and eliminate telescopic members and the locking devices.
Electromagnetic relays	Electromagnetic relays become inoperative due to ice formation on conductive parts in low temperature areas.	Electromagnetic relays protected by hermetic seals prohibit the entrance of moisture to vital parts.

TABLE 4-12 (Continued).
DIFFICULTIES PRODUCED BY THE ARCTIC AND SUBARCTIC ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Batteries for floodlights on equipment	Use of batteries as the power source for flood lights in power equipment is unsatisfactory in the arctic.	Other power sources should be used.
Floodlights	Silver emulsion loses effectiveness at -40°F and peels at -65°F.	
Cable	Cable insulation at extreme low temperatures becomes stiff and difficult to work with and may crack.	The use of polyvinyl chloride compounds at extremely low temperatures offers no problem, provided they are not flexed sharply. Special low temperature compounds are available that flex at -76°F, but they are not flameproof nor oil and solvent resistant.

time only, and (4) ground generally unfrozen, wet, and muddy. The island of Adak, Alaska, was selected because its climate, offering the worst in cold-wet weather for a continuous period of from 4 to 5 mo, represents the extreme of this type with frequent and violent windstorms. The first test, a 10-day field maneuver, was held in December. During this maneuver, Task Force Williwaw moved into the field to prepare defensive positions and to determine the problems involved and the probable tactical efficiency of such positions in cold-wet climates.

In January, a second 10-day field maneuver was carried out. The tactical phase, climaxed by firing exercises, included marches of approximately 28 mi over mountainous terrain. During this test the weather was unusually cold—the ground was frozen for most of the time—so that mobility of some of the support vehicles was sufficient to provide supply capability. Tentage, clothing, weapons, and individual equipment were studied during the problem. Tests of other items included prefabricated trailer-mounted kitchens that were adapted especially for cold weather operations. Also, an experimental study was conducted to ascertain the relative effects of cold-wet conditions on the efficiencies of personnel.

The third field exercise was conducted for 10 days during February. Major problems studied during this period were methods of weapon and equipment portability, the determination of distance and time problems encountered during marches over the rugged terrain of Adak, the ever-present logistic problems, and a 48-hr foxhole exposure test designed to determine the limits of exposure for individuals in cold-wet climates.

The effects produced by the cold-wet climate and terrain encountered during Task Force Williwaw are detailed in the paragraphs that follow.

4-3.2.1 Motor Vehicles

Vehicular mobility was limited on the terrain of Adak Island. Inability to use wheeled or heavy, tracked vehicles affected all elements of both tactical and support operations. The terrain is covered with a thick mass of vegetation consisting of grasses, mosses, lichens, and other small plants. This vegetation is interwoven closely and varies in depth from a few inches to more than a foot. It provides excellent insulation and, even in below freezing temperatures, the ground beneath is seldom frozen. A peculiarity of this heavy mat is that few roots extend deeply into the ground. Consequently, no bond connects the vegetation and the muck beneath it. This vegetation has been described as being like "a rug on a muck floor". The black muck beneath the vegetation varies from 6 in. in depth on slopes to several feet on the flats. It has a jellylike consistency and shakes perceptibly over a large area when vehicles cross it. The moisture content of the ground is very high. Even on slopes, the water level is within a few inches of the surface. This terrain provides little support or traction for the passage of vehicles, and, once a vehicle breaks through the mat of vegetation, it becomes embedded. When this terrain freezes to a depth of 3 in. or more, it offers an adequate foundation for the passage of all but the heaviest wheeled and tracked vehicles. When the terrain is unfrozen (normal), all wheeled vehicles and all tracked vehicles having ground pressures of over 9 lb $in.^{-2}$ are road-bound for all practical purposes. For steep slope operation, the maximum ground pressure is 5 lb $in.^{-2}$. An illustration from another area of failure of tracked vehicles on soft terrain is shown in Fig. 4-7.

4-3.2.2 Subsistence Materiel

A brief discussion of subsistence items follows:

(1) *Rations and messing.* Weather and terrain had the greatest effect on messing procedures and ration supply. The extremes

(A) In soil

(B) In snow

Figure 4-7. Failure of Tracked Vehicles (Ref. 14)

encountered complicated many problems of supplying, feeding, and preparing rations—especially for frontline troops that could not be overcome by the equipment and methods normally used. Although fog and low ceiling conditions had no effect on feeding, the winds with velocities up to 110 mi hr^{-1} and the great amount of precipitation made the operation of all unsheltered stoves difficult and at times impossible. The problem of bringing food to the company area was primarily one of transportation and supply. At times man-packing was the only solution. Free-dropping and parachute dropping from aircraft were accomplished successfully several times but were not a reliable means of supply because of the frequent low ceilings and high winds. The number of days during the month when flying was possible was very limited. Other problems were encountered in field heating of individual rations. No heat tablets or stoves used were sufficient for heating of rations during the high winds encountered. Extreme temperatures were never a serious problem. Both low and high extremes encountered were no worse than in cold-temperate climates. Special problems were caused by extremes of wind and precipitation and the unusually soft and rugged terrain at Adak. Cooling of food by the high winds was a particular problem when warm or hot food was placed in metal containers such as the standard metal tray or in individual mess kits made of stainless steel or aluminum. Rapid cooling usually occurred since little shelter from the wind was available, with the result that most food was cold before it could be eaten.

(2) *Sleeping equipment and tents.* The mountain sleeping bag was used. It was sufficiently warm for all conditions encountered when adequate protection from ground moisture and from snow and rain was available. Some type of insulation under the sleeping bag was found to be a necessity. The bag was carried by the soldier but constituted the major bulk of the soldier's pack, making it cumbersome to carry. Protection from ground moisture was required at all times with a waterproof ground clothing of some type. The poncho was suitable for this purpose. After several consecutive nights of use, sleeping bags became damp as a result of perspiration, and it was necessary to dry them out. Tents and heaters were used but were not very satisfactory. A means of removing moisture from the bag rapidly under cold-wet conditions would be extremely useful. The sleeping bag could not be used in the open without some type of shelter since the strong winds blew snow and rain into the bag.

The floorless tents presented an important and difficult problem. The fibrous soil common on Adak retains water in a manner similar to that of a sponge. When a bed roll or sleeping bag is placed on the ground, the pressure of the individual in the bag forces the water out of the ground and causes the sleeping bag to become extremely wet. Makeshift floors, consisting of old canvas tarpaulins, ponchos, and boards, were used to correct this problem. Some type of floor appears necessary as a component part of all tents. The only tent tested with a floor was also extremely unsatisfactory because it did not have a means to let water drain out. As a result, occupants become just as wet as those individuals in a floorless tent.

All tents flap vigorously during winds, causing the coating to be whipped off plastic-coated tents. Constant flexing also caused all tent materials to become weather-beaten and badly worn after 2 or 3 weeks of use, permitting rain to penetrate through the tents and causing occupants and their equipment to become extremely wet. During medium winds ranging from 30 to 75 mph accompanied by rain or snow, wind blows the rain or snow through the material of all tents, many tents are ripped, center poles and ridge poles break, and moisture flows through the entrances and through the stovepipe exits. During winds of hurricane velocities, 75 to 110 mph, no tents tested were able to withstand the pressure exerted upon them, and all were destroyed.

Waterproofing of the tent and condensation within are closely related. One impervious tent was tested. Excessive condensation was always present inside the tent. All other tents were made of a permeable material and although condensation was not a problem moisture could penetrate. Shelter halves and the two-man, mountain tents were used. The shelter halves flap and jerk during high winds. In many cases, the pins are pulled out of the ground or the upright poles broken. After a short time in the field, the buttons, button holes, and rope loops tear out, decreasing the efficiency of the tent as a shelter. Rain and snow blow through the closure where the two shelter halves button together, causing the occupants and their equipment to become wet. The two-man mountain tent, a lightweight, one-piece tent with an integral floor, is plastic coated. During high winds, the plastic coating blew off the fabric, allowing rain and snow to enter the tent. Gusts of wind of a velocity of 25 mph or more exert pressure on the sides and ends of the tent and cause the poles to break. When the poles and pegs were rolled up with the tent, many small holes were punched in the material, causing the tent to leak. After a short time, water penetrates through holes of the flooring of the tent, causing the occupants and their equipment to become wet. Both shelters were unsatisfactory for use under cold-wet conditions.

Four types of tents were used for group sleeping: two American, a Japanese, and a Swedish. None were satisfactory under conditions encountered by the task force. It was nearly impossible to prevent moisture from entering through the door closures, stovepipe exits, or through the canvas itself. Construction of the tents was not strong enough to withstand high winds and the uninsulated stovepipe exits on many of the tents were fire hazards.

Three types of rigid shelters were used for group sleeping: the portable squad shelter, the 16 X 32 ft Jamesway shelter, and the 24 X 48 ft Jamesway shelter. Portable squad shelters consisted of units equipped with a plywood roof or an aluminum roof. They were completely unsatisfactory in winds over 35 mph. Roof panels blew out, canvas ends blew out, and in winds of over 75 mph the entire structure was destroyed.

(3) *Clothing.* Footgear was generally satisfactory; however, leather footgear leaks excessively. Shell leather gloves and field caps were generally satisfactory under calm conditions. Water-repellent outer garments are generally satisfactory under calm conditions with some slight leakage after prolonged exposure to rain. Under gale winds, 30 to 75 mph, the outer garments become wet unless covered by waterproof shells, but leakage through water-repellent and wind-resistant garments still occurs. Under conditions of hurricane winds, 75 to 100 mph (a rare condition), the feet become cold easily when clad with leather footgear if the soldier is not active. Shoe packs were generally satisfactory even under these conditions. Gloves were unsatisfactory below −25°F. All leather and leather-cloth combinations absorbed excessive moisture and created problems, and top garments, even those that are water-repellent and wind-resistant, provide inadequate protection from the cold and rain.

4-3.2.3 Support Operations

In support of the tactical exercises, a number of additional personnel were employed including medical, quartermaster, signal corps, and engineer personnel. The overall environmental impact on the ability of these support elements to perform their functions is discussed in the subparagraphs that follow:

(1) *Engineer.* Among the problems encountered by engineering forces were the poor bearing quality of the soil, poor drainage, and the high rate of precipitation. These conditions necessitated continuous maintenance of the road network in order for it to remain passable. The roads were important because engineer tractors with standard tracks, when used as prime movers for cross-country operations, readily cut through the tundra and became immobilized. Most materiel of any size and weight and all wheeled vehicles were confined to roads, and it was necessary to employ low ground pressure, track-laying vehicles for required cross-country transportation of personnel, equipment, or materials. Although proved satisfactory, the cargo capacity of the carriers was extremely limited and a great number of vehicle hours and trips were required. Another problem resulted from the barren nature of the terrain with its limited amount of natural resources. This required that all engineer materials, with the exception of aggregate, be supplied from an outside source, particularly timber, which was nonexistent in the area.

(2) *Signal.* The cold-wet climate provided very little hindrance to operation of radio equipment. Since most of the sets were mounted in vehicles, operators were provided with heated shelters in order to maintain efficiency. Maintenance and installation are also more difficult unless shelters are provided. Communication lines cannot be laid as rapidly in cold-wet areas as under more favorable conditions because the lineman's efficiency is reduced by the necessity of wearing gloves. Splicing and tying wire is difficult under these conditions, when maintaining the lines as well as when making initial installations. High winds necessitated

some protection for radio sets that were not waterproof and made overhead lines break or become shorted at the tiepoint. Track-laying vehicles capable of tundra passage were required for wire construction crews and passengers. Even in van-mounted equipment, the operator must wear gloves or suffer from cold and numb fingers. Efficiency of radio operators, switchboard and teletype operators, and linemen is reduced approximately 20 percent (unless heated shelters are provided).

(3) *Quartermaster.* Because wheeled vehicles cannot traverse the tundra, extensive road networks are necessary for normal operation of quartermaster units on tundra under cold-wet conditions with the equipment normally used by quartermaster units. However, if quartermaster units are required to operate in forward areas with no hard surface roads, full-tracked, low ground pressure cargo vehicles are required. Shelters are required for mobile installations such as bakery, laundry, and shower units. More than average amounts of dunnage are necessary to keep supplies and equipment above the tundra. Normal dunnage over pierced planking is satisfactory. Shelter from both high winds and precipitation is necessary for supplies and equipment in field dumps. Tarpaulins must be well secured because of unusually high winds. Artificial camouflage of dumps is necessary because of the lack of trees and bushes in most tundra areas. Additional personnel and supporting supplies are necessary because the difficulty of working in bulky clothing and the additional effort required from each man for his own personal welfare and comfort reduce efficiency an estimated 20 percent.

(4) *Ordnance maintenance.* Ordnance maintenance units are confronted with various problems–personnel efficiency is lowered; field maintenance requires shelter; ventilated work clothing is needed; and unpackaged supplies require protection from the elements. Rate of movement is influenced by snow depth and poor visibility during heavy rain, snow, or ground fog. Cold-wet conditions complicated by high winds and tundra such as encountered on Adak--posed further problems. Recovery, evacuation, and field maintenance is difficult because all wheeled and heavy tracked vehicles are roadbound. The performance of maintenance personnel was reduced significantly, particularly in winds in excess of 30 mph with accompanying rain, sleet, snow, or ground fog.

The maintenance tent on two occasions collapsed when the wind velocity reached approximately 75 mph. The presence of numerous lakes and streams in such areas makes waders or amphibious suits necessary for recovery operations of partially submerged materiel. Because of the difficulty of evacuating heavy materiel over unfrozen terrain, contact parties should be prepared to perform a maximum amount of "on-the-spot" maintenance when roads are inadequate.

(5) *Medical units.* Mud and the possibility of deep snow make the use of tracked vehicles a necessity for medical troops and equipment in this environment. The cold-wet conditions make rapid evacuation of the patient from the field essential because of the increased tendency of a wounded patient to go into shock when left exposed for any length of time. Without tracked vehicles, great difficulties were experienced in getting patients to the battalion aid stations. The limited amount of snow on the ground seldom permitted the use of a toboggan or skis in evacuation. It was usually necessary to hand-carry all patients. In one case during the December exercise, it required 20 men to carry one patient a distance of approximately 4 mi.

The patient must be kept warm and protected from the elements. Standard methods are satisfactory with regard to warmth but the mountain-type sleeping bag used to protect the patients was unsatisfactory in providing accessibility to the patient and roominess. For example, it was extremely difficult to place a patient with a leg splint into one of these sleeping bags. As with all other units, suitable temporary shelters from the high winds were not available.

4-3.2.4 Tactical Operations—Units

The effects of the cold-wet climate and the terrain of Adak on various elements of the tactical operation are given in the following subparagraphs:

(1) *Infantry*. Cold-wet conditions complicate life for infantrymen in the field. Because of the large amount of precipitation, waterproof clothing is a necessity. When wearing this waterproof clothing during strenuous work, ventilation is a major problem. Special waterproof footgear and handgear are needed but they greatly limit dexterity and add weight to the soldier's combat load. Keeping dry while sleeping is a problem and condensation present inside waterproof equipment adds to an individual's discomfort. The prevalent fog, rain, and snow limit visibility, which in turn reduces defensive sectors, slows movement slightly, limits reconnaissance, and hampers communications. The tundra and high winds encountered complicated the cold-wet problems immensely.

The most pressing complication was the effect on movement. The lack of suitable vehicles required the individual soldier to carry on his back all the necessities of life as well as his fighting equipment. Crew-serviced weapons are of excessive weight, and insufficient ammunition can be carried by presently authorized crews. Individual equipment, shelters, and sleeping gear are also too heavy and burden the individual until he is no longer an effective fighting man. When operations are carried out in mountainous terrain, movement is an even greater problem. In addition, resupply and communication are extremely difficult. High winds caused additional difficulties men become wet, cold, and more easily fatigued; supply and communications failed; and tents were destroyed or damaged. Digging is unsatisfactory since excavations only a few feet deep fill with water. No timber or brush is available, so all shelter must be carried by the troops. Rations are a major problem. Since mobile kitchens are road bound, troops cannot be fed hot kitchen-cooked meals but must carry operational rations and the means of heating them. These rations and cooking equipment, together with meat cans and eating tools contribute to the weight of the soldier's pack. Further, it is impossible to heat operational rations to a palatable temperature in winds over 30 mph.

Some of the problems encountered with weapons carried by infantrymen were:

(a) Wooden rifle stocks swelled when exposed to cold-wet conditions for short periods of time, causing operating parts to bind.

(b) Metal parts on all weapons rusted easily and necessitated constant maintenance.

(c) Driving snow and rain blew into the objective lens of telescopic sights on rifles; moisture collected on the lens and the firer could not see his target.

(d) Sight adjustments were difficult to make on all weapons whenever gunners were wearing mittens or gloves.

(e) The trigger guard of the carbine was too small to allow for satisfactory firing when the firer was wearing mittens or gloves.

(f) Some of the larger weapons were so heavy they could not be carried with normal complements of men.

(g) Some problems were encountered with mortar stability in the tundra terrain. Both 60 and 81 mm mortars settled improperly whenever fired on the soft tundra. They continued to sink into the ground and slide to the rear with each round fired. In some cases the mortars became inoperative after approximately three rounds because the mortar sank so deeply into the ground that the piece would not function. To stabilize the weapons, it was necessary to dig a hole, fill sandbags with the soil, place sandbags in the holes, place the baseplate on the sandbags, and then place additional sandbags on the baseplate. No problem was experienced when firing mortars on frozen tundra.

(h) White phosphorus projectiles were satisfactory except when winds were higher than 10 mph. When the wind was blowing at 10 mph or more, the smoke dispersed so rapidly that an effective cloud could not be established.

(i) Severe problems were experienced with optical equipment. Blowing rain and snow collect on objectives and lenses, limiting vision. No optical instruments functioned efficiently in the haze, fog, rain, and snow. Several instruments were found to have moisture between lenses after exposure to the elements (it was later discovered that these instruments were not sealed properly).

For infantry units under these conditions, movement is slower; defensive sectors are limited by poor visibility; movement has to be in a column of fives because of the rugged terrain; reconnaissance is difficult and slow; security is difficult because of limited visibility and rugged terrain; and supply is a major problem because few vehicles can traverse the terrain encountered.

(2) *Armor.* Armored crews experienced the same problems with bulky clothing and operation of knobs, screws, handtools, etc., as infantrymen. Mobility problems were similar to those experienced by other units, in that wheeled vehicles were limited to the road network. After periods of considerable precipitation followed by falling temperature, tank turrets freeze so that manual hydraulic traverse is impossible. Lubrication problems particularly with exposed weapons, gears, and the majority of unit assemblies were increased. Visibility is decreased to such an extent that rates of movement are retarded, observation of tank fire is limited, reconnaissance becomes a slower and more deliberate operation, and security of positions becomes important. Moisture entered the optical elements of telescopes and periscopes in the tank optical equipment. Impact fuzes were not sensitive enough in many cases for detonation on top of the tundra. The ignition systems of most wheeled vehicles became faulty after prolonged periods of exposure. Because of the problem of mobility, little opportunity was afforded for tactical use of tanks. When armored vehicles capable of tundra passage have been developed, the tactical doctrine may require modification to a slight degree; for example, the tundra may exclude column formations, and poor visibility and observation may exclude leap frogging or movement by bounds. Present armor techniques are affected adversely by the weather and the terrain—rates of movement are retarded; the time required to alert and move troops and equipment is prolonged; and reconnaissance is slower and more deliberate because of the limited observation, rugged terrain, and extreme weather conditions.

(3) *Field artillery.* Field artillery units experience the same difficulties with mobility on tundra as other large weapon systems including tanks and motor vehicles. In addition, the stability of weapons during firing and the effectiveness of impact projectiles was greatly impaired. Low visibility directly affected the observation required for field artillery purposes. Problems also were noted with clothing in field artillery units for operations in the cold-wet climate. The absence of trees makes the concealment of positions and installations difficult. Vehicle tracks on tundra do not disappear readily, and the marks made by a vehicle frequently remain visible for several months; hence, attempts to conceal tracks by camouflage will probably be less effective than attempts to confuse the enemy by making many tracks.

Significant difficulties were encountered with cross-country operations by the various artillery pieces. For example, the heavy artillery 155 mm gun was unsuited for cross-country operation. On wheels, the piece is immobile even on flat terrain. The wheels break through the mat of vegetation and act as blunt plows, soon immobilizing the prime mover. The gun can be towed across country on its wheels when the tundra is frozen to a depth of 3 in. or more. The piece can be kept above ground by the use of sleds. If sleds are not available, the gun can be moved across country on wheels for short distances on pierced steel planks or runways laid under the wheels. The planks can be laid and relaid again and again as the wheels clear them.

Self-propelled artillery pieces were not employed in these tests. However, these vehicles have performance similar to the M24 Light Tank, except that they are slightly heavier and have a correspondingly higher ground pressure. Consequently, their performance would be somewhat poorer than that of the tank. The light tank is unable to cross flat, unfrozen, soft tundra; however, it is able to cross flat, well-drained, firm tundra. When equipped with wide tracks, it is much more effective and can traverse some of the very soft alluvial areas. The mobility of a field artillery weapon is the major factor that determines whether or not it should be employed on tundra under cold-wet conditions.

Artillery can be fired on tundra but auxiliary flotation devices are generally necessary to support the piece. These devices must be issued because trees and other materiel generally are not found in this type of terrain. Ammunition fuzed to burst on impact is degraded seriously by the soft tundra which permits the projectile to penetrate the ground deeply before the fuze is activated.

4-3.2.5 Tactical Operations—Deployment

The tactical exercises formulated for each field period during Task Force Williwaw were infantry-related problems for two reasons: first, those factors that adversely affect the individual and, consequently the unit to the greatest extent normally are noticed more quickly in infantry units; and second, all motorized organizations of the task force virtually were immobilized because of the type of terrain prevalent in the area. The major effect on operations under the climatic and terrain conditions encountered was an increase in the time required in the performance of all tasks. This increase in time, a direct result of the effect of climatic and terrain conditions on the capabilities of the individual, was caused by three factors:

(1) A general loss of efficiency, directly attributable to the cold-wet climate, was evident.

(2) The rate of movement of foot elements with and without individual equipment over the type of terrain encountered was greatly reduced.

(3) The general lack of suitable vehicles capable of negotiating the tundra reduced the mobility of personnel, weapons, ammunition, and supplies.

Factors involved in conduct of the operations are described in the subparagraphs that follow. Limitations noted are applicable to company and battalion size units of all arms.

(1) *Movement.* The lack of cross-country mobility was caused by the terrain encountered. The rates of movement by the individual were limited mainly by the mat of vegetation that covered the greater part of the island. This vegetation normally presented no problem at elevations above 800 to 1000 ft, but at such elevations movement of the individual was still retarded by the ruggedness of the terrain (mountain slopes and corridors). Movement over the tundra by foot was further impeded by the icy conditions of the terrain, which were most prevalent during January and February.

Normally, all wheeled and heavy tracked vehicles were completely road-bound. The cargo carrier (M29-C) and the LVT were most suitable for cross-country operations. Rain, sleet, and snow—especially when accompanied by high winds—reduced all rates of movement during such periods. Hurricane winds (75 to 110 mph) proved to be an additional adverse factor, but such extreme high winds were rare and of short duration.

(2) *Reconnaissance* Ground reconnaissance was limited by the reduced rates of movement and the restricted visibility due to the prevalence of overcast skies and frequent precipitation.

(3) *Security*. The frequently restricted visibility, which limited observation, and the varying terrain contour emphasized the necessity for adequate security measures when in bivouac, in the defense, in movement, and in the offense. Limited observation and hearing during the frequent inclement weather periods increased the number of outposts required during defensive operations. These factors in conjunction with the rugged terrain necessitated a thorough reconnaissance of routes by advanced and flank guards during all movement.

(4) *Time required to alert and move troops*. The time required to alert and move troops was increased correspondingly by the general loss of efficiency when operating under cold-wet conditions. Since the terrain limits mobility under cold-wet conditions, the time required for the alerting and movement of a company or battalion during the day or night will be approximately double that normally expected under more favorable weather and terrain conditions. An increase will be evident when the terrain is not a limiting factor, but the overall increase will not exceed 50 percent of that normally required under milder climatic conditions.

(5) *The offense*. Terrain corridors provided a suitable avenue of approach during the attack by offering a degree of protection from hostile observation and provided protection from the weather, especially when high winds were prevalent. Terrain corridors further emphasized the importance of insuring that advancing troops must control the corridor. The creation of artificial corridors by the use of smoke was not attempted; however, such a use of smoke would have been limited due to the winds. Since the normal rate of movement was greatly reduced, movement in the approach march and attack problems was consequently reduced. Movement normally was canalized by the terrain which, in turn, limited the width of the offensive zones. When two platoons were used abreast on a frontage greater than 400 yd, control became a major problem even in squads. Armor could not be employed because of its general immobility on the tundra. During the conduct of all problems, the effect of the high winds with their destructive force often resulted in the loss of shelters and supplies. This loss and its harassing effect—which could easily be caused by an enemy—emphasize the importance of lines of communication as primary objectives for an offensive force. Pack artillery could probably negotiate the terrain. Towed light and medium artillery could probably support infantry on flat and rolling tundra; however, heavy artillery was unsuitable for movement on the terrain encountered. In the use of artillery, greater dispersement was indicated because of the lack of natural concealment. Poor visibility rendered observation undependable, resulting in the necessity for an observer party with every infantry company.

(6) *The defense*. The defensive sector was normally reduced by poor visibility which in any situation intensifies the problems of security. The general ineffectiveness in tundra or snow of ammunition used for detonation on impact would limit the effectiveness of such supporting weapons as artillery and mortar in the defense; effectiveness was estimated to be not more than 50 percent. It was impossible to utilize tanks as defensive armor because of their inability to negotiate the tundra. On the other hand, the defense likewise expected no use of tanks by

the enemy. Camouflage was difficult due to the lack of natural concealment, which necessitated a greater dispersal of installations and the use of camouflage clothing.

(7) *Ratio of combat, supporting, and service troops.* The ratio of combat, supporting, and service troops was the same as under milder climates except when the supporting units were immobilized and man-packing became necessary. In one instance, the proportion of service troops required to support the tactical plans (hauling the rations, ammunition, and evacuating casualties) of the infantry company was increased to an approximate ratio of two service individuals for each three infantrymen. In this problem, only 150 infantrymen participated, and 110 individuals were required to support the operation. The requirement for engineer troops to support the operations over tundra-type terrain is greatly increased. Construction and maintenance of roads and bridges is a continuous problem. A major operation over terrain similar to the tundra found on Adak should require a 100-percent increase in the engineering units. Since tracked vehicles are prerequisite, an increase in the normal authorization or the substitution of tracked vehicles for wheeled vehicles would present an added maintenance problem.

Table 4-13 shows the effect of windspeeds and soil types on the employment of infantry units in a cold-wet climate.

4-3.2.6 Tactical Operations—Personnel

In the December 10-day tactical exercise, the first 4 days were to be spent in a stationary position and the last 6 days in a tactical march. During the first 4 days, the infantry company of about 160 men dug in and set up a defensive position. Weather was moderate with temperatures near 32°F and winds at 15 to 30 mph with wet snow or freezing rain during most of the period. The men slept in two-man mountain tents. Due to the wet snow and rain, by the end of the fourth day many sleeping bags were wet. Attempts to dry them with wood fires and with gasoline tent heaters were only partially successful. The wet bags were the major factors contributing to personnel discomfort.

At the end of 4 days, the infantry company with attached medical personnel detrucked and marched 4 mi over frozen tundra and rocky, mountainous irregular terrain, carrying equipment averaging 75 lb in weight. Additional ammunition, supplies, and heavy weapons were lashed to toboggans. These loads ranged from 300 to 500 lb with six to eight men assigned to pull each toboggan. Aid station equipment weighing 400 lb was lashed to two toboggans, and eight men were assigned to pull each of these toboggans. The men carrying their equipment were able to walk 4 mi in about 4 hr. It soon became apparent that the toboggans were much more difficult to maneuver than anticipated. The rifle squads who reached the bivouac site descended the 1,000-ft mountain slopes of average 40 percent grade to assist the heavy weapon sections with the toboggans. It finally became necessary to abandon the toboggans. The men reached the bivouac site after making two trips over very difficult terrain and after struggling vainly to bring up the toboggans.

The men were too tired and cold to prepare warm drink and food. Some men ate cold canned rations while others ate or drank nothing. This overexertion caused in turn the low morale the next day. The men were tired, had no energy, and many had mild transient gastrointestinal disturbances including cramps, nausea and vomiting, presumably due to indigestibility of the cold rations in conjunction with overexertion. During the night, the windspeeds reached a steady 65 mph with 90 mph gusts. The temperature dropped to 19°F, accompanied by heavy driving snow. Nearly all two-man mountain tents were destroyed or damaged, leaving the men without shelter. Early the next morning, it was obvious the maneuver could not continue, and the order was given to return to the detrucking point. Since the first part of the march consisted of scaling a 500-ft, 50- to 60-deg slope head on against the still violent gale, many men abandoned their packs in order to surmount the obstacle. During the march of the previous day, one case of exhaustion that simulated abdominal disease occurred. This man was evacuated on a toboggan from which medical equipment was removed. Twenty men were required to pull the toboggan, and the rate of progress was about 0.5 mph. This took all the litter bearers over the same route twice in one day. Since they were not able to reach the bivouac site, they spent the night on the slope of the ridge. At this time another exhaustion patient had to be evacuated from the bivouac site and 40 men were pressed into service as a toboggan team. They required 6.5 hr to traverse the 4 mi and were exhausted when they reached the trucking point.

The most important phase of this problem from the medical standpoint was the tactical march. Many of the problems associated with the situation were primarily psychological in nature, resulting from lack of experience on the part of the men. The men became panicky in the storm and allowed their discomfort (there were no cases of permanent injury) to interfere with their sense of duty. They did not realize the importance of hot food and hot drink. Physical exertion beyond the limits of capability was demanded of them, and this drain on energy was without a doubt a major factor in the low morale level. Shelter or the lack of it was also a major psychological concern.

The psychological effect of the march in the December field exercise especially was notable when the reactions of the men in stationary positions were compared with those of the men participating in the cross-country march. Although shelters were destroyed and equipment was scattered by the storm, the men in locations where vehicles and roads were available showed only a minimum amount of emotional stress, and morale remained at a reasonable level. By comparison, the men who were in bivouac several miles from the road net in a snow-covered mountain area during the same storm became panicky. The factor of isolation appears to be the outstanding reason for the difference in emotional stability between the two groups. It was felt that more training and experience under similar conditions would tend to strengthen the emotional stability of groups of men in such situations. During the active phase of the January field exercise, the same type of terrain was covered under moderately severe weather conditions. Prolonged marches and overnight bivouac in isolated locations were made by infantry and medical personnel. The weather conditions encountered were not as severe as those on the march during December. Morale remained at a reasonably high level and no severe casualties occurred. In addition, the men seemed to be more confident as a result of the first-hand experiences obtained during the first march. The exertions for any one day were kept significantly under the level for the march in December.

Weather crises precipitated a strong tendency toward emotional instability and low morale, although, under more adverse conditions of terrain on long marches but with relative mild weather, no such effect was noted. Of the various weather factors involved, high winds produced the greatest effect on the individual. High winds produce a rapid loss of body heat out of all proportion to the temperature and relative humidity. Unless adequate protective covering is available to prevent this heat loss while insufficient body activity is taking place to replace it, the body temperature eventually will be lowered to a dangerous level. This factor must be taken into account particularly when considering the probable survival time of an unaided wounded man exposed to such weather conditions.

4-3.3 OPERATIONS IN THE ARCTIC CLIMATE

The arctic climate (generally the extreme

TABLE 4-13.

EFFECTS OF A COLD-WET CLIMATE ON THE EMPLOYMENT OF UNITS (SPECIFICALLY INFANTRY) OV

	Cold-wet condition; Characteristics 1. Average temperature between 20 and 40 F 2. High relative humidity, frequent precipitation 3. Usually overcast and foggy	
Meteorological condition	Organic soils (muskeg, tundra, swamps, bogs, usually muddy)	Fine grained soils (clay, silts, compactable, muddy during heavy rains,
Hurricane winds (75-100 mph) with rain, sleet, or snow. rare condition)	1. Movement. All movement extremely limited. Use of low-ground-pressure tracked vehicles imperative. Individual movement practically impossible. Acclimatization, morale, and accustomization training important. Timely warning orders necessary. 2. Reconnaissance. Extremely limited. Necessity for prior planning evident. 3. Security. Importance of stationary outposts emphasized. Adequate warning system highly important. 4. Offensive action. Extremely thorough training and physical hardening necessary. Control, identification, and coordination with supports emphasized. Zones limited as indicated for gale winds. 5. Defensive action. Extremely limited; organization of firepower and outposts is necessary. Ineffectiveness of HE ammunition fuzed for detonation on impact limits capabilities of artillery and mortars. Zones same as for gale winds. 6. Supports. Requirements for engineers doubled by terrain conditions. Ordnance maintenance proportionately increased by larger number of tracked vehicles required. 7. Individual requirements. Warming and drying facilities absolutely necessary. Frequent hot food and drink important. Individual maintenance responsibility stressed. Adequate water-resistant clothing and sleeping equipment highly important.	1. Movement. All movement extremely limited by weather. tracked vehicles normal; wheel vehicles limited. Individual movement precluded by weather. Acclimatization, morale, and acc tion training important. Timely warning orders necessary. 2. Reconnaissance. Extremely limited mainly by weather. planning necessary. 3. Security. Importance of stationary outposts emphasized. quate warning system should be stressed. 4. Offensive action. Extremely limited by weather; thorou ing and physical hardening necessary. Control most importa Greater use of vehicles to attain mobility required. Zones as indicated for gale winds. 5. Defensive action. Sectors limited mainly by poor obse Attention to outposts, coordination of fires, and antimecha measures (warning system) emphasized. Zones same as for ga 6. Supports. Use of armor should be stressed. Ordnance m requirements increased with use of armor and other tracked v 7. Individual requirements. Warming and drying facilities hot food and drink, adequate water-resistant clothing, and equipment are most obvious requirements.
Gale winds (30-75 mph) with rain, sleet, or snow. (occasional condition)	1. Movement. Limited but entirely possible. Low-ground-pressure tracked vehicles necessary. Time required to alert and move troops almost double than under most favorable conditions. Thorough training very important. Timely warning orders necessary. 2. Reconnaissance. Ground reconnaissance restricted by poor visibility and terrain. Utilize air reconnaissance when practicable. 3. Security. Larger number of security outposts and patrols necessary. Need for warning systems is evidenced by limited observation and hearing. 4. Offensive action. Ideal for offensive to obtain surprise. Physical conditioning, control, identification among attacking members, depth in reserved and defined boundaries important. Zones should not be over 300 and 600 yd for Cos and Bns, respectively. 5. Defensive action. Sectors limited as for offensive action; warning systems important; organization of firepower and coordination with reserves important. Ineffectiveness of HE ammunition fuzed for detonation on impact limits artillery and mortars. 6. Support. Normal proportion of engineers increased 100 %. Greater requirements for tracked vehicles proportionately increased requirement for additional ordnance maintenance units. Supporting armor should be exploited. 7. Individual requirements. Warming and drying facilities for change of clothing necessary. Frequent hot food and drink important. Adequate sleeping equipment and water-resistant clothing required.	1. Movement. Limited under extremely muddy conditions. T quired to alert and move troops almost double that under th favorable conditions. Thorough training important. Timely orders important. 2. Reconnaissance. Ground reconnaissance restricted mainl visibility. Utilize air reconnaissance whenever practicabl 3. Security. Large number of security outposts and patrol Need for adequate antimechanized warning system is evidence limited observation and hearing. 4. Offensive action. Control, identification, and defined aries are important. Zones should not be over 300 and 600 Cos and Bns, respectively. 5. Defensive action. Sectors limited as in offense. Anti mechanized warning system highly important. 6. Supports. Armor and supporting aviation should be give consideration. Requirements for ordnance maintenance units tionately increased with use of armor and other tracked veh 7. Individual requirements. Warming and drying facilities necessary. Frequent hot food and drink important. Water-resistant clothing is a requirement.
Calm conditions and wind up to 30 mph with rain, sleet, or snow. (frequent condition)	1. Movement. All rates of movement reduced mainly by terrain. Low-ground-pressure tracked vehicles necessary. Time to alert and move troops 50 % higher than under most favorable conditions. 2. Reconnaissance. Ground reconnaissance feasible, but slow. Use air reconnaissance. 3. Security. Generally normal. Limited observation and hearing will emphasize need for warning system. 4. Offensive action. Control and coordination with supports emphasized. Use of airborne troops feasible. Zones limited occasionally but 500 and 1,000 yd feasible for Cos and Bns, respectively. 5. Defensive action. Sectors occasionally limited by restricted observation. Zones same as in offense. 6. Supports. Increased engineer requirements most important. Supplement ordnance maintenance units proportionately with increase in number of tracked vehicles. 7. Individual requirements. Warming and drying facilities most important. Stress lighter individual loads under all conditions.	1. Movement. Normal, except that weather will increase t alert and move troops at least 50 % than under most favora weather conditions. 2. Reconnaissance. Normal, except during periods of preci Exploit air reconnaissance. 3. Security. Generally normal. Limited observation and h will emphasize need for warning systems. 4. Offensive action. Generally normal except that zones w limited by lack of observation but 500 and 1,000 yd feasibl Cos and Bns, respectively. 5. Defense action. Sectors limited as in offense. 6. Supports. Maintenance requirements increased by use of and larger number of tracked vehicles. Increase ordnance m units to meet this need. 7. Individual requirements. Warming and drying facilities important. Stress lighter loads under all conditions.

TABLE 4-13.

DYMENT OF UNITS (SPECIFICALLY INFANTRY) OVER VARIOUS TERRAIN (SOIL) CONDITIONS (Ref. 12)

Cold-wet condition;

Characteristics
1. Average temperature between 20 and 4[illegible]
2. High relative humidity, frequent precipitation
3. Usually overcast and foggy

Fine grained soils (clay, silt, compactable, muddy during heavy rains)	Coarse grained soils (gravel, sand incompactable, seldom muddy)
1. Movement. All movement extremely limited by weather. Use of tracked vehicles normal; wheel vehicles limited. Individual movement precluded by weather. Acclimatization, morale, and accustomization training important. Timely warning orders necessary. 2. Reconnaissance. Extremely limited mainly by weather. Prior planning necessary. 3. Security. Importance of stationary outposts emphasized. Adequate warning system should be stressed. 4. Offensive action. Extremely limited by weather; thorough training and physical hardening necessary. Control most important. Greater use of vehicles to attain mobility required. Zones limited as indicated for gale winds. 5. Defensive action. Sectors limited mainly by poor observation. Attention to outposts, coordination of fires, and antimechanized measures (warning system) emphasized. Zones same as for offense. 6. Supports. Use of armor should be stressed. Ordnance maintenance requirements increased with use of armor and other tracked vehicles. 7. Individual requirements. Warming and drying facilities, frequent hot food and drink, adequate water-resistant clothing, and sleeping equipment are most obvious requirements.	1. Movement. All movement limited mainly by weather and when operation is over mountainous terrain. Individual movement restricted by weather. Thorough training highly important. Timely warning orders necessary. 2. Reconnaissance. Extremely limited by weather. Prior planning a necessity. 3. Security. Importance of stationary outposts emphasized. Warning system should be stressed. 4. Offensive action. Limited mainly by weather. Zones limited as indicated for gale winds. Use of vehicles necessary but difficult in mountainous terrain. 5. Defensive action. Sectors limited mainly by weather as in offense. Antimechanized defense necessary. 6. Supports. Use of armor should be stressed. Engineer requirements increased when operating over mountainous terrain. Pack animals should be considered. 7. Individual requirements. Warming and drying facilities, frequent hot food and drink, adequate water-resistant clothing, and sleeping equipment are most obvious requirements.
1. Movement. Limited under extremely muddy conditions. Time required to alert and move troops almost double that under the most favorable conditions. Thorough training important. Timely warning orders important. 2. Reconnaissance. Ground reconnaissance restricted mainly by poor visibility. Utilize air reconnaissance whenever practicable. 3. Security. Large number of security outposts and patrols necessary. Need for adequate antimechanized warning system is evidenced by limited observation and hearing. 4. Offensive action. Control, identification, and defined boundaries are important. Zones should not be over 300 and 600 yd for Cos and Bns, respectively. 5. Defensive action. Sectors limited as in offense. Antimechanized warning system highly important. 6. Supports. Armor and supporting aviation should be given every consideration. Requirements for ordnance maintenance units proportionately increased with use of armor and other tracked vehicles. 7. Individual requirements. Warming and drying facilities necessary. Frequent hot food and drink important. Water-resistant clothing is a requirement.	1. Movement. Limited, except when operating over mountainous terrain. Time required to alert and move troops almost double than under the most favorable conditions. Thorough training necessary. 2. Reconnaissance. Limited mainly by restricted visibility. Utilize air reconnaissance. 3. Security. Limited observations and hearing require increase in outposts and patrols. 4. Offensive action. Control, identification, and defined boundaries are important. Zones should not be over 300 and 600 yd for Cos and Bns, respectively. 5. Defensive action. Sectors limited as in offense. 6. Supports. Supporting aviation and armor important. Engineer requirements doubled when operating over mountainous terrain. Pack animals should be considered. 7. Individual requirements. Warming and drying facilities necessary. Frequent hot food and drink important. Water-resistant clothing and sleeping equipment required.
1. Movement. Normal, except that weather will increase time to alert and move troops at least 50 % than under most favorable weather conditions. 2. Reconnaissance. Normal, except during periods of precipitation. Exploit air reconnaissance. 3. Security. Generally normal. Limited observation and hearing will emphasize need for warning systems. 4. Offensive action. Generally normal except that zones will be limited by lack of observation but 500 and 1,000 yd feasible for Cos and Bns, respectively. 5. Defense action. Sectors limited as in offense. 6. Supports. Maintenance requirements increased by use of armor and larger number of tracked vehicles. Increase ordnance maintenance units to meet this need. 7. Individual requirements. Warming and drying facilities most important. Stress lighter loads under all conditions.	1. Movement. Normal, except weather increases time to alert and move troops at least 50 % more than under most favorable conditions and in mountainous terrain may limit rates of movement. 2. Reconnaissance. Generally normal, except weather restricts visibility. Exploit air reconnaissance. 3. Security. Generally normal, limited observation and hearing will emphasize need for warning system. 4. Offensive action. Zones of 500 and 1,000 yd feasible for Cos and Bns, respectively; occasionally limited by restricted visibility. 5. Defensive action. Sectors same as in offense; otherwise normal. 6. Supports. Practically normal. Ordnance maintenance units should be increased proportionately with increase in number of tracked vehicles. 100 % increase in engineers when operating over mountainous terrain. 7. Individual requirements. Warming and drying facilities should be furnished. Stress lighter individual loads under all conditions.

cold climatic category of AR 70-38) is differentiated from others by the occurrence of extreme low temperatures, which present different challenges to materiel performance than those of the cold-wet climate (Ref. 10). Much of the knowledge of these effects is derived from Army arctic operations but additional valuable experience has been gained in the nonmilitary experience in Antarctica.

Prime effects are on vehicles, weapons, and aircraft as discussed in the subparagraphs that follow.

4-3.3.1 Vehicular Operations

Many tests of vehicles and their engines have been conducted by the military in arctic and subarctic regions. The results of some of these tests are described briefly in this subparagraph to indicate the problems with vehicle operation in the arctic climate.

A number of transport vehicles including a special-purpose, 2-1/2-ton truck (T23); and standard 1-1/4-ton, 3/4-ton, 2-1/2-ton, and 5-ton vehicles; as well as a snow tractor (T121) were tested on unfrozen muskeg during the arctic summer (Ref. 15). None of the wheeled vehicles was able to traverse muskeg areas. The snow tractor was capable of transversing the summer muskeg in excess of the rated payload but presented some steering and suspension problems. Off-road operation of wheeled vehicles in unfrozen muskeg has not been proved feasible. In many cases the heavier tracked vehicles with high track loadings are marginal in these circumstances. Another environmental problem associated with vehicular operations is the load-bearing capacity of ice. This is given in Table 4-14 for ice on fresh water which is stronger than salt-water ice.

Ordnance materiel was tested under extreme winter conditions at Big Delta, Alaska, and Ft. Churchill, Canada (Ref. 16). The M47 Tank required modification to eliminate a serious carburetor-icing condition. Extended idling, minor carburetor maladjustments, and improper firing, which are relatively unimportant during temperate climate operations, become important because they contribute to crankcase oil dilution in cold climates. Another problem encountered with tanks involved fire control equipment fogging and defrosting of optical devices such as periscopes and telescopes. Operation of the tank turret was compromised as a result of general sluggishness in the power-traverse response. Increased weapon elevation and wheel efforts experienced with decreasing ambient temperatures, although the units had been serviced with proper hydraulic oils, indicated unsatisfactory performance at much lower temperatures. In addition, the normally anticipated traction difficulties on hard-packed ice and snow were encountered.

Testing of wheeled vehicles indicated that in general they would operate successfully in snow no deeper than the vehicle ground clearance and were very limited in slope operation. The automatic transmissions employed were satisfactory except that in the 2-1/2-ton truck (M135) the hydramatic transmission had a severe downshift from second to first gear, which caused skidding on ice. Cold starting was satisfactory down to -40°F. Icing of the fuel systems of the M37 and M41 Trucks was encountered below -20°F, and alcohol had to be added to prevent freezing. In most vehicles tested, the heat distribution systems were poor, resulting in excessive heat at some spots within the cab and cold spots in other areas. An antifog compound was tested on the windshields but was not found to be satisfactory in these climates.

In tests at Ft. Churchill, Canada, an amphibious cargo carrier (T46) was tested during ambient temperatures between -20° and -30°F. The only major problem encountered was in the track design, which required modification to provide better traction in snow.

In field tests at Ft. Greely, Alaska, a 2-1/2-ton truck (M34) was tested. The major

TABLE 4-14.
LOAD-BEARING CAPACITY OF FRESH-WATER ICE (Ref. 17)

	Min. ice thickness, in.	Min. distance between units, ft	m
Man	2	15	5
Vehicles			
1/4-ton truck	8	50	15
3/4-ton truck	10	65	20
2-1/2-ton truck	16	80	25
5-ton truck	22	200	60
5-ton tractor w/loaded trailer	36	260	75
M561 cargo carrier	10	65	20
M8A2 tractor	26	230	70
M41A1 tank	26	200	60
M48A2 tank	32	230	70
M60 tank	32	230	70
M108 howitzer, SP, 105 mm	20	130	40
M88 tank recovery vehicle	34	230	70
M109 howitzer, SP, 155 mm	20	130	40
M110 howitzer, SP, 8 mm	22	165	50
M113 APC	18	80	25
M114 armored carrier	16	65	20
M116 cargo carrier	14	50	15
M578 recovery vehicle	26	200	60
Tractor, D7, std.	20	130	40
Tractor, D8, std.	24	165	50
Crane, 20 ton	24	230	70
Grader	16	165	50
M-6 transporter, rolling liquid	10	NA	
Aircraft			
O-1A, E	8	30	10
OV-1A, B, C,	18	65	20
U-1A	10	65	20
U-6A	10	50	15
U-8D, F	10	65	20
CV-2A	20	180	55
CV-7A	20	200	60
OH-13H	8	30	10
OH-23D	8	30	10
UH-1A, B, D,	10	65	20
UH-19D	12	65	20
CH-21C	14	80	25
CH-34C	13	80	25
CH-37B	20	200	60
CH-47A	20	200	60

deficiency noted was the failure of the transmission on two occasions. The battery heating pads failed after approximately 200 mi of operation. Front spring seats broke twice. The sparkplugs became fouled, and the ignition points failed on all three vehicles tested. The clutch lever of the winch broke off twice during temperatures below 0°F. The safety catch proved unsatisfactory in that it was necessary for the operator to remove his arctic mittens to release it. Operation of the heaters was generally satisfactory, but, at temperatures below -30°F, personnel found the cab uncomfortable. Numerous air leaks were noted around the cab during operation above 25 mph. The rubber around doors and windows came out continually.

Low ground pressure tracked vehicles employed for oversnow transport are shown in Fig. 4-8.

The T41E1 Tank also was tested at Ft. Greely. Six hundred mi of cross-country and highway operations under simulated field conditions were completed on one vehicle and 240 mi on the other. Numerous problems were present at the beginning of the test season and continued throughout the winter. Overall operation of these vehicles under the extremes of the Arctic was unsatisfactory. Excessive oil dilution and low engine operating temperatures were experienced during the entire season. At no time was it possible to operate the vehicle at proper engine temperatures. Continual troubles were experienced with carburetor adjustment. This had a tendency to make the vehicle always operate at about 50 percent performance. Difficulty was experienced in starting the auxiliary generator below -20°F. At -55°F it failed to start under any conditions. Materials used in the construction of gunner's and operator's controls had a tendency to stick to the men's hands when gloves were removed to make fine adjustments. The canvas-type grille covers were unsatisfactory in that they required constant attention and eventually would come loose, start flapping, and blow off the vehicle. Fenders and sand shield were completely torn loose and bent after the first 100 mi of cross-country operation. Deposits of broken limbs, pine needles, etc., would lodge around the muffler guard plates and cause fires to break out in that location after continued operation. Failures common

Figure 4-8. Low Ground Pressure Tracked Vehicles for Oversnow Transport (Photograph by R. W. Gerdel)

to tests in temperate climates were also common in the Arctic, such as failing shock absorbers, suspension components, and electrical relay instruments. It was noticed that at −55°F it took 5 min to elevate the weapon to its maximum elevation from the traveling position and required 2 min of effort to rotate the turret 90 deg.

The general durability and performance of 2-1/2-ton cargo trucks (M35 and M211), 5-ton cargo truck (M54), and the ambulance (M43) were evaluated under arctic conditions during Operation Flin Flon (Ref. 18). All trucks were appropriately winterized according to established procedures. Unsatisfactory components included the transmissions on all vehicles, the M43 differential, fanbelts on the M35 and M54, tire tubes, and winches. Although lubricated with arctic lubricants, all of the transmissions except that for the M43 Truck had extremely short life. The failures appeared to be the result of improper lubrication. The M43 Truck experienced severe difficulties in starting in extremely low temperatures. Starts below −10°F ambient were generally unreliable although starts were made at temperatures as low as −24°F, but only with considerable difficulty. On the M54 vehicle, recurrent failure of the radiator inlet neck was experienced. This was attributed to the stiffness of the hose and the general geometry of the installation. No doubt the cold temperatures contributed to the hose stiffness so that this failure is more likely to show up in extremely cold environments than in temperate or hot environments.

Engines were removed from a tracked infantry vehicle (T95) and inspected for wear and damage after 2,020 mi of endurance operation under arctic conditions using arctic-type fuels and lubricants (Ref. 19). Of the total 2,020 mi, 197 mi were on gravel or prepared surfaces and 1,823 mi were over the cross-country course and neighboring areas. The cross-country course consisted primarily of frozen, snow-covered muskeg, some deep snow, and occasional patches of smooth ice. Approximately 50 mi in neighboring areas were made up of snow drifts, deep level snow, heavily wooded areas, and slopes. The total number of engine hours accumulated was 148.4 on the left engine and 141.4 on the right engine. Both engine air cleaners were operated dry after it was found that they become clogged with a sludgy mixture of snow and oil within a few hours of operation. Blown snow cannot be prevented from entering the engine compartments while the vehicle is in operation.

The T95 Engines were rated as lacking in endurance characteristics as a result of excessive wear of internal components. This included:

(1) Severe ring wear

(2) Piston and cylinder wall scuffing

(3) Excessive fatigue damage to bearing inserts

(4) Excessive valve burning and leakage, attributed to excessive valve stem-to-guide clearances.

Wear of the engines resulted from inadequate lubrication, no doubt influenced directly by the high viscosity and poor distribution of the oil and by the amount of antiscuff agent in the oil. The arctic oils used provided inadequate lubrication on this particular engine.

A 90 mm gun tank (M47) was operated for a total of 1,071 mi, approximately 60 mi on prepared surfaces and 1,011 mi over the cross-country course and neighboring areas at Ft. Greely. The engine was removed and inspected. Basically, this engine performed very well. Sludge had accumulated in the crankcase, which indicated considerable low temperature operation. It coated the connecting rods, crankshaft, and rocker arms.

In addition to difficult starting of internal combustion engines in the arctic environment, crankcase oil dilution is a serious problem contributing to frequent engine failure. A study of the effect of winter operation in Alaska on crankcase oil dilution confirmed that significant crankcase oil dilution occurs as a result of water and gasoline accumulation in the crankcase oil (Ref. 19). One of the factors believed to affect the overall dilution level is the exposure to low temperatures. In these tests, as anticipated, oil dilution resulting from water condensation in the crankcase was greater for those vehicles parked outside. The type of operation also affected the oil dilution level. The vehicles that were used in short-run, light-load service had significantly more crankcase oil dilution than vehicles operated for sufficient lengths of time for the engine to heat up to normal operating temperatures. Water dilution varied from essentially zero to as much as 5 percent; however, it was less than 1 percent for the majority of vehicles. Fuel dilution was significantly higher, varying from less than 1 percent up to as high as 58 percent. The 58-percent dilution was an anomalous figure. Most of the fuel dilution values were less than 2 percent for vehicles stored indoors, while for outdoor storage, fuel dilution was less than 5 percent.

Dilution was caused by (1) failure of engine components, which usually resulted in extremely high fuel dilution, (2) excessive fuel accumulation during cold starts (especially when difficulties were experienced in starting the engine), (3) overnight soaking (mainly water), and (4) operating at very low engine temperatures, (idling and short-run, light-load operation).

4-3.3.2 Effects on Weapons

The arctic environment causes more difficulty in the operational employment of weapons, both individual and crew-served, than the other extreme environments. The inability of infantry soldiers to man-pack even the smaller crew-served weapons, along with an adequate supply of ammunition, plus the general problems of vehicular mobility caused by the arctic environment, cause great difficulty. Crew-served weapons with heavy recoil and/or weight are limited seriously in operational use on muskeg and other similar soft terrain during the arctic summer. Heavy snow cover causes erratic behavior of impact-fuzed high explosive artillery and mortar rounds as well as rendering conventional mines ineffective in many cases. Finally, the extreme cold of the arctic winter has contributed to mechanical failure of a variety of weapons as a result of metal embrittlement.

Examples of problems encountered in the operational use of weapons in the arctic are described in the subparagraphs that follow. These examples are taken from a number of extensive field exercises conducted by the military in arctic-type environments.

A number of weapons have been tested—the 105 mm mortar, the 4.2 in. mortar, 75 mm recoilless rifle, and a cal .30 machine-gun—during arctic summer (Ref. 20). These tests were made in unfrozen muskeg without using sandbags. Although all weapons operated satisfactorily, the mortar bases were extremely difficult to extract from the muskeg into which they were driven by recoil.

In arms and ammunition tests, a 4-1/2 in. rocket launcher (T123) was fired from frozen muskeg (Ref. 8). The spade and trail stakes bent when attempts were made to drive them into the frozen muskeg. However, during three firings of 25 rounds, each without the trail or wheel stakes, the launcher was stable. During the firing, ignition delays up to 3 s were noted. Prior to arctic test, the launcher had satisfactorily functioned in a cold chamber at −65°F; however, in the outdoor tests the handwheel effort of the traversing mechanism of the launcher increased tremendously, from a normal 7-lb effort to an effort estimated to be over 100 lb, although the outdoor temperature was well above the temperature of the cold chamber.

To emplace an 81 mm mortar (M29) on the frozen muskeg, it was necessary to use dynamite to make a hole, but this practice allowed the weapon to be emplaced in 5 to 10 min. On three different occasions, a weld that holds a ring on the titanium base plate broke and the base plate ultimately fractured. Loss of projectile fins caused mishaps and erratic flights.

In other tests the employment and use of the 4.2 in. mortar (M30) with mount (M24) was investigated. Of the three mortars tested, the bridge shattered on two units, the base plate failed on one, and the upper support column failed on one. At no time was it possible to properly seat the mortar for what is considered to be satisfactory firing. Numerous methods and devices were attempted, but they were time consuming and unsatisfactory. The 60 mm and the 81 mm mortar also had similar characteristics plus limited fragmentation patterns. On some types of fragmenting projectiles, fuze action was unsatisfactory at temperatures below +20°F; at −25°F, 100-percent failure occurred. It was concluded at the time of these tests that mortars in their present form were unsatisfactory for use or employment in the Arctic during the extremes of winter.

The 4.5 in. rocket launcher (T123) functioned properly, but large dispersion patterns up to a 1,000 yd in width were noted, and the launcher had a tendency to blow a large cavity under itself when fired in deep snow. This, in turn, caused the launcher to settle into this hole. As a result, it had to be moved after several firings.

The difficulty of operating the trigger of conventional rifles and related small arms is of great importance. Some means is needed to permit the infantryman to fire small arms and rifles without removing the arctic mittens. The trigger-finger glove principle has not proved satisfactory.

The following additional problems associated with weapon employment in the Arctic have been observed. The range of mortar projectiles exposed to low temperatures is decreased by as much as 15 percent below firing table ranges due to slow, irregular, or partial burning of propellants, and increased air density. Low temperatures cause problems with spotter systems. Mismatch occurs between major and minor caliber systems because of different propellant temperature coefficients. A system is generally reliable only at the temperature for which the system is "fired in". The same situation exists in the alignment and sighting of tank and artillery weapons. Alignment is valid only for the particular temperature at which the alignment was made. Changes in temperature require realignment of the weapon. The U S Army Arctic Test Center reports that 1,500-yd corrections required as a result of weather changes were experienced several times with the 105 mm howitzer (Ref. 20).

The changing nature of snow affects the performance of mines and fragmenting munitions. The spatial distribution of fragments from high-explosive (HE) loaded projectiles is greatly reduced when detonated under snow. Test results indicate a smothering factor as high as 80 percent when they are detonated under less than 6 in. of snow. This effect is noted with point-detonating (PD) fuzed mortar projectiles, hand grenades, antipersonnel mines, and most other PD-fuzed HE projectiles. Snow has a blanketing effect on fragmenting munitions, and its softness interferes with the performance of certain types of mines. In tests performed in Alaska, antipersonnel mines that functioned properly when planted on hard ground and hard packed snow were unreliable in deep snow. When an attempt was made to actuate the mine in deep snow, it was merely pushed farther into the snow. Sufficient resistance could not be developed in deep snow to generate the force necessary to make the mine function. Trip-wire devices failed because blowing snow packed hard into the actuator cavity, thus preventing the trip rod from moving.

Weapon performance has also been evaluated on the Greenland Ice Cap. Terrain consisted of 200 ft of snow on top of 7,000 ft of ice, producing a flat, wide-open surface containing no vegetation. No way could be found to emplace the 81 mm mortar. Despite heavy sandbagging, shifting occurred and the weapon could not be made stable. Twenty-four rounds of HE ammunition with a PD fuze were fired, and 21 failed to detonate on impact because the resistance developed by the snow was insufficient to cause the fuze to function on impact with the surface.

White phosphorus rounds detonated but only after penetrating the snow to an indeterminate depth that smothered their effects Because of the flatness of the Greenland terrain, flat trajectory rounds fired by the 106 mm recoilless weapon would not explode unless a direct hit was made on the target. The round bounced and tumbled when striking the surface without exploding. Neither tracer rounds used with the 106 mm recoilless weapon nor the puff of smoke usually seen on hitting a target could be observed because of optical conditions caused by light reflectance and diffusion from the ice cap. Results from firing the 3.5 in. rocket were the same as for the recoilless round. Range estimation was extremely difficult because of the optical conditions.

4-3.3.3 Effects on Aircraft Operations

Aircraft operations in arctic environments, involving supply, close support, and artillery fire observation, frequently are hampered or completely stopped because of poor visibility. Poor visibility is the major restriction on air operations in the cold regions. An example of obscuration by blowing snow is shown in Fig. 4-9. Other effects include difficult starting of engines, icing impairment of vital components, icing in fuel systems, clogging of critical areas with blown snow, and the necessity for airport snow removal. Examples of impairment of aircraft operation from these causes as observed in field exercises are discussed in the paragraphs that follow.

An aviation support operation for topographic mapping in Antarctica by the U S Geological Survey and the National Science Foundation during Operation Deep Freeze employed HU-1B Iroquois helicopters (Ref. 21). Several problems were encountered with the helicopters as a result of the adverse environment. One involved a control failure that nearly resulted in the loss of an aircraft and its crew. The aircraft was operating at an altitude of 10,000 ft (temperature −20°C) executing a right turn. A rolling motion to the right followed by an increasing nose-low attitude was noted by the pilot. Unable to move the control stick rearward, he turned off the hydraulic power. The craft was brought under partial control, and the hydraulic power turned on again. Immediately, the aircraft started rolling to the right as before. Hydraulic power was then turned off for the remainder of the flight. A landing was effected, and investigation revealed that an accumulation of ice had blocked a relief vent in the hydraulic control system. Once the vent had been cleaned and the system purged, the hydraulic system functioned normally. This incident illustrates a typical problem resulting from thawing and freezing of water.

Another problem involved a skid-type landing gear that provided insufficient flotation on soft snow, thus allowing the aircraft to settle so that the underside of the fuselage contacted the snow surface. Consequently, the possibility of damage to the structure and attached electronic equipment exists. Because the greater percentage of the aircraft weight is concentrated on the aft skids, the tail boom contacts the ground surface first as the aft skids settle through the snow crust.

Problems also were noted with engine starting at high altitudes. This indirectly caused failure of one engine. During attempts to start at progressively higher elevations, tailpipe temperatures became in-

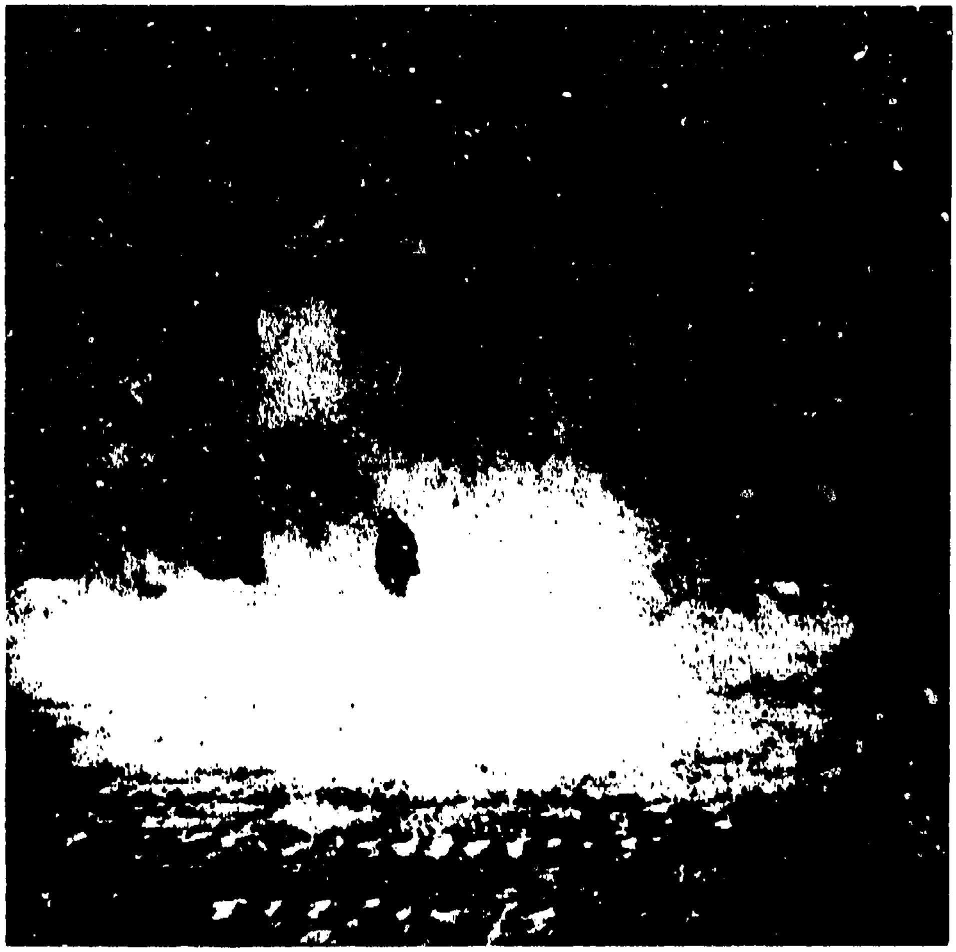


Figure 4-9. Attenuation of Visibility by Blowing Snow (Photo by R. W. Gerdel)

creasingly critical. Temperatures were recorded carefully, and during the last starting attempt, the temperature exceeded the authorized limits. This last attempt was at an elevation of 10,500 ft at a temperature reading of −27°C. Three starting sequences were aborted due to high tailpipe temperatures. On the fourth attempt, the tailpipe temperature exceeded 760°C. The engine start was successful but attempts to accelerate resulted in compressor stall and the engine speed required for takeoff could not be attained. A new engine was installed and a successful start was accomplished. Inspection of the replaced engine following disassembly revealed that all blades were burned on the first-stage turbine wheel.

Icing within fuel systems was a recurring problem. Water contained in the fuel, possibly in suspension, could not be separated fully during refueling operations utilizing available strainers. Frequent draining of the fuel pumps at regular intervals was required to prevent freezing of the trapped water.

In 1960 Operation Lead Dog conducted operations over the Greenland Ice Cap from Camp Tuto to Crown Prince Christian Land

and to Peary Land (Ref. 22). Helicopters were used in this operation along with other types of aircraft. Whiteout and grayout were encountered, resulting in blending of the sky and ice cap, thereby eliminating the horizon and making it impossible for pilots to determine visually the altitude of aircraft above the snow surface. It was concluded that it is unwise to attempt operations during periods of restricted visibility on the ice cap. In several instances aircraft were able to carry out operations on the landmass but could not return to the ice cap base even though it was only 6 mi away and clearly visible from the edge of the ice cap. Another environmental problem encountered involved parachuting of supplies by aircraft. In high winds parachutes would drag after hitting the ground and disperse their loads over large areas since the terrain presented no obstacles to prevent dragging. An automatic release on the parachute straps was recommended. Overall, during 35 days that the helicopters were assigned to the operation, weather interfered with flying operations on 17 days.

Operation Pole Hop in 1960 carried out aerial operations in the polar basin north of Ellesmere Island in order to study logistic and operational capabilities in extreme northern regions (Ref. 23). Problems were experienced with the removal of ice and snow from engine, control surfaces, and wings of U1A aircraft following snow storms. The engine, cowling, carburetor air intake, and, hollow surfaces of the empennage became glazed with ice. The ice and snow could only be removed with heaters, 400,000-Btu units being required to thaw the large surface areas involved.

4-4 IMPAIRMENT OF OPERATION EXECUTION—DESERT CLIMATE

The major characteristics of desert environments are high temperature, high solar radiation, and low rainfall. Deteriorative effects of these factors on materiel are discussed in Part Two of this Environmental Series as well as in Chaps. 3 and 5 of this part.

In general, most vehicular problems encountered in the desert environment are caused by sand and dust and by extreme high temperatures. Vapor lock is a problem caused by high temperatures but can be prevented. Vehicle mobility in deep sand and powdered clay is inadequate in many cases and the entrance of sand, dust, and grit causes personnel problems as well as problems with the operating mechanisms of vehicles. Transmissions and engines fail much more rapidly than in temperate uses. Batteries rapidly deteriorate in desert regions because of the high temperatures. Satisfactory fuels and lubricants are available for desert operations, but contamination, primarily with foreign particulate matter in the form of dust and grit, is a serious problem.

Special equipment is required to supply cool air in enclosed spaces and to maintain proper relative humidity for human comfort. This equipment cannot completely filter fine sand and dust from intake air, thereby causing discomfort to personnel, especially in moving vehicles. The problems associated with photographic equipment in desert regions are those attributable primarily to the high temperatures, which cause changes in processing variables and rapid deterioration of both unexposed and exposed film. Shelter in desert regions is not nearly so significant as in arctic regions, yet, in many cases, must be provided for protection from heat and high solar radiation. Problems with electronic equipment in desert operations involve the high temperature and the ambient solar radiation. High temperature limits are summarized in Fig. 4-10. Hot spots develop around operating components that dissipate heat and are further aggravated by direct exposure to solar radiation. Fine sand and dust also contribute problems by infiltrating mechanical moving parts, thus causing excessive wear and, on occasions, failure of equipment. Generally, in desert areas electronic equipment must be provided dust-free ventilation and cooled air to

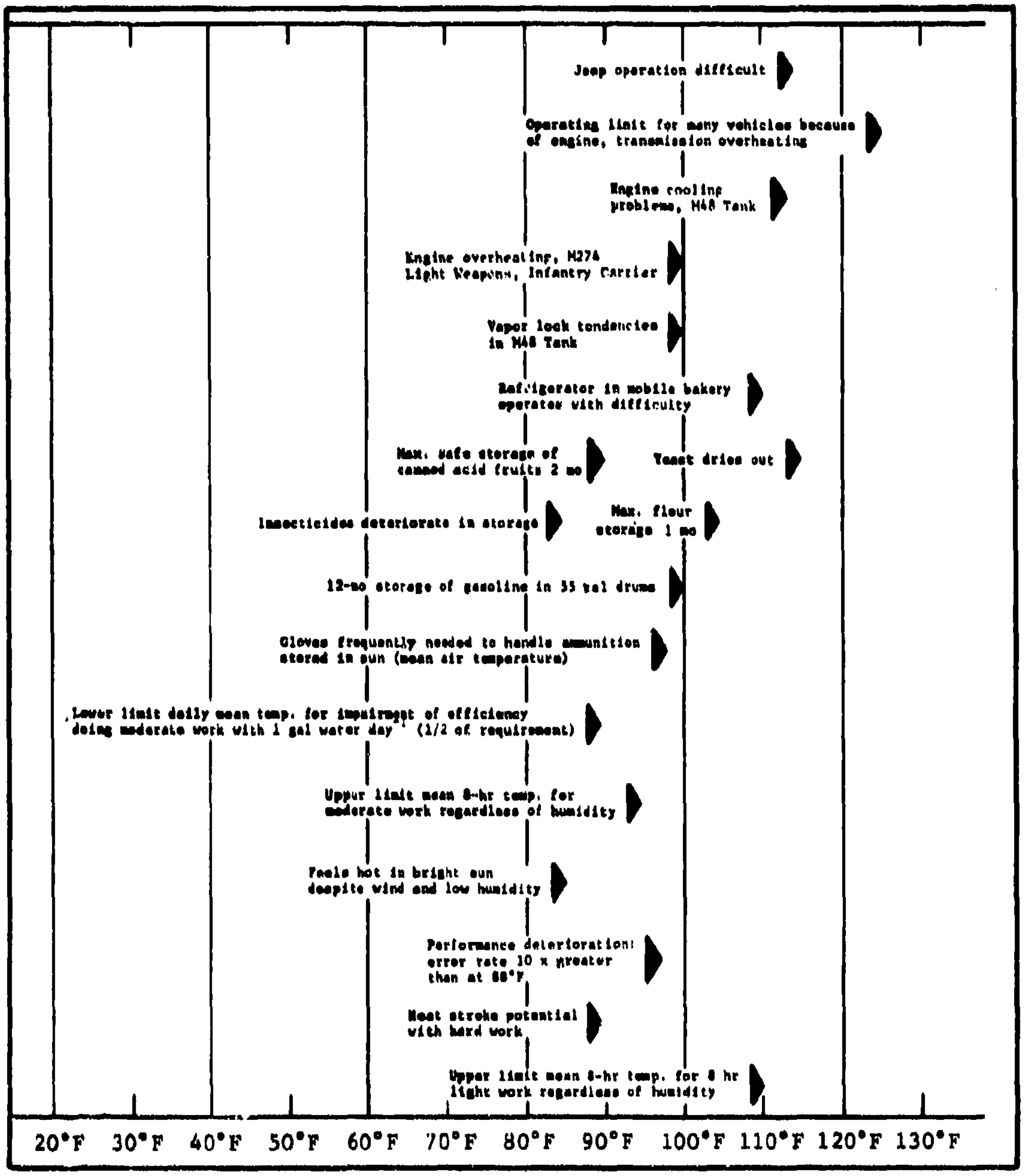


Figure 4-10. High Temperature Limits on Operations (Ref. 24)

maintain operational reliability. Table 4-15 presents some of the difficulties produced by the desert environment on various types of ground support equipment.

A number of field exercises have been conducted to determine the effect of the desert environment on military materiel and personnel. Most of these have centered around evaluation of vehicular performance and capability. Summer desert tests were conducted at the Yuma Proving Ground on the performance of ordnance vehicles and equipment (Refs. 25-27). As a general rule, these tests revealed that problems resulting from severe mechanical and thermal stresses imposed by desert operating conditions are not unusually serious or difficult to solve. Transport vehicles, combat vehicles, and miscellaneous components were tested. Examples from these tests of the effects of the desert environment on vehicular performance are summarized in the subparagraphs that follow.

4-4.1 MOBILITY

The mobility testing of wheeled vehicles confirmed previously developed data indicating that decreased tire pressures increase vehicle mobility in loose sand, enable vehicles to climb steeper grades and longer slopes, increase draw bar pulling capacity, and decrease resistance to towing. In addition, comparative tests between single- and dual-tired vehicles of similar types clearly reveal the superiority of vehicles equipped with a larger size single tire in traversing level sandy terrain or in traversing prepared or unprepared sand dunes or other types of deep, loose sandy terrain. In tests at Death Valley, Calif., the mobility of the T43E1 vehicle was hampered by the protruding guns striking the ground when traversing gulleys, not uncommon in desert areas. This is a general problem with vehicles carrying long-barreled weapons.

4-4.2 VAPOR LOCK

In one desert test, only a few types of wheeled vehicles equipped with standard fuel pumps could be operated without vapor lock occurring. During another test, the only wheeled vehicle found suitable without modification was the M135 Cargo Truck, which was equipped with a submerged-type electric fuel pump as standard equipment. In general, the replacement of the standard fuel pump with a submerged-type pump eliminated vapor lock. Most main engines in tracked combat vehicles tested at Yuma appeared to be immune to vapor lock. In all cases, however, auxiliary engines with which they were equipped experienced severe vapor lock and required major corrective treatment.

The main engine fuel system for the 155 mm self-propelled gun (T97) experienced incipient vapor lock with the A41-2 auxiliary generator engine. During these summer tests, a number of transport vehicles were tested for vapor lock characteristics during operation at Death Valley, Calif. The M38A1, M37, M35, and M54 Trucks, all equipped with standard fuel systems, failed to meet vapor lock specifications.

4-4.3 VEHICLE COOLING SYSTEMS

Wheeled vehicle cooling systems functioned satisfactorily during the engineering and cross-country cooling tests conducted in desert tests under moderate stresses with the exception of one vehicle. With more rigorous test conditions, the cooling systems generally did not function satisfactorily. The cooling systems of tracked vehicles were generally adequate for moderate test conditions but were inadequate in more rigorous conditions.

The lightweight, general utility, 1/4-ton truck failed to meet cooling specifications. Cylinder head temperatures, the most critical, exceeded 525°F during road tests at an ambient temperature of 105°F. Full throttle cooling tests at engine speeds above 1,800 rpm were not conducted because of the critical cylinder head temperatures. The 1/4-ton ambulance (M170) failed to meet cooling requirements because gear and trans-

TABLE 4-15.
DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Electronic equipment		
	Dust and sand penetrate defective seals and packings, some greases fail at high desert temperatures, and shock and vibration cause damage due to rough desert terrain.	Hermetic seals; use of packing and greases approved for desert use; vibration- and shock-proof mountings; weight reduction and greater strength of structural details of components and units are required.
Components	Functional characteristics and equipment life are reduced by the high temperatures generated within the equipment itself. The high atmospheric temperatures and ever-present dust are secondary considerations.	In desert areas the requirement for positive heat dissipation is most important. Continual vigilance is necessary and inspection, cleaning and maintenance schedules must be stepped up to meet day-to-day conditions.
Shelters		
Wooden shelters	Buckling of large wood or steel sections is possible where sufficient allowance for expansion and contraction has not been provided.	
Painted surfaces	Wind-born sand is abrasive and damages painted surfaces.	
	The high daytime and low nighttime temperatures cause materials to expand and contract in a continuous cycle. This causes premature failure of brittle paint films and glued joints.	Generally, paint performance in hot climates is very poor, repainting being needed every 1 to 3 yr, depending on the locality and type of paint.

TABLE 4-15 (Continued).
DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Ventilation	Inside air temperature of enclosed spaces may be as high at 40 to 60 deg F above ambient. The fact that ambient temperature may go as high as 130°F and higher makes this problem critical.	Suitable ventilation should be provided, but this provision of airflow will be complicated if the area is subject to sand storms.
Foundations	In windy areas, sand may be blown away from beneath foundations.	This can be prevented by adding to the depth of the wall beneath the surface, or by placing the shelter in a position where it cannot be undermined by the wind. Foundation construction is greatly simplified, because the sand, when confined and compacted, makes an excellent base. Desert areas provide very suitable foundations.
Masonry and earth	Stone and mud bricks are the only available building material.	There are few climatic and environmental factors that promote undue deterioration in masonry materials; in fact,the chief agencies of destruction in the temperate zones (frost and corrosive gases) are virtually absent in the desert. When soundly constructed, earth shelters may last for a very long time in dry climates. The principal factor deteriorating such shelters is water.
Roofs	Intense solar radiation makes indoor temperature extremely high unless adequate roof insulation is provided.	All buildings should be designed with particular attention to roof insulation, either by double roofs or suitable insulating materials, or both.

TABLE 4-15 (Continued).
DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Material	Environmental effect	Remedy
Lubricants		
	Dust and sand in conjunction with shock and vibration in the desert permit erosive materials to pass screens and seals into lubricants and cause excessive wear on all moving or bearing surfaces.	Frequent inspection, cleaning, and excellent maintenance are required to keep dust and grit out of lubricants.
	Air cleaners become quickly clogged, resulting in quick cylinder and ring wear by the entrance of grit to the lubricating system.	Clean air cleaners every 10 hr.
	See "Lubricants," Table 4-16.	See "Lubricants," Table 4-16.
Electrical power generating equipment		
Gasoline and diesel driven generating equipment	The major difficulties of diesel and gasoline power plants aggravaced by the desert are those caused by sand and dust, high atmospheric temperatures, and intense solar radiation.	The difficulties, as compared to vehicle power plants, are generally alleviated by their inherent installation, being sheltered from blowing sand and dust and intense solar radiation. The difficulties exist unrelieved for portable and unsheltered engines.
Generators and motor generators	Wear of carbon brushes is excessive in dry atmospheres.	The conditioning of the atmosphere appears to be the solution.
	Bearings seize at extremely high ambient temperatures. The different coefficients of expansion of bearings and journals cause seizing and also increase wear.	
	Electric motor ball bearings fail prematurely at high elevated temperatures (150°C) because of poor lubrication and bearing design. Also lubricants flow out of bearings and attack insulation.	Silicone-lithium soap greases give satisfactory 1,000 hr continuous operation at 150°C without regreasing.

TABLE 4-15 (Continued).
DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
		The lubricating system should be so designed that the fluid bled from the grease will migrate into the bearing.
Dry cell batteries	At high temperatures dry cell batteries corrode at an increased rate, leading to an excessive drying and a decrease in electrical capacity. This problem is particularly critical during storage.	Dry cell batteries should be stored at temperatures between 0° and 40°F. Retention of 98% of their capacity for two years is thus possible. When refrigeration facilities at these low temperatures are not available (and generally they are not), storage at temperatures of 35° to 45°F obtained in most types of refrigeration units will considerably improve shelf life.
Wet cell batteries	The effects of high temperature on lead acid batteries are: (1) loss of capacity during short storage or idling (2) deterioration during long-term storage (3) loss of water (4) shortened life.	These difficulties can be overcome by: (1) recharging (2) cool storage (3) replenishing of lost water (4) avoiding internal heat due to solar radiation and by proper maintenance and installation.
Vehicles		
Self-propelled	The major operating problems confronting all types of vehicles in the desert are those caused by contact with sand and dust, rough terrain, daily high atmospheric temperatures, and the high incidence of ozone and solar radiation.	Sealing, filtering, and screening should be used where possible. Inspection and maintenance should be complete, frequent, and periodic with short intervals for vital parts. Heat resistant materials and coatings should be used. Trained, experienced operators should be employed.

TABLE 4-15 (Continued).
DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	Rough terrain and lack of roads cause abnormally high stresses resulting in excessive breakdowns.	
Power plants	Engines are inclined to overheat in the desert.	Operate engine within or below capacity. Keep system filled with corrosion resistant coolant. Meticulous maintenance is required.
	Vapor lock may occur in high temperatures especially if combined with low atmospheric pressure.	Fuel pumps and fuel lines should be located in a free flow of air and away from the heat source. Insulation protection may be installed. Temporary expedient wet cloth wrappings may be used. Submerged fuel pumps prevent vapor lock.
	Engine attachments are subjected to heavy stresses in desert terrain. Brackets such as the oil filter bracket, crankshaft pulleys, fan belts, water pumps, exhaust piping, mufflers, and other auxiliaries, including instruments and panels, have not possessed the required strength for durability and reliability.	Design of thicker, heavier parts, or selection of special metals for particular parts to provide greater strength and longer life.
Transmission and Gearing	In general, filler plugs for transmission and transfer cases are often difficult to remove. Frequent shifting of gears in difficult and deep sand terrain causes accelerated wear.	Plugs should be designed to provide ease of removal and replacement. Plugs should be frequently inspected and carefully maintained and cleaned before replacing. Automatic transmissions should be durable to meet desert stresses and shift mechanisms should be easily operated for frequent use.

TABLE 4-15 (Continued).
DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Chassis	Rubber, natural and synthetic, deteriorates when exposed to heat, light, oxygen, or ozone. This affects mountings and seals in addition to tires. Tire life is short in the hot, rugged, sandy terrain.	No acceptable solution has been obtained. However, 100 % GRS synthetic rubber has stood up well for engine mountings and brake cylinder cups. As a coating for rubber parts exposed to the desert atmosphere, vinylite seems best. Reduced tire inflation aids mobility.
Traction	The deep sand and powdered clay of the desert give poor traction surface to wheeled vehicles. Powered wheels dig themselves into ruts and heavy loads aggravate the condition. Dual wheels and tires have proven to be less effective than single tires.	The use of single, partially inflated tires has been more satisfactory than multiple tires. Moderate application of the available power by experienced drivers is best for starting the horizontal movement. Oversize balloon sand tires are helpful.
Brakes	Sand and dust cause excessive wear.	Brakes must be shielded from sand and dust.
Preservatives	Cooling systems become clogged with rust. Crankcase develops sludge. Bearings corrode. Exhaust valves stick.	These problems usually can be corrected by frequent inspection followed by necessary maintenance. Correct pH values for coolant may be determined by a phenophthalein indicator. Engine sludge can be prevented with covers and seals and with maintenance; bearing corrosion by the use of the proper lubricant.
Lubricants	Observations show that heavy dust required changing oil cleaners every 10 hr and lubricating oil about every 150 hr. In high atmospheric temperatures, grease is thrown out of the bearings and becomes unstable in storage.	Careful, frequent inspection and maintenance with special attention to seals, covers, and packing is required.

TABLE 4-15 (Continued).
DIFFICULTIES PRODUCED BY THE DESERT ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Trailers	The effect of high temperatures on the ability of personnel to work efficiently is the limiting factor of trailer operation.	Air cooling systems, either permanently installed or external, are a necessity for maximum efficiency. Also paint exterior surfaces white.
	Electronic components required to operate at high temperatures of about 165°F suffer a serious reduction in life.	
	Excessive wear of moving parts is caused by fine sand and dust.	This is a problem of continual maintenance with particular attention being paid to air and lubrication filters.
	Vibration and shock induced by poor roads and rough terrain cause excessive damage to equipment items installed in trailers.	
Spare parts	Tires and rubber parts suffer ozone cracks when exposed under strain.	Rubber cured under strain cracks faster than when cured at rest. Tires and other rubber parts in open storage should be covered with butyl sheath or waterproof paper. Two percent wax incorporated in rubber compounds protects against ozone cracking.
	Exposure to direct sunlight causes a cracked condition on the surface which is quite different from that produced by ozone.	Avoid exposure to direct sun rays.

mission oil temperatures were high. The 1/4-ton utility truck (XM151) failed to meet cooling requirements under more severe operating conditions because temperatures of various critical items exceeded the specified limits during full throttle vehicle operation at 100°F ambient. Cooling characteristics probably would be borderline for road load operations at 125°F ambient temperature. The 2-1/2-ton cargo truck (M35) would not meet cooling specifications during the more severe throttle operations at low road speeds. Failures experienced during the 10,000 mi lubricant test included excessive ring and pinion gear wear on the M37 Truck, a center main bearing failure on a M35 Truck (attributed to high engine-oil temperature), and two transmission failures on M211 Trucks.

In the combat vehicles, cooling characteristics of standard M48 vehicles were found to be unsatisfactory because cylinder head temperatures reached 534°F during tests at 107°F ambient.

4-4.4 WEAPONS AND RELATED COMPONENTS

Most weapons tested required special emplacement on the gravel and hard ground terrain found in the desert environment; however, the 105 mm howitzer seated satisfactorily in all types of desert terrain. Ammunition functioned satisfactorily although obscuration resulting from the effect of muzzle blast represented a minor problem. The T156E1 Telescope, the M20A1 Periscope, and the T46E1 Rangefinder on the fire control system on the M48 Tank did not maintain alignment during a 500-mi cross-country test. The firing of rocket launchers from dry desert soils resulted in a large dust cloud, which could reveal the launcher position.

The variation of temperature with height over arid and many semiarid surfaces produces a tendency for stable air conditions during the night, an important consideration in employment of chemical agents and a consideration in ballistics. High daytime temperatures and the consequent decrease of air density are important in ballistics and may also create a need for longer aircraft runways.

4-4.5 GENERAL OPERATIONS

During cross-country operations, dust clouds produced by tracked vehicles limited visibility to a considerable extent and betrayed position. During tests of tracked, armored infantry vehicles, personnel compartment temperatures range from 15 to 18 deg F above the prevailing ambient temperature, causing considerable crew discomfort. Opening of ventilation ports allowed dust to enter the personnel compartment, also causing crew discomfort. The provision of respirators for crew members and passengers, as well as improved methods of air intake, is desirable. Dust conditions impaired the cooling ability of combat vehicles after short periods of cross-country operation. High ambient temperatures, solar radiation, heat transfer from power packages, and dust conditions caused discomfort and fatigue to operating personnel. The transmission and engine control linkages of combat vehicles frequently experienced malfunction because of the entrance of dust during cross-country vehicle operations. Entrance of dust through the air cleaners, combustion-air induction systems, and other openings still presents a major problem to combat vehicle engines.

Heat and type of work dictate the amount of water needed by a person in arid and semiarid areas. A man's daily water requirement while doing strenuous work is 25 quarts when the temperature is 120°F, 10 times his requirement when the temperature is 60°F. Operational effectiveness becomes impaired rapidly when water intake is seriously deficient. Survival time for men without water is only 2 or 3 days when the mean temperature is above 90°F.

Excessive heat causes a reduction in the quality of performance of skilled tasks. While little difference in quality has been noted between work done with temperatures in the 80's from that with temperature in the 70's, deterioration increases quickly as the temperature climbs from 90° to over 100°F. Although the heat commonly experienced in the very hot and extremely hot climates greatly increases man's need for water, average food intake has been found to diminish by as much as 10 to 15 percent.

High temperatures affect storage of perishable and volatile supplies. Food storage is most critical, both because the deterioration rate is more sensitive to temperature and because it is less safe to use questionable supplies.

4-5 IMPAIRMENT OF OPERATION EXECUTION—TROPICAL ENVIRONMENT

The most commonly discussed effects of environment in the Tropics on materiel are deterioration and corrosion. So overpowering are these effects that most of the literature concerning the tropical environment and its effects on materiel are devoted to descriptions of these deteriorative processes. Although deterioration occurs in other environments, it occurs much more rapidly (particularly the growth of fungus) in the Tropics and the resulting deterioration can be surprisingly rapid. Because of the abundance of moisture in the tropical environment, metallic corrosion is rapid. Since deteriorative processes are most severe in the tropical environment, the major discussion of tropical environmental effects on materiel is contained in par. 4-6, "Impairment of Operational Readiness".

Rain and moisture, high ambient temperatures, biological attack, and solar radiation are the primary environmental factors that produce deleterious effects upon materiel. Such radiation is not as significant a factor, however, as in the desert environment. Electrical power-generating equipment that employs wet cell batteries encounters difficulties in the Tropics as in the desert regions because of the accelerated deterioration of cells at high temperatures.

Environmental control equipment in tropical areas is employed primarily to cool and dry the air. Because the Tropics ideally are suited to growth of microbiological organisms and many forms of macrobiological organisms such as insects, there are significant requirements in controlling these environmental factors. Termites are a very significant problem in the Tropics and attack virtually all items in which cellulosic materials are used. Fungi rapidly attack virtually all kinds of textile and leather materiel unless proper control is applied. Photographic equipment in tropical areas is subject to corrosion, particularly interior metal parts, to the extent that the equipment rapidly can become inoperative. The problem of sealing out moisture in photographic equipment is acute.

Most of the problems associated with shelter in the Tropics are those involved in providing protection of equipment and personnel from insect attack, high humidity, and high temperature. Because of the severity of the termite damage problem, it must be considered in the construction of all shelters in the Tropics.

Electronic equipment is severely tested in the tropical environments. It is necessary to combat moisture, fungous growth, and the ingress of insects that feed on organic material or spin webs that act as conductors when wet. Much progress has been made in tropical proofing of electronic equipment; however, constant inspection and care are still required to insure operation in the tropical environment. Ground electronic equipment should, wherever possible, be installed and operated in houses and shelters that provide temperature and humidity control and protection against insect attack. Storage of equipment and repair parts is also extremely important since these components also are attacked readily by the tropical environment. Table 4-16 details some of the difficulties produced by the tropical environment or various types of ground support equipment.

TABLE 4-16.
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Electronic equipment		
	Moisture due to heavy rainfall and high humidity is the basic cause of corrosion and fungous growth that quickly result in malfunctioning, deterioration, and ultimately in the destruction of electronic equipment. Similar difficulties occur in radar, radio, or control units without distinction as to the equipment function.	Air conditioned spaces control the humidity and the temperature, eliminating the first two of the following four requirements for fungous growth: (1) humidity, above 70% (2) temperature, above 50°F. (3) food for the fungi, and (4) oxygen. Selection of fungus-proof materials is a means for the control of fungous difficulties. Coatings have been developed that give very good protection.
	Fungous growths may appear on any material. The most vulnerable are cellulose, cordage, cotton, felt, glue, leather, paints, paper, phenolics, varnish, and waxes. They also attack instrument lenses and windows. Rough surfaces support the growth. Fungus reduces resistance between parts, causes currents and cross talk.	Fungous growth is best controlled by air-conditioned spaces. Circulation of dry air and the application of fungus-resistant materials assist in preventing growth. Cleaning, oiling, careful detailed inspection of small parts, excellent maintenance, the use of fungus-resistant coatings, hermetic seals, and desiccants as appropriate and practical are the usual methods of control. Any method that either eliminates moisture or maintains the temperature below 50°F will eliminate fungus.

TABLE 4-16 (Continued).
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	Shock damage is aggravated in the tropics by corrosion and fungous damage that follow the breaking of seals or other protective measures.	Shock damage is prevented by careful handling, proper storage, reusable, well constructed containers having molded or other cushioning supports. Materials should be retained in their original package until their use is required. All packages should be ruggedly designed to withstand rough handling.
Components	Electronic components in every day use in areas of high moisture content escape, for the most part, the damage suffered by components standing idle or in storage. The heat generated during periods of operation is sufficient to keep equipment dry and thus free of fungous growth.	Equipment standing idle or in storage, if not packaged to seal out moisture, must be kept dry or else be thoroughly dried out before being put into service. Wherever possible, components should be hermetically sealed as added protection against moisture and fungus.
<u>Lubricants</u>		
Wheel and bearing grease	Some greases, designated for use from -65° to 125°F are unsatisfactory for wheel, ball, and roller bearings in tropical climates because they become fluid and are not water repellant.	Care must be exercised in selecting a grease that satisfactorily meets the requirements for temperatures and water conditions.
Oil seals	Oil seals in gear boxes leak at high temperatures.	Use of a heavier lubricating oil prevents seal leaks.
Gears and gear boxes	Gears and gear boxes become corroded and rusted after periods of storage.	Means for rust inhibiting and corrosion protection must be incorporated in the regularly used oil. Seals against the entrance of moisture should be provided.

TABLE 4-16 (Continued).
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Ball bearings	Ball bearings cause trouble by failure of lubricants at high temperatures.	Ball bearing lubricants meeting high temperature requirements give the best results.
Gasoline storage tanks	Steel gasoline storage tanks corrode.	Coated tanks should be employed.
	Gasoline tanks deteriorate from molds and bacteria.	Coatings for gasoline tanks must incorporate a biostatic agent.
Shelters		
Wooden shelters	Subterranean termites, abundant in the tropics, attack sporadically and destroy wooden members.	Proper construction and use of termite resistant or chemically impregnated wood are the best preventive measures. All wood in or around the ground near the shelter should be removed to prevent termites from starting a colony. Wooden members should not come in contact with the ground or near it. Shrubs and trees in contact with the shelter should be avoided or removed. The best type of foundation is reinforced concrete, free from cracks. This type of foundation prevents termites from entering and forces them to build mud tunnels over the foundation which can be detected by frequent inspections. Placing of metal shields between the foundation and superstructure forms a barricade which increases the effectiveness of a suitable foundation.

TABLE 4-16 (Continued).
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
	Many species of fungi cause wood decay.	The preservation of wood against decay depends on the use of well-seasoned durable woods, suitable wood preservatives, provisions for adequate ventilation between floor and the ground, and steps to prevent prolonged contact with water. Wood, when kept dry, is impervious to fungous attack. In order to decay, it must contain moisture in an amount of 20% or greater, of its weight. It is important that no paint be applied to wood until it has dried out thoroughly. Good quality coal tar creosote is one of the best preservatives. Usually, woods treated or naturally resistant to termites are resistant to fungi.
Cement and concrete	Algae growth may cause surface staining and mild etching of concrete, cement mortar, and cement painted surfaces, and shorten the life of cement paint coatings.	
Electrical power generating equipment		
Gasoline and diesel driven generating equipment	The major difficulties of gasoline and diesel engines are similar to those listed under "Vehicles".	
Generators and motor generators	Moisture corrodes metal parts, short circuits wiring, and increases operating maintenance. Corrosion jams governor mechanisms and commutating brushes. Fungus spreads rapidly on insulation that has not been fungus proofed.	Commercial equipment that is not tropicalized will always fail in the tropics. It should be avoided.

TABLE 4-16 (Continued).
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Wet cell batteries	(See Table 4-15, under "Electrical Power Generating Equipment".)	(See Table 4-15, under "Electrical Power Generating Equipment".)
Vehicles		
Self-propelled	The difficulties in the tropics are due to heavy rainfall, high humidity, fungi and other biological growths.	Proper lubricants and coatings for materials offset humidity and biological growths. Solar radiation difficulties are overcome by simple shelters or covers. Provision for drainage and breathing must be provided in all closed spaces.
Trailers	The major problems are the degradation of materials under the influence of moisture and fungous growth, and the discomfort of personnel.	Most types of trailers, particularly those within which personnel must work, lend themselves to the installation of air conditioning equipment. Where not possible to employ air conditioning, the solution to the problem becomes one of continuous inspection, care, and maintenance to keep the components dry and operable.
Dollies	The major problem is the corrosion of unprotected materials caused by contact with moisture.	Maximum application of surface protectives and continual removal of moisture are required. The most dependable protection is afforded by air conditioned shelter or by the use of an external source of dry air.
Spare parts	Same as dollies.	In addition to the information on dollies above, it is imperative that parts in storage be properly packaged to seal out moisture.

TABLE 4-16 (Continued).
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Photographic equipment		
Cameras	Cameras give trouble by fogging and misting of glass components, biological infestations, mold growth, drying out of cements and sealing materials, and deposit of volatile components of lubricants and greases.	Tropicalization of camera equipment in which all possible measures are taken to seal out moisture and keep interior spaces dry will produce the best results.
	Functional units such as gears, cams, and shafts corrode readily.	Protective finishes have not been entirely satisfactory. Application of a thin film of oil or grease which is continually renewed is the best preventive.
	The watch-like construction of between-the-lens mechanisms renders them especially susceptible to rust.	Continual cleaning is essential to insure removal of moisture.
	Rusted roller pivots cause slow and erratic curtain speeds, and trip levers of focal-plane shutter curtains function improperly. The shutter-tripping mechanisms may be impaired by rust on either the trip lever, cam stop lever, or snubber segment.	Same as previous two remedies.
	The normal gliding action between the retard segment or pallet is lost if rusting occurs on either part.	Same as previous two remedies.
Optical cements	Bonding cements deteriorate under prolonged exposure to sunlight and moisture, showing rainbow-like patterns and edge separation.	There is no completely satisfactory all-purpose cement; however, this situation is improving.

TABLE 4-16 (Continued).
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Projectors	Projector equipment is usually more permanently installed and much more likely to be adequately sheltered than cameras; however, all of the difficulties encountered are the same as for cameras.	Adequate preventive maintenance and careful supervision can insure maximum reliable operation.
Film	Exposed, developed, and unexposed film alike suffer from deterioration typified by etching and spotting.	Photographic film and plates must be protected from temperatures in excess of 60°F, and papers, 70°F, and relative humidities maintained between 40 and 60% for optimal results.
	Photographic film and plates, after prolonged exposure in areas of high relative humidity, become attacked by microbes which will eventually liquefy or consume the gelatin. Fungous attack is sometimes associated with infestation by mites.	Incorporating fungicides in the emulsion has not been entirely satisfactory. Minor fungous damage can be repaired by certain cleaning methods. An extremely thin film of wax applied to the surface is beneficial. For long-term storage, film must be cleaned and dried at regular intervals.
	Heat, like moisture, makes film soft and pliable and reduces tensile strength, while very low temperatures, on the contrary, make it brittle. Emulsion coated film is more brittle than the base alone.	Film should not be stored at temperatures in excess of 70°F nor lower than 5°F.
Electrical systems: permanent and portable field lighting, floodlights and components		
	In the presence of high humidity, materials such as phenolic resins, insulating tape, and cadmium-plated materials corrode.	Humidity control measures or the removal of the contaminating materials from contact with the cadmium-plated materials will control the corrosion.

TABLE 4-16 (Continued).
DIFFICULTIES PRODUCED BY THE TROPICAL ENVIRONMENT ON VARIOUS TYPES OF GROUND SUPPORT EQUIPMENT (Ref. 13)

Materiel	Environmental effect	Remedy
Electrical generation and distribution systems	Insects and rodents are a primary source of trouble for electrical systems in the Tropics.	Ratproofing and screening of enclosures, frequent inspection, and good maintenance eliminate insects and rodents.
Cable	Cold rubber cable has poor resistance to water, humidity, sunlight, ozone, fungus, oils, and greases.	The use of cold rubber cable should be avoided in the desert and Tropics. Insulating compounds have been developed that are far superior and whose physical and chemical properties are excellent.
	Wooden cable reels decay, when exposed to high humidity and temperature, to such an extent that it is extremely difficult, if not impossible, to unwind the cable.	Creosote is a standard preservative and can be used; however, the treated reels cannot be painted or stenciled with code numbers and identifying marks. Creosoted wood will bleed from the effect of intense solar radiation after rains, thus losing its usefulness.

The major factors affecting operational execution involve terrain and terrain interfaces; e.g., in amphibious operations involving land areas protected by barrier reefs, the reefs impose significant obstacles to the approach of landing craft and, when combined with high wind and waves, can become significant hazards to operations.

Rugged terrain typical of some mountainous tropical areas poses a barrier to the mobility of men and vehicles just as such terrain does in all climatic areas. Land-water interfaces cause difficulties in the tropical environment in the same manner that these difficulties occur in other environments. However, in the tropical environment (particularly in tropical jungles), the normally heavy rainfall results in large numbers of streams. As a result, the number of land-water interfaces encountered in traversing jungle terrain can make this factor more significant. Inadequate drainage and soft soil types in many cases impair mobility of both men and materiel (see Fig. 4-11). Swampy areas are more common in the Tropics and generally are relatively impassable to man on foot and are frequently formidable to vehicles as well. Mud and its effects on vehicular and personnel mobility find ample

Figure 4-11. Personnel Mobility in a Tropical Climate (Ref. 2)

representation in the Tropics (see Fig. 4-12).

As a result of warm temperatures and heavy rainfall, tropic vegetation is thick and lush. From an operational standpoint, the thick tropical vegetation characteristic of tropical jungles has two effects. First, visibility is reduced greatly so that coordination, communication, fire direction, and all of the other aspects of a military operation that require visibility for performance are severely limited. Second, the presence of underbrush and trees acts as physical barriers and greatly reduces mobility. In most cases, tropical jungles are so thick that no progress can be made by individual soldiers without first cutting a path through the underbrush, greatly slowing the advancement of troops and limiting mobility severely. Large numbers of large, closely spaced trees can act as effective barriers to vehicular traffic as well. When this is combined with the moist, low load-bearing soils usually associated with such tropical jungles, mobility impairment is compounded. In summary, the problems associated with operations in the tropical environment can be extremely severe in their effect on mobility and vision.

Effects on personnel in the tropical environment are the result of temperature, humidity, and microbiological factors. It has been demonstrated abundantly in the literature that the hot-humid characteristic of the tropical environment causes a performance decrement in personnel.

The attack of the tropical environment on clothing and items of personal equipment, including boots, belts, etc., requires attention from the average soldier in the field and thereby reduces his military effectiveness. In addition, the presence of snakes, biting insects, and other macrobiological species constitutes an annoyance factor, which occasionally can become significant.

4-6 IMPAIRMENT OF OPERATIONAL READINESS

Operational readiness is defined here to mean that materiel, when placed into use in the operational environment, is capable of performing the design function for which it was intended. Within this context, any form of deterioration in performance or physical characteristics or any other deteriorative process that results in impairment or limitation in the usefulness of materiel reduces operational readiness of that materiel.

Environmental factors can affect operational readiness of equipment or materiel in a number of ways. If it is presumed that equipment or materiel is fully operational upon delivery to the Armed Forces (which should normally be the case), then those things that contribute to materiel unreadi-

Figure 4-12. Armored Vehicles Traversing Heavy Mud (Ref. 28)

ness must occur at some point in the life cycle of the materiel before it is called upon to perform its function. The logistic environment—which embraces transportation, handling, and storage within the logistic cycle—can result in exposure to environmental factors that cause deterioration of materiel or impairment of the function of materiel. These factors are discussed in Chap. 5 of this handbook.

When materiel has been delivered to the user, it is still possible for deteriorative processes and impairment of function to occur before or during use of the materiel. These include user storage of the materiel, transportation and handling within the operational environment, and similar activities after the materiel has been delivered to the user but before or between usages of the materiel. To discuss in detail the types of failures of individual equipments and materiel that can occur in these circumstances would require significantly more discussion than is practical and would be repetitive.

To illustrate the variety of factors and processes leading to operational unreadiness, a number of examples of materiel whose operational readiness has been compromised by environment are discussed. Par. 4-6.1 reviews some of the findings of the Army Air Forces Tropical Science Mission, which organized field studies of materiel in storage and in use in tropical areas (Ref. 29). This survey was conducted during the latter stages and post war period of World War II, so it reflects packaging and handling conditions, storage conditions, and materiel as they existed at that time at overseas operational bases. Packaging techniques, as well as transportation and handling techniques, have been improved significantly since that time, yet the natural environments are unchanged.

Because of the age of the data from this survey, it should not be interpreted as representative of deterioration experienced by materiel using modern packaging and preservation techniques. On the other hand, in the event of complete failure or violation of the integrity of the packaging or preservation techniques so that environmental factors can gain access to materiel, the resulting deterioration by the tropical climate essentially should be the same.

Because the tropical environment is the most aggressive with respect to deterioration, one tends to think solely of it whenever the subject of deterioration as a cause of operational unreadiness is considered. Deterioration occurs much faster and is of much greater magnitude in the Tropics; however, deterioration as a cause of operational unreadiness can and does occur in temperate, desert, and arctic climates as well. Pars. 4-6.2 through 4-6.4 give examples of deterioration in temperate, arctic, and desert environments. Also included is an interesting comparison of the effect of arctic, desert, and tropical environments on aircraft that have lain dormant since crashing during World War II.

4-6.1 THE TROPICAL ENVIRONMENT

To illustrate the magnitude of deterioration that can occur under tropical conditions when materiel is poorly or improperly packaged, preserved, and/or stored, examples of the damage caused by deterioration on World War II materiel under prolonged tropical storage have been excerpted from two studies made by the Armed Forces during the 1940's (Refs. 29,30).

Significant advances in packaging and preservation techniques have been accomplished since these surveys were made. Consequently, the specific examples quoted are not intended to be indicative of the effect of deteriorative agents on materiel packaged and preserved according to the present state-of-the-art techniques. These examples indicate the deteriorative effects of wet, tropical environments when the packaging or the preservation methods have been penetrated by the environment.

Tropical deterioration occurred in materiel scattered throughout the Pacific Islands as a result of the large-scale operations in the Pacific theater during World War II. Various classes of materiel were examined for evidence of tropical deterioration (Ref. 29). The following observations were obtained from the first study:

(1) *Personal equipment*. For personal equipment, the most serious losses occurred through direct and protracted wetting of items during shipping, in initial combat storage, or in demobilization activities. It was pointed out, however, that packaging can be a complete answer to protection from mildew and corrosion.

In New Guinea, practically all items of personal equipment deteriorated rapidly when used under combat conditions. Metal fasteners corroded, particularly slide fasteners, so they could not be used. Unless they could be laundered, fabrics were subject to fungous attack. Canvas tents and tarpaulins rotted rapidly unless protected by fungicides. Australian troops were given a complete new issue of clothing after two weeks of jungle fighting. Normal wear under such conditions was sufficient to make the clothing unserviceable in that length of time. Mildew was a problem at all locations where packaging was inadequate or where storage areas contained moisture. Leather that had not been chrome-tanned (vegetable-tanned leathers) was very susceptible to mildew and rot.

The most serious losses in personal equipment occurred through direct and protracted wetting of items in shipment and in initial combat storage. The second most frequently occurring difficulty was that experienced with the corrosion of slide fasteners, which resulted in complete stopping of slider action or in loss of tooth-binding strength of the tape. With the advent of new and improved slide fasteners that incorporate corrosion-resistant or corrosion-proof materials, this particular condition should no longer be of any difficulty except for very old items of issue. Many "sealed" plastic containers permitted the accumulation of condensed moisture and caused mildew and corrosion significantly worse than would be experienced if the materiel had been stored in an open container exposed to the humidity of the warehouses. Small parts of items also caused serious difficulties. Staples in booklets or clothing tags commonly caused weak spots and ugly rust stains. Compass needles were thoroughly rusted, whereas the cases were barely corroded.

(2) *Aircraft materiel*. Inspections of aircraft at the numerous tropical locations showed that condensation caused corrosion on interior surfaces, particularly those not properly painted or ventilated. Severe corrosion was observed in numerous aircraft on structural members subject to such conditions. Chloride from salt spray or coral dust, in some instances, collected on aluminum alloy surfaces and caused pitting and corrosion of the alloy, the degree of corrosion depending on the amount of chloride and moisture present. Galvanic corrosion occurred in a few instances where aluminum alloy was in contact with improperly plated steel fittings or with other dissimilar metals.

Most of the air strips constructed during World War II in tropical areas were located near bodies of salt water and built of crushed coral that generally contained a high content of chlorides. Chlorides play a major part in accelerating corrosion in tropical areas. On some of the smaller islands, unpainted aluminum alloy was exposed to salt water spray (generally caused by engine runup, taxiing, takeoffs, and landings) which resulted in corrosion of external and internal surfaces. Steel hardware that was unprotected against corrosion or had a flash coating of cadmium or zinc corroded very rapidly after short service and caused annoying maintenance problems. A variety of bolts, nuts, cotter pins, and other fittings on aircraft of all types gave significant problems to maintenance personnel. Cadmium and zinc plating, when painted, provided good protection against corrosion in the Tropics. In many cases, however, the plating alone was insufficient to maintain surface integrity. Treated steel corroded after a few months of service. Chromium-plated steel parts on the other hand performed quite well, with only occasional pin hole corrosion due to inadequate or porous plating.

Power plant corrosion (except in the most severe cases where no protection was provided) was limited to cylinder barrels, pistons, ring grooves, and connecting rods. Corrosion was even found on surfaces that had a complete coverage of oil. As with many of the other problems experienced, it was felt that proper maintenance along with general cleanliness of equipment would eliminate a sizable percentage of the corrosion.

Corrosion appears to be the principal cause of deterioration in electrical accessories. In New Guinea it was found that corrosion caused failure of brush holders, springs, generators, relay switches, relay boxes, and terminal boards. Any exposure to outside storage conditions caused heavy corrosion. Salt fog or salt spray produced heavy corrosion, usually more severe than the typical humidity corrosion on exposed unplated metallic parts. The principal damage that occurred on flight and navigation instruments was caused by corrosion of the instrument cases, corrosion within the cases, and fungous attack. One of the most striking evidences of deterioration was the fungous attack observed in almost every instrument incorporating an optical system.

At one air base on Oahu, Hawaii, the landing surface was approximately 100 yd from the edge of the water and the elevation only 6 ft above sea level. Consequently, waves often washed over the runway and a constant salt mist enveloped the base. This caused serious corrosion problems. For example, all copper-clad-steel antenna wire corroded so badly in a few days time that maintenance crews replaced all wire antennas every 7 days whether the aircraft had been flown or had been sitting on the ground for the entire week. Cadmium-plated stub and dipole antennas were seriously corroded after a 15-day exposure to salt spray. As a result, these antennas were cleaned and painted with a protective coating.

Airborne communications and electronic equipment and associated ground equipment, whether in operation, in storage, or in the repair shop, were subject to conditions of salt spray, coral dust, volcanic gases, long periods of humidity, water condensation, and fungous attack. Moisture appears to be the most important factor in the deterioration of electronic equipment, being responsible for approximately 90 percent of operational failures. Many failures are due to deterioration attributed to salt spray, fungus, dust, and volcanic gases. The sun during the heat of the day dries the surface of the roads, air strips, and areas in and around warehouses and storage dumps, producing coral dust, volcanic ash, or clay dust in such quantities that only moderate traffic and winds raise clouds of dust which penetrate all equipment not completely enclosed.

(3) *General observations.* Most losses of metallic materials were the result of inadequate preservation or packaging, rough handling, open storage, negligence, and inadequate repackaging. In general, aluminum alloys presented few problems, but in certain circumstances difficulties were encountered; for example, condensation on interior surfaces without proper drainage caused corrosion. In addition, chloride from salt spray or coral dust that collected on aluminum alloy surfaces caused pitting. Galvanic corrosion occurred when an aluminum alloy was in contact with improperly plated steel fittings or other dissimilar metals. This problem was most severe in the case of repair parts that had been exposed to condensation of free water in the package during storage. Virtually no corrosion of aluminum-based alloys was found where the parts were properly protected and the coatings were not damaged. In addition, no corrosion was found on parts fabricated

from corrosion-resistant steel, and no difficulties were reported with the stabilized corrosion- and heat-resistant alloys used in exhaust systems. In nearly all cases, unprotected zinc-based diecastings were coated with a heavy white corrosion product. Hardware on vehicles, such as door handles, gave very poor service. Attempts at protective finishes on the die-cast parts were not always effective.

In a second study the effects of environment on a variety of materiel in the New Guinea area were surveyed (Ref. 29). Comments and observations concerning various types of deterioration occurring as a result of exposure to various environmental factors are summarized in the paragraphs that follow. They largely corroborate the findings of the previous study.

(1) *Macrobiological organisms.* Marine borers can destroy piers and wooden vessels in a short time. While ordinarily confined to salt water, some of the more destructive types also are found in fresh water in the upper regions of some tropical rivers. Spiders, another macro-organism, also cause some problems; e.g., webs inside electrical equipment collect moisture and cause short circuits and electrical leakage.

(2) *Optical instruments.* Optical instruments are damaged easily by fungi that thrive on paint, fabrics, oil or waxes, the balsam used between lenses, dust, and even fingerprints on the surfaces of lenses and prisms. The first sign of fungus on glass is a fogging caused by the presence of the fungi itself. Fogging may take place very quickly, sometimes within 2 weeks. Depending on the construction of the instrument, the fungus sometimes can be wiped off easily. If fungus is permitted to grow on glass for more than a few days, serious damage results. The stain is of ultramicroscopic thickness and sometimes shows diffraction colors. Prolonged contact with fungus leads to major damage, causing the surface of glass to become roughened and etched.

(3) *Tentage.* Untreated tents, tarpaulins, and canopies have a very short life in the tropics. In the Port Moresby, New Guinea, area, they leaked within 6 mo and become unserviceable after 9 to 12 mo. At Milne Bay, New Guinea, they leaked in 3 to 4 mo and were useless after 6 to 8 mo.

(4) *Vehicles and vehicle repair parts.* The following list of incidents typifies vehicle problems in tropical climates:

(a) Cylinders of engines of newly arrived tanks were very rusty internally and externally. In addition, crankshafts, camshafts, voltage regulators, differentials, ball bearings, and tank gun components often arrived with a coating of rust.

(b) It was necessary to paint the woodwork on trucks that had just arrived before placing them in service. Canopies of newly arrived trailers were torn and showed definite signs of rotting. Assembled vehicles, when shipped as deck cargo, often arrived with unserviceable engines. General internal corrosion of jeeps was so bad that 50 manhours were required to recondition each engine. While external corrosion of vehicle bodies was not serious, some rust had developed at the walls and seams.

(c) Unless engines of vehicles held at vehicle parks were run at regular and frequent intervals, they became unserviceable because of corrosion of the cylinder walls. Gear boxes and rear axles held at workshops were subject to severe internal corrosion. Unless carriers and tanks were moved once a week, the tracks froze because of corrosion. In some areas, brakes were relined after the vehicle was run 20 to 30 mi a day for 2 weeks. Internal corrosion of die-cast carburetors and fuel pumps occurred if vehicles were left stationary for more than a week. In some cases, the white deposit caused blockage of jets and freezing of screws.

(d) Bolts and wooden bodies of truck floors corroded, degraded, and in some cases broke because of wood shrinkage.

(5) *Airframes, aircraft instruments, and accessories.* Condensation inside aircraft occasionally impaired operation of instruments.

Electrochemical corrosion was a serious problem in many cases with aircraft-alloy landing wheels, for example, readily corroded.

(6) *Armament.* Rifles received in New Guinea were severely rusted as a result of being packaged in cartons that became wet during transit and fell to pieces. Many repair parts for small arms arrived in a rusty condition. Small arms rust rapidly in service. Main springs of pistols rust quickly, then snap. Installed machine guns in aircraft are subject to atmospheric corrosion which, in low altitude flying, is accentuated by salt in the atmosphere. Repair parts for most artillery and antiaircraft guns arrived in a rusted condition.

(7) *Ammunition.* Outer wooden boxes are attacked often by termites, becoming useless after 6 mo of open storage. Metal strapping on ammunition boxes also rusts. In exposed storage, about 15 percent of grenades became useless. Many mortar projectiles became unserviceable because of corrosion.

4-6.2 MATERIEL READINESS IN OTHER CLIMATES

As a general rule, all deteriorative agents present in the tropical climate are also present in other climates. The difference lies in the magnitude of their effects. By and large, fungous attack is relatively unimportant except in tropical and semitropical regions or in warm-damp spaces in buildings. In temperate zones where proper combinations of moisture and temperature occur seasonally, microbes will damage materiel but a lesser degree than in the Tropics. In cold climates, such deterioration is negligible.

All natural and most induced factors occur in temperate climates and cause deterioration and impairment of operational readiness; however, in temperate climates these factors require reasonably long periods to produce damage sufficient to affect materiel readiness. Given proper conditions, such damage can and does occur. Examples include wood rot, age deterioration of rations, especially when improperly stored, mildew of textiles, termite attack of wooden structures, metal corrosion, and zones without deterioration is difficult. Controlled environment warehouses are often necessary to maintain readiness; weapons, vehicles, and electronic items require careful preparation for long-term storage.

Unlike the temperate climate, the desert environment is an extreme environment characterized by high solar radiation, low humidity, low rainfall, high temperature, and increased exposure to sand and dust. Severe microbiological attack does not occur because of the low humidity, although temperatures are in the right range. Corrosion is reduced greatly because of the absence of rainfall and the accompanying extremely low humidities. In fact, the desert is the site of large storage depots for aircraft and vehicles because of these favorable conditions.

The few problems that result from deterioration in the desert environment are associated primarily with the high temperatures and high solar radiation, plus blowing sand and dust. It is difficult to prevent deterioration of materiel susceptible to high temperature or low humidities, although protection from sand and dust and direct solar radiation is possible. Certain textiles and plastic materials are susceptible to the ultraviolet wavelengths in solar radiation. These wavelengths are attenuated by atmospheric moisture in temperate and tropical climates but not in the desert. In the desert, therefore, ultraviolet exposures are significantly higher. Consequently, deteriorative processes in plastics and textiles that have as their prime agent the exposure to ultraviolet light progress rapidly.

The combined solar radiation and high

ambient temperature levels also produce very high temperatures in materiel. The deteriorative processes that depend upon high temperature—of major importance are those that occur with respect to subsistence items such as food—are accelerated in such an environment. Low humidity can also cause deterioration of textiles and leathers which require water in the material to give it proper flexibility. Without the required water content, they crack rapidly when flexed.

The effects of the desert environment in Southwest Asia on selected military materiel have been evaluated (Ref. 31). Many packaged foods normally used by the military (those of the nonperishable type) are extremely shortlived in high temperature environments, particularly in open storage. For many foods the deterioration rate doubles for each 18 deg F increase in storage temperature.

Gasoline deteriorates largely through the formation of gum, which causes filter clogging and lowering of octane number. The effect of varying temperature is similar for all gasoline—the rate of gum formation approximately quadruples for each 20 deg F rise in temperature. For a typical gasoline with inhibitors added, 5 mg of gum per 100 ml of gasoline might form in 12 mo at a storage temperature of 100°F—this is enough gum to cause rejection.

The arctic climate, like the desert climate, is an extreme climate. In the Arctic, however, the factors that are important for operational readiness are associated with low temperature, solid precipitation, wind, and, in some cases, humidity. Starting of vehicles is a chronic problem because of the temperature effects on batteries and lubricants. Small quantities of water (resulting from water vapor condensation as temperature is lowered) can freeze and clog fuel systems, rendering vehicles inactive and incapable of starting when needed. Dilution of engine lubricants results from both moisture condensation in the crankcase and from passage of gasoline into the crankcase. Oil dilution also is increased by the required extended warm-up time for engines. Idling engines use rich fuel-air ratios which are conducive to crankcase oil dilution.

Blowing snow and ice cause problems involving operational readiness of materiel that is stored out-of-doors in arctic climates. Snow and ice blown into crevices and cracks freeze, causing various mechanisms to become inoperative (this is a chronic problem). A similar problem occurs whenever vehicles that have been in use are parked. The vehicle, being warmer than the freezing point, melts snow that may have fallen upon it. Then, as the vehicle cools, the water that was melted from snow freezes, becoming solid ice and causing seizure of various mechanisms. Examples of this type of problem range from the freezing of windshield wipers to the freezing of turrets in tanks, which prohibits aiming of the weapon. The problems of snow and ice coverings on materiel also represent some hampering of operational readiness. On occasion, when snow and ice loads become sufficient, mechanical and structural damage can occur.

Rockets and gun propellants crack when exposed for long periods to low temperatures (Ref. 20). NIKE-HERCULES propellants were sent to the Arctic for a 10-yr storage program. After 3 yr of storage, longitudinal cracks had developed along the core, which were about 1/8 in. wide at the surface. Gun propellants exhibit the same phenomenon. Gun propellants exposed to low temperatures are known to crack, thereby exposing a much larger surface area to burn. Despite the lowered burning rates produced by low temperatures, increased burning can occur as a result of cracking because of the increased surface area. The excess pressures developed may be sufficiently high to rupture gun tubes.

4-6.3 LONG-TERM EXPOSURE TO EXTREME NATURAL ENVIRONMENTS

A study of long-term exposure of aircraft components to extreme environments provides interesting information on operations environment (Ref. 32). Components from four crashed aircraft were analyzed.

(1) A B-24 aircraft that had crashed and remained undisturbed in the North African Desert for 17 yr receiving full exposure to the desert climate (Fig. 4-13)

(2) A B-17 aircraft that had crashed on the Greenland Ice Cap in 1942 and had remained undisturbed in the arctic climate for 23 yr (Fig. 4-14)

(3) A C-54 aircraft (Fig. 4-15) and a B-24 aircraft that had crashed in the jungles of Panama.

Table 4-17 compares climatic conditions for the downed aircraft. Discussion of the effects of long-term exposure of the four aircraft to the desert, arctic, and tropical climates follows.

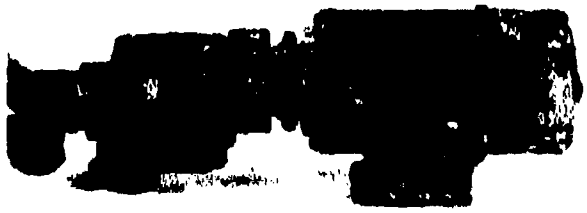
In 1960, 16 pieces of equipment removed from a B-24 aircraft that had lain in the Libyan Desert for 17 yr were examined. The desert climate is generally hot and dry—excellent for preservation of the equipment as the investigations proved. The aircraft had spent 17 yr in the equivalent of a solar oven, baking at air temperatures as high as 120°F. It was estimated that equipment temperatures inside the plane reached 200°F. The removed equipment, including an engine-driven pump, turret retraction motors, and other portions of the hydraulic systems, were in extremely good condition.

In 1964 a B-17 aircraft that had crashed on the Greenland Ice Cap in 1942 on its way to England was discovered. The aircraft had lain on the ice cap for 23 yr, completely undisturbed in the frigid arctic environment, with temperatures ranging from −80°F in the winter to an occasional +38°F in the summer. In the winter, winds of 180 mph swept across the ice cap, creating an extremely hostile environment. Equipment was removed from the aircraft for examination and analysis. Clothing in flightbags on the aircraft was found to be in excellent condition in spite of this prolonged storage. The hydraulic turret transmission and hydraulic accumulator were removed from the aircraft and examined. The hydraulic accumulator was found to contain its normal 325-psi air charge and the turret transmission, upon test, met the requirements of a new unit. The turret transmission was disassembled and found to be in

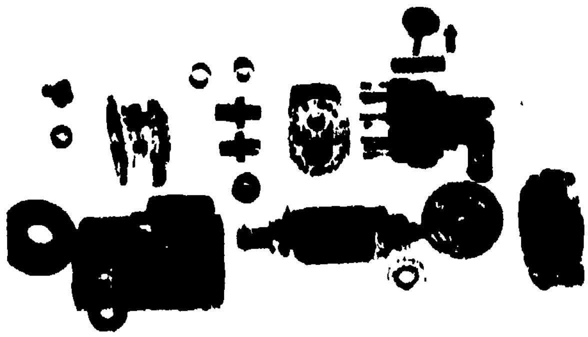
Figure 4-13. Crashed B-24 in North African Desert (Ref. 32)

Figure 4-14. Crashed B-17 on Greenland Ice Cap (Ref. 32)

Figure 4-15. Crashed C-54 in Panama Jungle (Ref. 32)



(A) External corrosion



(B) Internal parts showing little corrosion

Figure 4-16. Electric Motor Driven Pump from Crashed C-54 After 6 Yr in Tropical Jungle (Ref. 32)

excellent condition with all parts bright and shiny. Seals were soft and pliable and did not leak. Other equipment, including flight instruments, a cal .45 automatic pistol, navigation equipment, and first-aid kits, were in good condition.

These investigations, involving first the desert and then the arctic climates, showed that equipment survives in excellent condition. The other major environment is the extremely humid, fungus-growing tropical jungle. During World War II approximately one aircraft per week crashed either in the jungle or in the sea in the Panama area. Although the positions of 20 crashed aircraft were known precisely in 1966, only two could be found in the thick jungle growth, a C-54 cargo-type aircraft which crashed in 1960, and a B-24 bomber.

Among items removed from the C-54 was an engine-driven hydraulic pump, the shaft end of which had not deteriorated. When the unit was disassembled, the bearings and shaft were found to be in serviceable condition while the shaft seal and O-rings were still soft and pliable. The electric motor on the hydraulic pump was covered with fungus and external corrosion and when tested it would not turn. Disassembly revealed several open leads. When tested separately, however, the gear pump produced its normal 900-psi system pressure and its internal parts showed very little corrosion or deterioration (see Fig. 4-16).

TABLE 4-17.
COMPARISON OF ENVIRONMENTAL CONDITIONS OF CRASHED AIRCRAFT (Ref. 32)

Item	Environment and location		
	Desert, Africa	Arctic, Greenland	Jungle, Panama
Aircraft	B-24	B-17	C-54
Location	Libyan Desert	Ice Cap	Mountain rain forest
Temperature extremes, °F	+26 to +120 (Component temp. to +200)	-80 to +38	+71 to +88
Average humidity, %	10 to 36	55 to 70	90 to 100
Average yearly rain, in.	Less than 1/4	No rain; heavy snow	148
Maximum wind velocity, mph	50	In excess of 180	70

The engine-driven fuel pump had only minor external deterioration and its internal parts were in fair-to-good condition. The wing flap cylinder was also removed. It operated normally when system pressure was applied under test; when disassembled, the cylinder piston rod was bright and shiny and the elastomeric seals were soft and pliable enough to seal under pressure.

The second aircraft, the B-24 bomber, crashed in 1942 approximately 240 mi northwest of Panama City near the Costa Rican border. In this area the average rainfall is 106 in. yr^{-1}; the average relative humidity is 87 percent; and the average temperature is 85°F. Although the aircraft had been stripped of a great many of its parts by local Indians, a flap gear assembly, parts of an electric motor, and other items were obtained for examination. A radio panel removed from the aircraft was very heavily corroded. The fuel flow transmitter was covered with corrosion and fungus, but on disassembly, internal parts were found to be in fair condition. Almost all of the hose sections, although apparently in fair condition, leaked badly.

Overall, equipment exposed 17 yr in the desert climate was in excellent condition with most of it meeting the requirements of new units. Some large seals, such as the accumulator diaphragm, hardened slightly as a result of the low humidity found in the desert. The equipment exposed 23 yr in the arctic climate was also in excellent condition. It met the requirements of new equipment in most cases. The accumulator diaphragm was in like-new condition, having retained its air charge. It appears that the somewhat higher arctic humidity assures good seal life over extended storage periods, without being hot enough to cause excessive corrosion. The equipment removed after 6 to 24 yr in the tropical climate showed heavy deterioration on items that were not sealed, such as electric motors, radio panels, and thin gage metallic sections. The fungous growth on much of this equipment was heavy and damaging. On the seal components, such as hydraulic pumps, deterioration was only partial, with some of the units still operable. The O-rings were in good condition and still functional in most cases. Since the hydraulic equipment primarily examined in these studies are essentially sealed units, it appears that if equipment can be sealed, its chances of surviving long-term exposure in the tropics is excellent.

Components were also removed from aircraft at the Davis-Monthan Air Base in Arizona for study. These aircraft, with components installed, were stored in the open desert by the Air Force for 5- to 10-yr periods. The hydraulic equipment, instrumentation, and various other items of equipment checked in these stored aircraft were in excellent condition.

REFERENCES

1. H. C. Schafer, "Some Thoughts on RDT&E Environmental Theory Related to Propulsion Systems", *Proceedings*, Institute of Environmental Sciences, Mt. Prospect, Ill., 1970, pp. 108-10.

2. T. M. Rienzi, *Vietnam Studies, Communications-Electronics 1962-1970*, Department of the Army, Washington, DC, 1972.

3. *Lessons Learned*, Combat Service Support, RVN, Adjutant General's Office, Washington, DC, June 1966 (AD-855 111).

4. R. D. Campbell, *The Environmental Element in Military Operations*, George Washington University, Washington, D.C., for US Army Engineer Waterways Experiment Station, Vicksburg, Miss., September 1957.

5. R. W. Forsyth and V. P. Forsyth, "Concepts in Mobility: Why Not a New Approach?", Ordnance, LVII, May-June 1973, p. 476.

6. S. J. Tompkins, "Tomorrow's Army Transport", Ordnance, LVII, May-June 1973, p. 470.

7. N. R. Mason, Jr., *The Impact of Environment on Military Operations*, George Washington University, Washington, DC, for US Army Engineer Waterways Experiment Station, Vicksburg, Miss., September 1957.

8. C. E. Hesaltine, Jr., *Military Operations as Characterized by the Effects of Environment*, George Washington University, Washington, DC, for US Army Engineer Waterways Experiment Station, Vicksburg, Miss., September 1957.

9. *Project Wheeltrack I*, Vol. 1, US Army Transportation Board, Ft. Eustis, Va., 1963

10. AR 70-38, *Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions*.

11. R. A. Liston, "Unusual Vehicle and Component Concepts", in Tech. Report 9560, Research Report No. 6, Components Research and Development Laboratories, US Army Tank-Automotive Command, Warren, Mich., November 1966, p. 288 (AD-651 726).

12. *Report of Army Ground Forces Winter Test Program 1946-1947, Final Report of AGF Task Force Williwaw, Cold-Wet Conditions*, Vol. III, Development Section, Hq. Army Ground Forces, Ft. Ord, Calif., 12 June 1947.

13. W. S. Newton and C. G. Makrides, *Effect of Climate and Environment on Ground Support Equipment*, WADC TR-54-132, Corvey Engineering Co., for Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, May 1954.

14. M. G. Bekker, Rev. by S. H. Woods, *Introduction to Research on Vehicle Mobility*, Part I, Stability Problems, Report No. 22, Ordnance (now Army) Tank-Automotive Command, Warren, Michigan, May 1957.

15. *Overall Summary Report on Summer Environmental Tests 1952, 53rd Rept. on Project TB5-1401, Summer Desert Tests, Yuma, Arizona, Summer Arctic Tests, Ft. Churchill, Canada*, Ordnance Climatic Test Div., Development and Proof Services, Aberdeen Proving Ground, Md., 1952.

16. *Summary of Critique on Winter Testing 1951-52*, Ordnance Corps, Development and Proof Services, Aberdeen Proving Ground, Md., 14 April 1952.

17. R. D. Sands et al., *Environmental Guide for Arctic Testing Activities for Fort Greely, Alaska*, U S Army Natick Laboratories, Natick, Mass., May 1971.

18. *Supplement, Arctic Test, Wheeled Transport Vehicles, Operation Flin Flon, 1953-54*, 157th Report of Project No. TB5-1401, Development and Proof Services, Aberdeen Proving Ground, Md., 9 September 1954.

19. *Inspection of Ordnance Engines After Endurance Operation under Arctic Conditions at Ft. Churchill, Manitoba, Canada*, 227th Report on Project TB5-1401, Development and Proof Services, Aberdeen Proving Ground, Md., 22 December 1954.

20. M. Resnick and V. T. Riedinger, "The Effects of the Arctic Environment on Munitions", *Proceedings*, Institute of Environmental Sciences, 1966, Mt. Prospect, Ill., 1966, pp. 307-19.

21. *Report of Environmental Operation, Topo-Antarctica 1962*, U.S. Army Transportation Board, Ft. Eustis, Va., May 1962.

22. *Report of Environmental Operation, Lead Dog 1960*, U S Army Transportation Board, Ft. Eustis, Va., 1960.

23. *Report of Environmental Operation, Pole Hop 1960*, U S Army Transportation Board, Ft. Eustis, Va., May 1962.

24. G. H. Howe et al., *Classification of World Desert Areas*, Tech. Report 69-38-ES, U S Army Natick Laboratories, Natick, Mass., December 1968.

25. *Ordnance Corps Environmental Testing, Summer Desert Tests, 1951 & 1952, Yuma Test Station, Yuma, Arizona*, Ordnance Climatic Test Division, Development and Proof Services, Aberdeen Proving Ground, Md.

26. *Overall Summary Report on Summer Environmental Tests 1954, 220th Report on Project TB5-1401, Summer Desert Tests, Yuma Test Station, Yuma, Ariz., Summer Arctic Tests, Ft. Churchill, Manitoba, Canada*, Ordnance Climatic Test Division, Development and Proof Services, Aberdeen Proving Ground, Md., 25 October 1954.

27. *Overall Summary Report on Summer Environmental Tests 1953, 140th Report on Project TB5-1401, Summer Desert Tests, Yuma Test Station, Yuma, Ariz., Summer Arctic Tests, Ft. Churchill, Manitoba, Canada*, Ordnance Climatic Test Division, Development and Proof Services, Aberdeen Proving Ground, Md., 30 October 1953.

28. Army Research and Development, 13, No. 5 (August 1972), p. 4.

29. *Tropical Deterioration of Air Force Materiel and Equipment*, Army Air Forces Tropical Science Mission, Air Technical Service Command, Wright Field, Ohio, 15 May 1946.

30. *Causes and Control of Deterioration of Materiel in the Wet Tropics*, Report of Headquarters Army Air Forces Tactical Center; Arctic, Desert, and Tropic Information Center, July 1944.

31. *Southwest Asia: Environment and Its Relationship to Military Activities*, Quartermaster Research and Engineering Center, Environmental Protection Research Division, Natick, Mass., July 1959.

32. A. B. Billet, "Jungle Explorations of World War II Aircraft", *Proceedings*, Institute of Environmental Sciences, Mt. Prospect, Ill., 1967, pp. 353-61.

CHAPTER 5

LOGISTIC ENVIRONMENT

5-1 INTRODUCTION

5-1.1 GENERAL

The logistic environment is sufficiently different from the operational environment to merit separate treatment. In the logistic environment, various precautions are taken to ameliorate the effects of environment on materiel or to prevent exposure to certain environmental factors. Packaging and warehousing are examples of these precautions. Generally, the factors that can be excluded from the logistic environment include snow, rain, ice, direct solar radiation, and, to some extent, blowing sand and dust, and snow. Packaging also may protect materiel from mechanical environmental factors such as shock and vibration. It is more difficult to provide protection against temperature, humidity, air pressure, corrosive vapors, and induced electromagnetic and nuclear radiation effects. When it is necessary to prevent exposure of materiel to these latter factors, special packaging or storage facilities are required.

If the packaging and the shelter provided by storage facilities or covered transportation vehicles were removed, the effects on materiel would be the same in the logistic and operational environments in many respects. In field-supply operations and at advanced bases, the protective packaging and shelters of the logistic environment are often either unavailable or their integrity is violated so that materiel is exposed to the ambient environment. Thus, the effects of environment on materiel in these advanced portions of the logistic cycle is considered to be more accurately represented by the operational environment.

In many treatments of the transportation aspects of the logistic environment, much emphasis has been placed on mobility in adverse environments. In applying advanced bases and field operations, mobility is an important factor; it is still more important as a characteristic of the operational environment. Even so, when material is removed from its protective warehousing and loaded on transportive equipment that cannot move (because of mobility impairment), the materiel is exposed to severe environments for much longer periods of time than normally encountered during transportation. To that extent, mobility is an environmental factor in the logistic environment.

Rough terrain also causes materiel in transit to receive a much more severe shock and vibration exposure than normally is obtained in over-the-road operations. This is an important environmental hazard although little work on the quantitation of these effects has been done, and few reports on the severity of this environment have been published.

The logistic system provides support for military operations ranging from peacetime training to major warfare. The physical environment of this logistic system includes factors associated with terrain and climate as well as the influence of the development level of the inhabitants of the field of operations.

Terrain strongly affects the configuration of the distribution system. Major supporting stocks for an island campaign are on ships or on other islands, whereas, for operations conducted in large continental areas, a succession of supply depots and an overland transportation system are required. Other possible physical configurations include:

(1) Operation on the North American continent with overland distribution from the source of supply to the combat area

(2) Operations confined to narrow coastal regions (e.g., Vietnam)

(3) Operations deep within the perimeter of a large landmass (e.g., central Africa).

Distribution systems in mountainous terrain differ significantly from those on flat terrain, and in arctic and subarctic regions the distribution task is vastly more complicated than those in temperate areas.

Except for certain specific severe environmental conditions, discussions of these terrain factors are associated with the operational environment. By eliminating these logistic operations occurring at the end of the logistic chain closest to the user, the logistic environment can be described in terms of specific components.

Basically, the classes of operations carried out in the logistic system are:

(1) *Handling*. Loading, unloading, stock rotation within warehouses, movement within depots, transfer to and from storage to transport vehicles

(2) *Transportation*. Movement of materiel from one geographic point to another

(3) *Storage*. Holding materiel within warehouses and other storage areas.

The logistic flow for any one item is variable, depending upon its planned deployment. Fig. 5-1 illustrates a typical logistic flow, and Fig. 5-2 illustrates the distribution pattern for a typical ammunition item. As can be seen from these diagrams, handling, transportation, and storage are repetitive functions in the logistic cycle—each occurs many times.

The purpose of a logistic system is to provide supplies to the ultimate users when and where needed. The functions of the logistic system are (Ref. 2):

(1) Receipt. The process of accepting supplies into the military supply system

(2) Storage. The process of holding and caring for supplies prior to issue

(3) Transportation. The movement of supplies to, within, and from the distribution system

(4) Issue. The releasing of supplies to consuming or using agencies or activities.

Basically, the system moves supplies from the grower, producer, fabricator, or manufacturer to the user. Its goals are to be responsive to the user, to be sufficiently flexible to adapt to rapidly changing conditions, to be economical in terms of use of physical and manpower resources, and to be resistant to disruption by either the forces of nature or enemy actions.

5-1.2 LOGISTIC MATERIEL CLASSES

Operation of the Army requires over a million separate items of supply. The types and levels of supply support requirements vary, depending on environment, tactical concepts, training level, and intensity of combat. Army supplies are categorized in several ways for management purposes. Three examples are (1) according to importance or the nature of the items, (2) according to cost, and (3) by class of supply.

The breakdown of the items by importance or nature of the item follows (Ref. 1):

(1) *Principal Items*. Materiel items, the supply of which is, or is about to be, increasingly active; a high value item; or an item whose procurement will be difficult due to long lead time, shortage of strategic materials, or difficulty of manufacture.

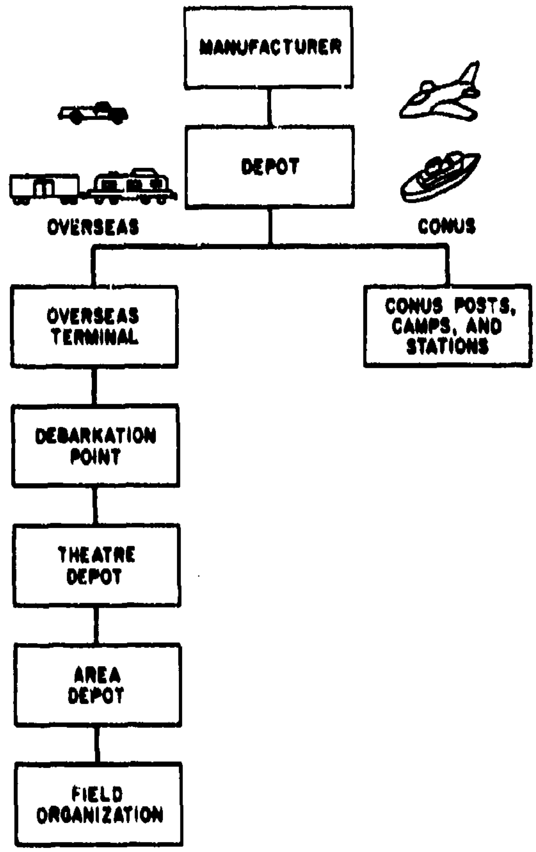


Figure 5-1. Typical Logistic Flow (Ref. 1)

Principal items represent less than 1 percent of the items stocked by the Army, yet they account for 60 percent of the procurement funds.

(2) *Secondary items.* All other supplies except repair parts, clothing, and subsistence; characterized by short lead time, low value, and ease of procurement

(3) *Repair items.* All essential elements, materials, components, assemblies, or subassemblies required for the maintenance and repair of an end item

(4) *Off-the-shelf items.* Items regularly stocked by commercial organizations to supply normal demands, either principal, secondary, or repair items

(5) *Bulk procurement items.* Items normally shipped in bulk form and not sent through depot facilities; usually secondary items.

Together, the secondary and repair items represent 85 to 90 percent of the entire workload and cost of the distribution system, yet they account for only 25 percent of the procurement funds.

Cost, the second categorization, is often considered in conjunction with mission essentiality. Items that are critical and very

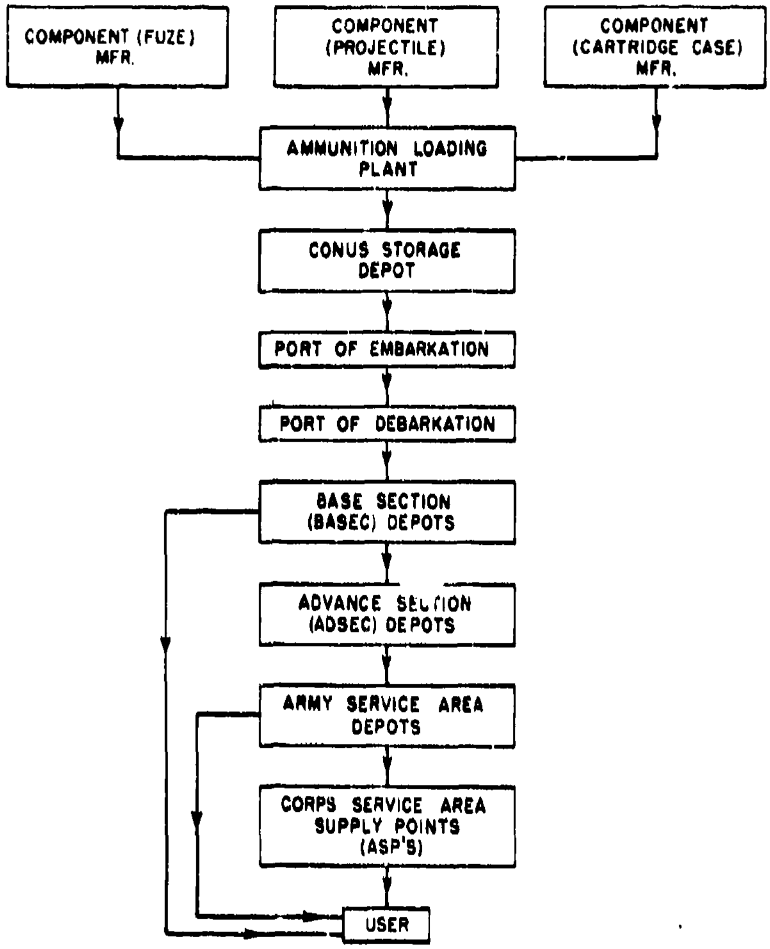


Figure 5-2. Distribution Pattern for Typical Ammunition Item (Ref. 1)

high in cost may be "intensively managed"; for example, major weapon systems such as tanks. Secondary items normally are divided into low, medium, and high dollar value items depending on the yearly demand for each.

The third category is comprised of 10 classes of supply (Ref. 2):

(1) *Class I.* Subsistence

(2) *Class II.* Clothing, individual equipment, tentage, organizational tool sets and tool kits, hand tools, and administrative and housekeeping supplies and equipment

(3) *Class III.* Petroleum, fuels, hydraulic and insulation oils, and lubricants (POL); preservatives; liquid and compressed gases; bulk chemical products; coolants, deicing, and antifreeze components, together with components and additives of such products; and coal

(4) *Class IV.* Construction materials, including all installed equipment and all fortification/barrier materials

(5) *Class V.* Ammunition of all types, including chemical, radiological, and nuclear ordnance; bombs; explosives, mines; fuzes; detonators; pyrotechnics; missiles; rockets; propellants; and other associated items

(6) *Class VI.* Personal demand items: nonmilitary sales items

(7) *Class VII.* Major end items: A final assemblage of end products that is ready for its intended use; for example, launchers, tanks, whole machines, and vehicles

(8) *Class VIII.* Medical materiel, including medical peculiar repair parts

(9) *Class IX.* Repair parts (less medical peculiar repair parts): all repair parts and components to include kits, subassemblies and assemblies, reparable and irreparable, required for maintenance support of all equipment

(10) *Class X.* Materiel to support nonmilitary programs: agricultural and economic development.

Items also can be classified by their behavior in the supply system: either fast moving or slow moving. The turnover of an item is important from the standpoint of overpackaging. Since fast-moving items are readily depleted, it usually is not necessary to wrap the individual units extensively within the outer package.

5-2 PACKAGING TO PROTECT MATERIEL FROM ENVIRONMENTAL FACTORS

5-2.1 GENERAL

The purpose of military packaging is to protect items of materiel so that they can perform their intended function when their use is required. Basically, packaging must protect an item from the time of production, through transport and storage, until delivery to its ultimate user. During transport, protection must be achieved while complying with appropriate civil and military transportation regulations. Storage of military items may be for indefinite periods of time in both protected and unprotected facilities. During this storage period, the package must protect the item against physical damage and other environmentally induced deterioration. In some cases, the packaging must incorporate provisions for inspecting and performing maintenance on the packaged item. From the military standpoint, good packaging methods are those that protect materiel from deterioration and damage at a minimum cost.

Fundamentally, the objectives of uniform preservation and packaging of items of military supplies can be summarized as follows (Ref. 3):

(1) To provide efficient and economical protection to supplies, material, and equipment from physical and mechanical damage during handling, shipment, and storage from the time of original purchase until used

(2) To assure maximum life, utility, and performance of supplies, materials, and equipment through prevention of deterioration

(3) To facilitate efficient receipt, storage, inventory, transport, and issue

(4) To provide identification, handling, and shipment markings

(5) To assure the greatest practical uniformity in the development of requirements for preservation and packaging of the same or similar items

(6) To effect economy by insuring the use of packages of a minimum weight and cube, con[illegible]nt with anticipated storage and equipment hazards.

A detailed discussion of preservation, packaging, and packing is contained in Ref. 3.

Damage in transit is likely to be physical, due to the use of inappropriate or poorly constructed or designed containers. Improper use of strapping often results in damage. Articles that do not fill the container completely must be blocked, braced, fastened, or otherwise restrained to prevent moving or shifting with resulting damage to the contents and the container. While careless handling cannot always be avoided, the proper choice of containers, avoidance of overloading, effective interior packing, and correct strapping and nailing will go far to reduce the damage received during shipment and storage.

The subject of preservation and packing has become increasingly important due to the increase in worldwide movement of equipment, overtaxed transportation facilities, and overcrowded warehouses. An indication of the magnitude of the problem is revealed by the fact that commercial losses due to damage of goods in transit measured in dollar values paid out in claims by the railroads alone to manufacturers exceeded $91 million in a recent year (Ref. 3). Much of this loss was attributed to improper packaging, the balance to carelessness and neglect.

5-2.2 PACKAGING PROTECTION LEVELS

Military levels of package protection are described in terms of the performance expected of the package or pack and must be translated into specific technical or design requirements for individual items or categories of items. The performance criteria follow (Ref. 1):

(1) *Level A, Military Package or Pack.* Preservation and packaging or packing that will afford adequate protection against corrosion, deterioration, and damage during worldwide shipment, handling, and open storage.

(2) *Level B, Limited Military Package or Pack.* Preservation and packaging or packing that will afford adequate protection against damage during multiple shipments in which shipping and handling will be under cover and storage will be in warehouses or other structures providing equivalent protection from the weather. These conditions are less hazardous than those that Level A is designed to meet. This level provides a higher degree of protection than afforded by Level C. The design of Level B is based on knowledge of the shipment, handling, and storage conditions to be encountered and on the determination that the costs of preparation are less than Level A.

(3) *Level C, Minimum Military Package or Pack.* Preservation and packaging or packing that will afford adequate protection against corrosion, deterioration, and damage during direct domestic shipment from the supply source to the first receiving activity for immediate use or for controlled humidity storage. This level, at a minimum, will conform to applicable carrier rules and regulations.

As can be seen from the preceding definitions, the level to which a particular item is packaged is determined by the distribution requirements of the item. The degree of protection afforded within a particular level is based on the nature and characteristics of the item. Characteristics of military materiel that make the protection of materiel during storage and transport more difficult than under civilian circumstances are:

(1) When an item arrives at its destined point of use and is unpacked, it must perform its desired function. Essentially, protection is aimed at 100-percent reliability.

(2) The destination and means of transport for any given item of materiel are usually unknown.

(3) The type and duration of storage are also usually unknown; extreme variety of types and long durations of storage are possible.

5-2.3 ENVIRONMENTAL EFFECTS ON PACKAGING

The following examples of the effect of environment on packaging are included for illustrative purposes only. They are not intended to demonstrate the scope of environmental effects on packaging nor are the individual cases discussed represented to be of greater significance than any other case.

5-2.3.1 Air Cell Packing Material

Among the various packing materials, inflated cushioning types are finding many applications. One of the products that has evolved in seeking solutions to the problems of cushioning is the encapsulated air cell. This type of cushioning consists of plastic film materials sandwiched together with trapped air bubbles. A study was conducted to determine the reliability of the pebble grain and marshmallow-appearing air cells at the reduced atmospheric pressures experienced in nonpressurized military and commercial aircraft at high altitudes (Ref. 4). Sheets of the various types of such packing material were stacked to produce 1-in. nominal thickness test specimens of each material. The stacks were then confined, stress-loaded, and placed in an altitude chamber where they were subjected to changes of altitude ranging from ground level to 50,000 ft. The extent of rupture or delamination of the cells was determined. After such conditioning, the specimens were again confined, stress-loaded, and instrumented for dynamic impact analysis. Evaluation of the test data disclosed a rising percentage of cellular delamination coupled with a declining degree of shock attenuation as a consequence of the increasing elevations.

Delamination of the three types of material tested at flight altitudes spanning 25,000 to 50,000 ft was sufficiently severe to preclude their use in nonpressurized aircraft. From the study, it was recommended that such air-cushioning materials be restricted to ground level applications except in cases where air shipment affords a pressurized cargo section.

5-2.3.2 Labels

In another study a comparison test was performed among different shipping label covers in an outdoor weathering environment for a 6-mo period (Ref. 5). The "glue pot" technique of brushing on an adhesive, both to affix labels to containers and as overlay protection to make them water-resistant, has been the approved labeling method for many years. Recently, evaluations have been made of pressure-sensitive transparent tape labels and transparent pressure-sensitive label overlay methods.

Outdoor exposure was used to compare weathering effects on different label covers attached to two triple-walled, weather-resistant fiberboard boxes. Three different groups of pressure-sensitive, transparent tape overlay materials extending 5/8 in. beyond each edge of the label were tested along with a group with brush-on adhesive and no overlay protection, a group with brush-on adhesive and brush-on overlay, and a green-tinted polyethylene group to evaluate protection from ultraviolet radiation. The test labels with their six different label cover variables were placed on different faces of the test containers to permit a good exposure of each variable to north, south, east, west, and top exposures. Each container was placed on a separate pallet and secured with nonmetallic straps. Average temperatures for the 6-mo period varied from 42°F in December to a maximum average of 80°F in September. Total rainfall per month varied from 1.05 in. in August to 5.53 in. in December. The number of hours duration of gusty winds varied from 8 hr in August to 106 hr in November. Generally, wind gusts varied between 12 and 35 mph.

At the end of the test, weathering appeared to be severe in all exposed directions. Of the 12 labels under test on the top surfaces of the boxes, only one label and one-third of another remained intact. Labels on the sides fared considerably better, however. Obviously, the appropriate place for labels is not on the top surface of the package, if it is to be stored outdoors. The transparent, pressure-sensitive tape overlay test specimens outperformed all other groups after 6 mo whenever the covers were applied to extend 5/8 in. beyond the bottom and top edges of the labels and 3/4 in. beyond each side of the label. This study serves to illustrate the deterioration of labels in the outdoor environment and the orientation dependence of that deterioration.

5-3 HANDLING

5-3.1 GENERAL

Handling is the first operation encountered by materiel in the logistic cycle and occurs repetitively throughout all phases of transportation and storage. When the item of materiel is completed by the manufacturer, the materiel begins to experience handling stresses. Indeed, the packaging and/or packing that must be accomplished before delivery involve handling.

Handling is usually of relatively short duration and generally represents only a small fraction of the time that the materiel is in the logistic flow. Handling usually is associated with transportation; in fact, for most purposes it can be considered as a short-duration interface operation between two dissimilar stages in the logistic cycle. Illustrative of this characteristic of handling in the logistic cycle is a typical cycle, chronologically defined as:

(1) Manufacture

(2) *Handling*

(3) Transportation to storage

(4) *Handling*

(5) CONUS storage

(6) *Handling*

(7) Overseas transport

(8) *Handling*

(9) Overseas storagee

(10) *Handling*

(11) Transportation to user units

(12) *Handling*

(13), Storage by user units

(14) Issue to user (*handling*).

As can be seen, handling occupies an intermediate point chronologically whenever a major change in status of the materiel occurs in the logistic cycle. In spite of the fact that handling occurs frequently, because of the short duration of any given handling event, the total time that materiel is handled is relatively small when compared to the temporal length of the logistic cycle. On the other hand, storage (particularly depot or warehouse storage of an item of materiel) can continue uninterrupted for years. Consequently, it is axiomatic that the length of time that materiel remains in other stages or portions of the logistic cycle is generally significantly greater than the length of time it remains in the handling environment. Although not stated explicitly, it should be recognized that handling occurs within the storage and transportation portions of the logistic cycle when it is necessary to rotate stock or to rearrange loads.

Protection in the handling environment is directed toward prevention of rapid deterioration of materiel as a result of short-term exposure to specific, fast-acting environmental factors, such as shock and vibration (these factors, which cause physical damage and/or mechanical deformation, are probably the most significant). Handling stresses are among the most severe examples of mechanical environmental factors and, thus, often are the determining factor in package design.

5-3.2 MECHANICAL EFFECTS

When examining handling, it is pertinent to consider the means whereby stresses are imposed on materiel; i.e., what does the handling? Handling of items weighing less than 100 lb that are not packed in bulk or bulk packages weighing less than 100 lb normally utilizes the most sophisticated, and at times, the most destructive handling machine: man! Whenever materiel is handled directly by man with his hands, the process is referred to as manual handling. Again, when simple, non-self-propelled machines are used by man in handling materiel, the process is still called manual handling. The most widely used non-self-propelled handling machines are handtrucks, dollies, and wheelbarrows.

A wide variety of self-propelled or mechanically propelled machines are employed in handling materiel. While mechanical handling equipment is used widely for virtually all types of materiel, they are particularly appropriate for:

(1) Very large or heavy items

(2) Bulk-packaged items

(3) Palletized loads

(4) Large quantities of items

(5) Routine, repetitive operations.

Mechanically propelled handling equipment includes:

(1) Forklift trucks

(2) Wheeled warehouse tractors

(3) Warehouse truck cranes

(4) Pallet trucks

(5) Fixed platform trucks

(6) Straddle-carry trucks

(7) Hoists

(8) Overhead cranes

(9) Gantry cranes

(10) Belt conveyors

(11) Roller gravity conveyors

(12) Wheel gravity conveyors.

Belt conveyors are used primarily for transporting solid, particulate bulk materiel that is handled in large quantity, as well as for handling large quantities of small items between two fixed points in a local area. Pipelines are, of course, a type of conveyor, but, since they usually involve movement of materiel over long distances, it is felt that they are more properly classified as a mode of transportation rather than a piece of handling equipment. This implies that handling is the movement of materiel (either manually or mechanically) over short distances, while transportation involves the movement of materiel over longer distances. This is indeed the basis on which the distinction between handling and transportation is made. Since the terms "short distances" and "longer distances" are essentially qualitative, a certain amount of "arbitrariness" may be involved in the decision of whether a particular process is handling or transportation.

For purposes of this discussion, handling includes the following processes:

(1) Transfer of materiel from one point in a facility to a transportation vehicle for transportation to another facility

(2) Transfer of materiel between vehicles

(3) Transfer of materiel between different points in a storage facility

(4) Transfer from the user supply facility to the user. As can be seen from these processes, handling always involves loading,

unloading, repacking, rearranging, and/or local movement within a facility.

Having defined handling and the means (manual or mechanical) whereby handling is achieved, it is now appropriate to define, in qualitative terms, the handling environment. The handling environment is a composite of all the motions experienced by materiel as it is transferred between transport modes and within terminals. The different kinds of mechanical loads that recur frequently can be categorized into three types (Ref. 6):

(1) Materiel or its containers impacting against each other as they are positioned in yards, either on chassis or handling equipment

(2) Various bodies, such as handling gear and protrusions, impacting on materiel and its containers at random locations on panels, roofs, frame, and bottom

(3) Hard landing on surfaces, such as uneven ground surfaces, the apron of a dock, or a stacking position, causing concentrated bottom loads elsewhere than on the corner fittings.

Factors that contribute to mechanical damage include stacking, lifting, restraint measures, racking (which is the application of lateral loading and top corner fittings against a restraining force in the opposite direction from the bottom corner fittings), lashing, and various forms of endwall and sidewall pressures encountered by containers within the handling environment.

As demonstrated, the handling environment can be very severe, particularly with respect to impact that results in shock, vibration, and/or mechanical deformation. The emphasis of most Military Specifications on impact or shock reflects the severity of the handling environment. Most shock specifications involve drop and impact tests that can be recognized as direct analogs of events that can and do occur in the handling environment.

An indication of the types of handling impacts that are considered tolerable in the handling environment and for which materiel is packaged to provide protection can be understood best by examining the values of these parameters as defined in the various specifications on impact testing, drop testing, and other rough handling tests.

Rough handling tests include the incline-impact test, pendulum-impact test, edgewise-drop test, cornerwise-drop test, and drop test (free-fall) (Ref. 3). For edgewise-drops (which consist of two drops for each end of the packaged materiel) the height of drop is a function of weight. Table 5-1 outlines the characteristics of the various rough handling tests. The test methods for performance of these tests are contained in Federal Standard No. 101 (Ref. 7).

Many investigators deem the handling environment to be one of the most severe environments with respect to shock and impact loading of any portion of the logistic cycle. A considerable amount of discussion in the literature concerns the degree to which specifications on the various drop and impact tests reflect the real handling environment. Many investigators feel that the standards generally are too conservative and do not reflect the severity of the actual handling environment as it is encountered in normal handling operations. Quantification of the actual handling environment experienced by materiel and specification of the impact and drop levels that materiel must endure to be satisfactory are still in a state of flux.

5-3.3 OTHER ENVIRONMENTAL FACTORS

Aside from mechanical factors (primarily shock and vibration), other environmental factors such as temperature, humidity and rain, and solar radiation may, during handling operations, contribute to materiel deterioration. Further, it is not uncommon for the package to be compromised during handling, thus resulting in additional, con-

TABLE 5-1.
ROUGH HANDLING TESTS (Ref. 3)

Type	Packaged weight, lb	Height of drop, in.
Edgewise drop (2 drops each end)	< 250	30
	250-500	24
Cornerwise drop (2 drops on diagonally opposite corners)	500-1000	18
	> 1000	12
Pendulum-impact (one impact on 2 opposite ends)	< 250	14
	250-500	11
	500-1000	8
	> 1000	5
Incline-impact	< 250	84
	250-500	66
	500-1000	48
	> 1000	30

tinuing exposure to ambient environmental factors.

5-4 STORAGE

5-4.1 GENERAL

Not only must all military materiel be packaged so that it can withstand the handling environment, but most materiel, if it is to reach the user in operable condition, also must be protected in the storage environment. This requires additional constraints on packaging since the environments during handling and storage are essentially dissimilar. They are dissimilar both in temporal duration and in the factors that represent the major hazard to materiel.

First, the handling environment is of relatively short duration and generally represents only a small fraction of the time that the materiel is in the logistic system, in spite of the fact that handling occurs more frequently. Storage, particularly depot or warehouse storage, of an item of materiel can, however, continue uninterrupted for years and thus constitute a longer period of materiel exposure than any other function in the logistic cycle.

Second, protection in the handling environment is directed toward prevention of rapid deterioration of materiel as a result of short-term exposure to specific, fast-action environmental factors (such as shock and short-term vibration), while, in the storage environment, these factors are relatively unimportant. Materiel in the storage environment requires protection against deteriorative agents that are relatively slow in action—such as temperature, relative humidity, visible moisture, and microbiological and macrobiological attack.

In the paragraphs that follow, the classes of storage and the types of structures used for storage are discussed. Next, effects of various storage environments on materiel and the delineation of the environment in several representative storage structures are given. Finally, because food is generally the most perishable item in the logistic cycle and, therefore, the item most likely to be affected by long-term storage, several effects of storage on conventionally processed rations plus a sampling of environmental effects on food prepared by special processing techniques are presented.

5-4.2 CLASSES OF STORAGE

During storage, all military materiel must be packaged so that it is capable of withstanding the effects of the environmental conditions to be encountered. From a packaging standpoint the various classes and types of storage have been delineated as (Ref. 1):

(1) *Class A, Dormant Storage.* Packaged item is protected against the entry of the elements by preservation, sealing, covering, and placing in shelter and buildings, either dehumidified or nondehumidified. Items in dormant storage are not operated between reprocessing cycles.

(2) *Class B, Active Storage.* Packaged item is protected by the same basic measures as dormant storage except that certain preservation requirements are replaced or supplemented by specific periodic exercising, either by running the equipment or by operating the equipment with an external power or driving source.

(3) *Type 1, Outside of Buildings (Open) Storage.* Open storage consists of a storage area exposed to the extremes of the local, natural environment. The package must protect the packaged items from all weather elements as well as from fungus, pests, dust, pilferage, and the unpredictable results of idle curiosity. When it is known that materiel will be stored in open storage, maximum utilization of known packaging methods and materials is needed to insure the serviceability of the stored materiel. Constant surveillance and maintenance are required to prevent deterioration.

(4) *Type 2, Sheltered Storage.* Consists of ventilated or unventilated, heated or unheated buildings, shelters, and closures of structural characteristics designed to afford protection from the elements. The stored materiel is not protected from atmospheric changes of temperature and humidity. Periodic surveillance and maintenance are required to keep deterioration to a minimum.

(5) *Type 3, Dehumidified Structural Storage.* Consists of structures in which the atmosphere is maintained at a relative humidity of 40 percent or less. Controlled humidity storage in structures provides a high degree of protection and is the most economical method of storage for items of a critical nature since little surveillance and maintenance is required.

(6) *Type 4, Dehumidified Nonstructural Storage.* Consists of complete or partial sealing of the packaged item with a mechanical or static dehumidification of each item, singly or in series, in which the relative humidity of the atmosphere within the interior areas does not exceed 40 percent. Controlled humidity storage of individual items requires the surveillance of individual items to insure constant protection.

The storage of explosive materiel is determined by the potential hazards of the materiel as well as deterioration factors. Materials of an explosive nature must be stored in standard ammunition magazines designed for the purpose, or in areas designed specifically for the storage of explosives, ammunition, or loaded components. These areas usually are not wired for electricity and generally are not heated. The packaged item must be adequately preserved to protect it from deterioration.

Most nonperishable materiel is placed in dormant storage, where it is completely immobilized until required. Dormant storage usually lasts from 1 to 3 yr, depending on operational requirements for the item and on the need for inspection and for renewal of protective measures. Many items—especially mechanical equipment—must be kept in active storage where they can be operated every 60 to 90 days. This is necessary in order to redistribute preservatives over critical surfaces. The features of active and dormant storage are given in Table 5-2.

5-4.3 STORAGE STRUCTURES

Storage structures in the military can be classified broadly into two basic types, covered storage and open storage. Covered storage is storage within any roofed structure. Within the broad category of covered storage, the military services utilize a variety of structural types. The fundamental types in general use are (Ref. 8):

(1) General-purpose warehouse

(2) Refrigerated warehouse

(3) Flammable-storage warehouse

(4) Above-ground magazine

(5) Igloo

(6) Controlled-humidity warehouse

(7) Dry tank

(8) Shed.

5-4.3.1 General-purpose Warehouse

A general-purpose warehouse is constructed with roof, sidewalls, and endwalls and may be constructed on grade or raised with loading docks. Cantilever-supported canopies may also be provided. This type of warehouse may be heated or unheated. The greatest portion of the total available covered storage space at military installations normally is contained in this type of structure.

5-4.3.2 Refrigerated Warehouse

A refrigerated warehouse is used for the storage of perishable items. Outwardly, it resembles the general-purpose warehouse, with a truck and railcar platform on two opposing sides of the warehouse. The interior of the refrigerated warehouse usually is divided into two distinct parts. One part is designated as chill space in which the temperature can be controlled between 32° and 50°F. The other part is designated as freeze space. In this area, the temperature can be controlled below a level of 32°F.

5-4.3.3 Flammable-storage Warehouse

The flammable-storage warehouse is built of noncombustible materials and has firewalls with a 4-hr fire resistance rating. The main source of protection is provided by automatic deluge-type sprinklers connected to an adequate water supply plus an alarm-reporting system.

5-4.3.4 Above-ground Magazine

The above-ground magazine is designed and used for the storage of ammunition and explosives. It is constructed with roof, sidewalls, and endwalls. Because of the nature of the items stored in them, above-ground magazines are built of fireproof materials and are well ventilated to lessen the danger of explosion. The above-ground magazines are widely separated to minimize the destructiveness of an explosion.

5-4.3.5 Igloo

Igloos also are used for the storage of ammunition and high explosives. This type of magazine usually is constructed of masonry with an arched roof covered with earth. The arched roof is an added safety feature. In the event of an explosion, the highest point of the arch (being the weakest point) will collapse first, thereby lessening the damage caused. Good ventilation is provided in igloos, and, although they are not heated, the inside temperature ordinarily ranges between 40° and 45°F in the winter and 60° to 70°F in the summer. Igloos, too, generally are located in isolated locations.

TABLE 5-2.
FEATURES OF ACTIVE AND DORMANT STORAGE (Ref. 1)

Active storage	Dormant storage
Advantages	
(1) Lower initial cost	(1) Lower overall cost
(2) Redistributes lubricants and revitalizes perishable parts such as grease seals, gaskets, etc.	(2) Complete preservation and sealing of each component
(3) Prepared for activation on short notice	(3) Unit is immobilized, can be adequately protected by outer package.
Disadvantages	
(1) Requires periodic operation	(1) High initial cost for complete preservation
(2) Component parts that are not involved in redistribution of lubricants are not completely preserved.	(2) Preservatives tend to drain off or flow from critical surfaces.
(3) Exercising generates harmful products such as carbon, acids, water, etc.; cannot be securely protected by outer package.	(3) Requires long time for depreservation to prepare for immediate use

5-4.3.6 Controlled-humidity Warehouse

The controlled-humidity warehouse is designed to maintain relative humidity within a storage area at or below a predetermined level. Since controlled humidity in covered storage space has proved to be the most efficient and economical method for in-storage preservation of many items, it increasingly is being used for on-hand stocks as well as for newly procured items. When controlled-humidity warehouses are employed, packaging requirements often can be relaxed to permit a more economical grade of packaging. Almost any type of warehouse may be operated with controlled humidity if it is properly sealed and conditioned. The number and uses of controlled-humidity warehouses required at a storage installation depend on the annual relative humidity of the location, the assigned mission, and the characteristics of the stocked items.

5-4.3.7 Dry Tank

Dry tanks are constructed of metal except for a concrete floor. These tanks may have controlled temperature and humidity. They are sealed units and are built at ground level with no car loading and truck loading platforms. Dry tanks are used for long-term storage. Most are laid out in long lines to facilitate humidity control. Parts and equipment not destined for use for a number of years are stored in these tanks. Because of the size and shape of dry tanks, there usually are no operating aisles for material-handling equipment.

5-4.3.8 Shed

Sheds are used for storage of materiel that requires maximum ventilation and does not require complete protection from the weather. A variety of materiel may be stored in sheds in much the same manner as in a general-purpose warehouse. Shed-stored supplies requiring added protection from the weather may be protected by various means while other supplies requiring only minimum protection are left semiexposed (Fig. 5-3). For example, tarpaulins may be used as sidewalls, or serviceable unused pallets may be positioned to form a protective wall.

5-4.3.9 Open Storage

Open storage space is an improved or unimproved area designated for storing materiel. Open, improved storage space includes space that has been graded and surfaced with concrete, tar or asphalt, crushed stone or gravel, or other suitable topping (Fig. 5-4). Open, unimproved storage is an unsurfaced open area designated for storage purposes. The restrictions placed on the use of material-handling equipment is a significant disadvantage in unimproved open storage. In any type of open storage, materiel protection requirements should be a reasonable minimum, or stock should be placed in such a manner as to fully withstand the effects of weather exposure. For various reasons materiel stored in open areas often requires a protective covering such as tarpaulins. This adds considerably to the cost of storage operations both from the standpoint of materiel cost and the operating overhead in covering and uncovering during in-storage handling. This underlines the fact that only stocks able to withstand the full impact of weather conditions should be stored in open areas unless other overriding considerations make it necessary.

5-4.4 STORAGE AND CLIMATIC FACTORS

5-4.4.1 Effects of Storage Structure

5-4.4.1.1 *Introduction.* The Naval Civil Engineering Laboratory, Port Hueneme, Calif., investigated the effects on a variety of materiel (excluding food and clothing) of five different types of storage environments over a 5-yr period (Ref. 10). The five environments were an open-air slab, a shed, a standard warehouse, and two dehumidified warehouses, one with 50 percent relative humidity and the other with 40 percent relative humidity. All structures were one-story, 40 × 100 ft, and of prefabricated metal construction.

Figure 5-3. Typical Primitive, Covered-storage Shed and Open Storage (Ref. 9)

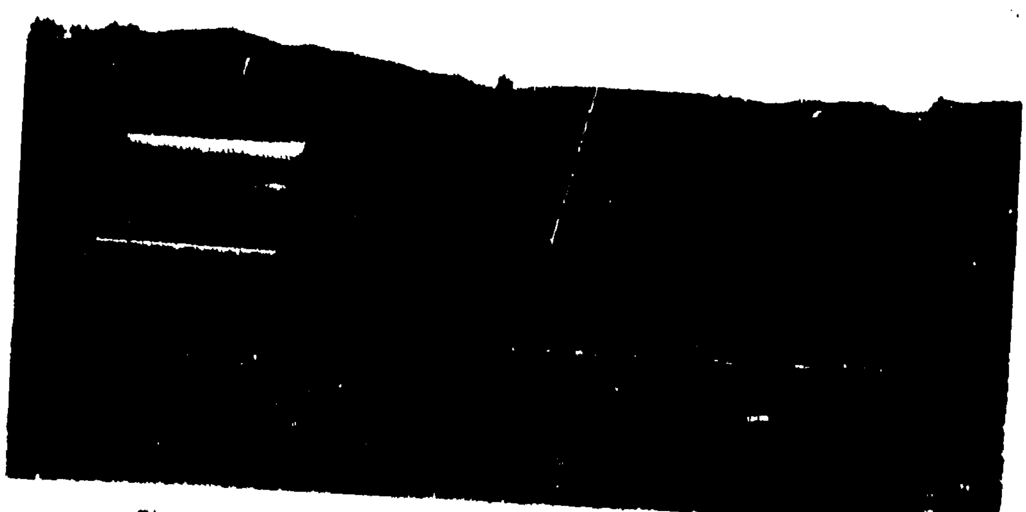


Figure 5-4. Example of Onen Storage (Da Nang, Vietnam) (Ref. 9)

The open-air slab and the floors in the other four structures were 4-in.-thick asphaltic concrete. The shed consisted of a building with its long leeward side open to the atmosphere. The standard warehouse was erected as received from stock except that the walls and ceiling were lined with insulation and fiberboard. The controlled-humidity warehouses were similar to the standard warehouse except that all joints were sealed with a bituminous cement, the windows and rear cargo doors were replaced with regular metal sidings, and the front cargo doors were sealed after stores were set in place.

To determine the possible effects of outside storage on equipment removed from warehouses, most of the items in the 40 percent relative humidity warehouse were placed on the open slab for the last 12 mo of the test. The test lasted for a period of 5 yr, and the equipment in the test included such items as jeeps, dump trucks, searchlights, steam boilers, pumps, welders, bake ovens, lathes, and telephone switchboards. The open-air and shed environments each contained 19 different items; the remaining environments each contained 29. Materiel was inspected periodically to determine the ability of each storage method to protect equipment from rust. Equipment in the open air was inspected every 3 mo, in the shed every 6 mo, and in the remaining three environments every 12 mo. Upon completion of the 5-yr exposure period, all equipment was given a final inspection.

5-4.4.1.2 *Environment-storage Relationships.* Fig. 5-5 gives the average temperature, relative humidity, and vapor pressure for the open-air slab and the shed for the period 1 February 1956 to 1 September 1958. The yearly temperature is nearly sinusoidal for these environments with an approximate 15-deg F amplitude. Mean lows vary from 50° to 55°F and the mean highs from 65° to 70°F. The relative humidity curve for the open-air shed shows a conspicuous drop during the late fall and early winter months. This drop is caused by frequent hot and dry east winds which lower the relative humidity. These winds are a seasonal occurrence. During this period, relative humidity as low as 5 percent has been recorded occasionally, but the average generally falls between 30 and 40 percent despite periodic rains. The relative humidity during the remainder of the year approximates 70 percent. The water vapor partial pressure varies directly with the dry-bulb temperature and relative humidity. The vapor partial pressure curve is somewhat sinusoidal with an amplitude of about 0.3 in. of mercury and varies from 0.2 to 0.5 in.

The yearly curves for the standard warehouse (Fig. 5-6) are similar to those of the open-air shed curves. Again, the temperature variation is nearly sinusoidal with an approximate 15-deg F amplitude, but it is about 5 deg F warmer inside the building. The mean lows vary from 55° to 62°F and the mean highs from 70° to 75°F. The building itself damped the fluctuations of the relative humidity somewhat, and its variations are less pronounced during the winter months. During the period of hot, dry, east winds, the relative humidity drops to around 15 percent, but throughout the fall and winter months, the average fluctuates between 40 and 45 percent. The relative humidity during the remainder of the year is around 55 percent. The water vapor partial pressure curve reflects less of a sinusoidal pattern than the open-air shed curve, and it varies from approximately 0.25 to 0.58 in. of mercury.

Figs. 5-7 and 5-8 are the curves for the controlled humidity warehouses. The temperature curves for both the 40 percent relative humidity and the 50 percent relative humidity environments are sinusoidal with approximate amplitudes of 15 deg F. The desiccant machines add heat to the warehouse air when a newly reactivated bed is cycled into use; therefore, it is slightly warmer in the dehumidified warehouse than in the standard warehouse. Also, because of longer desiccant machine operations, it is slightly warmer in the 40 percent relative

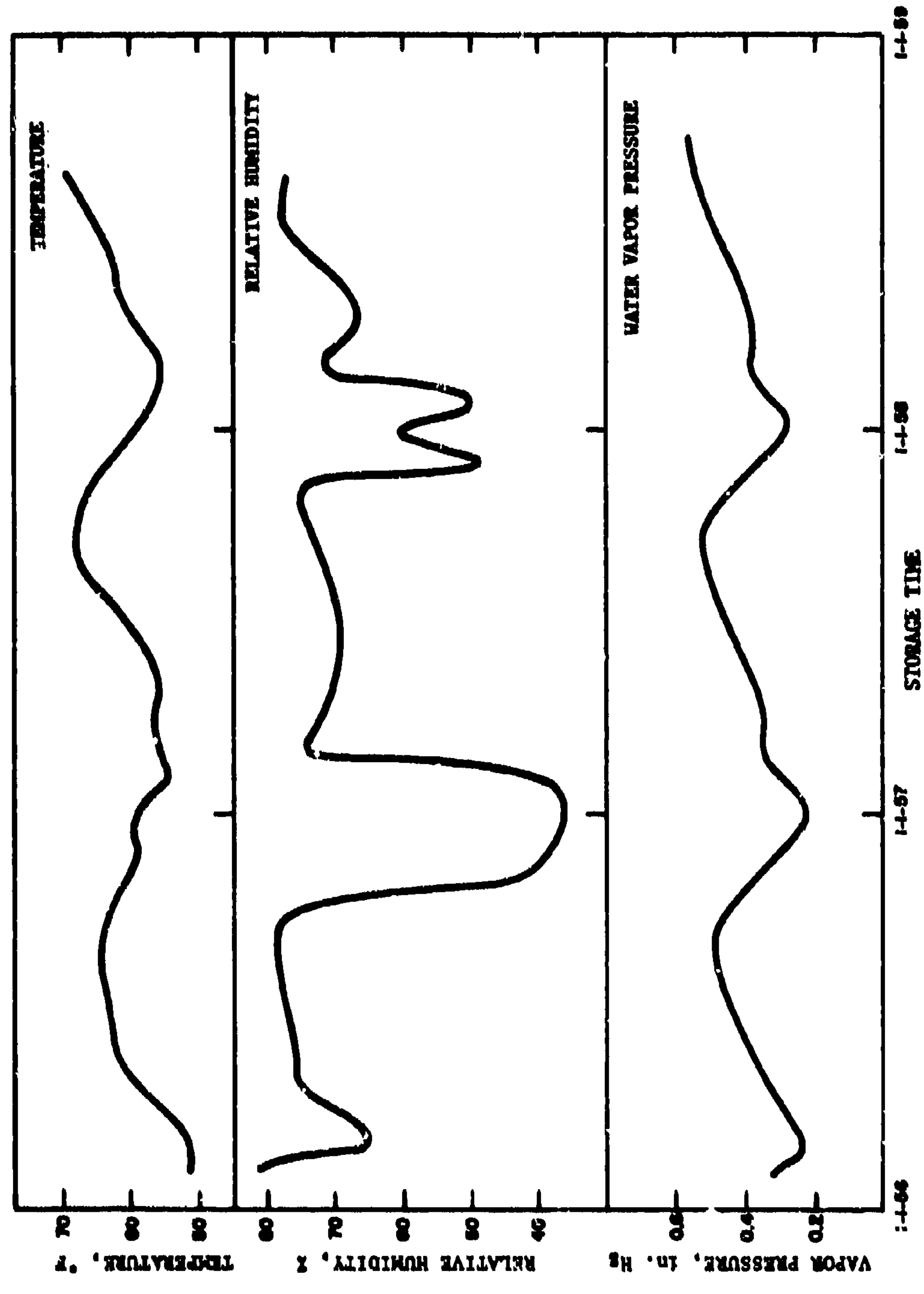


Figure 5-5. Environmental Conditions in Open-air Slab and Shed Storage (Ref. 11)

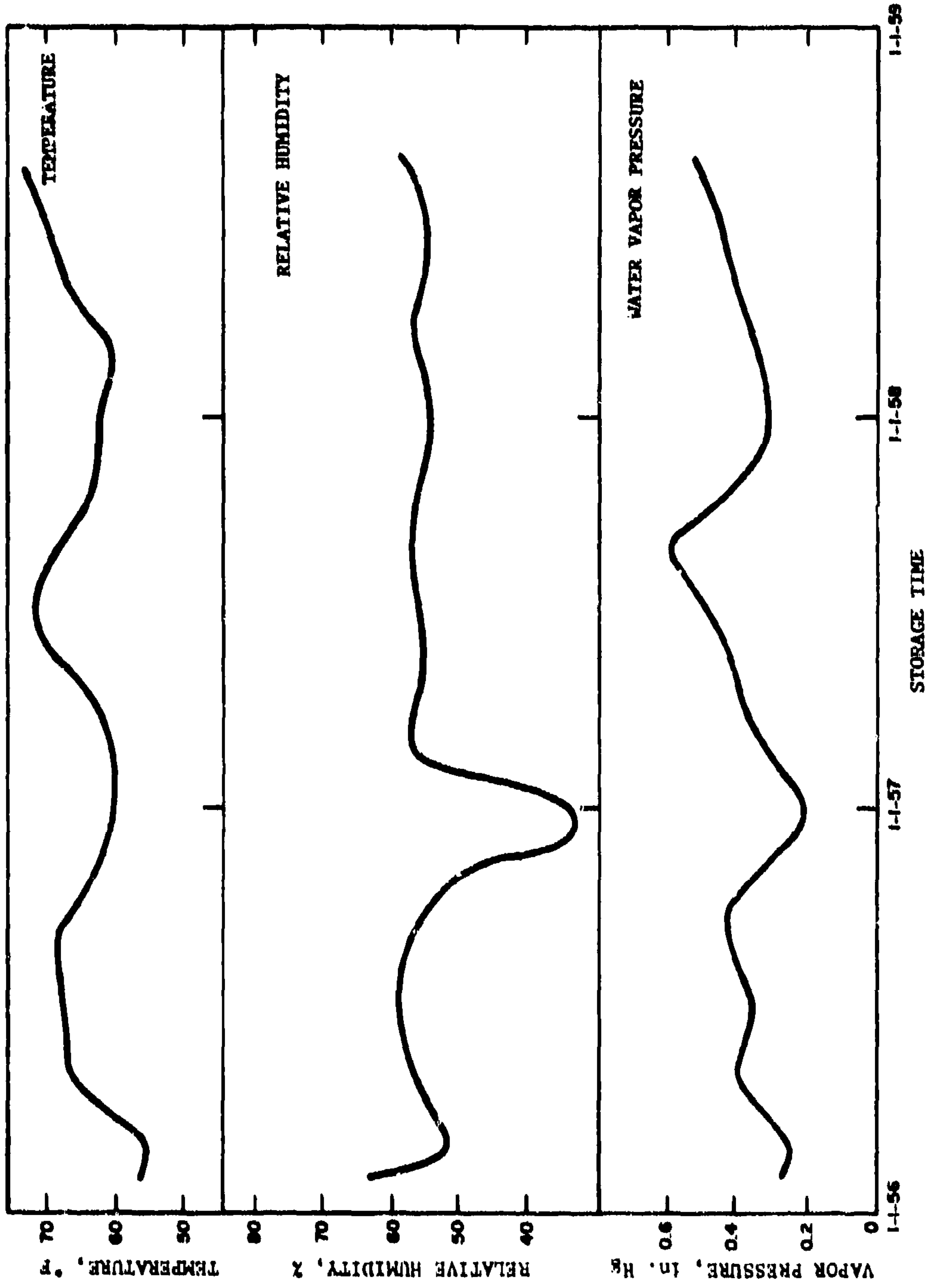


Figure 5-6. Environmental Conditions in Standard Warehouse (Ref. 11)

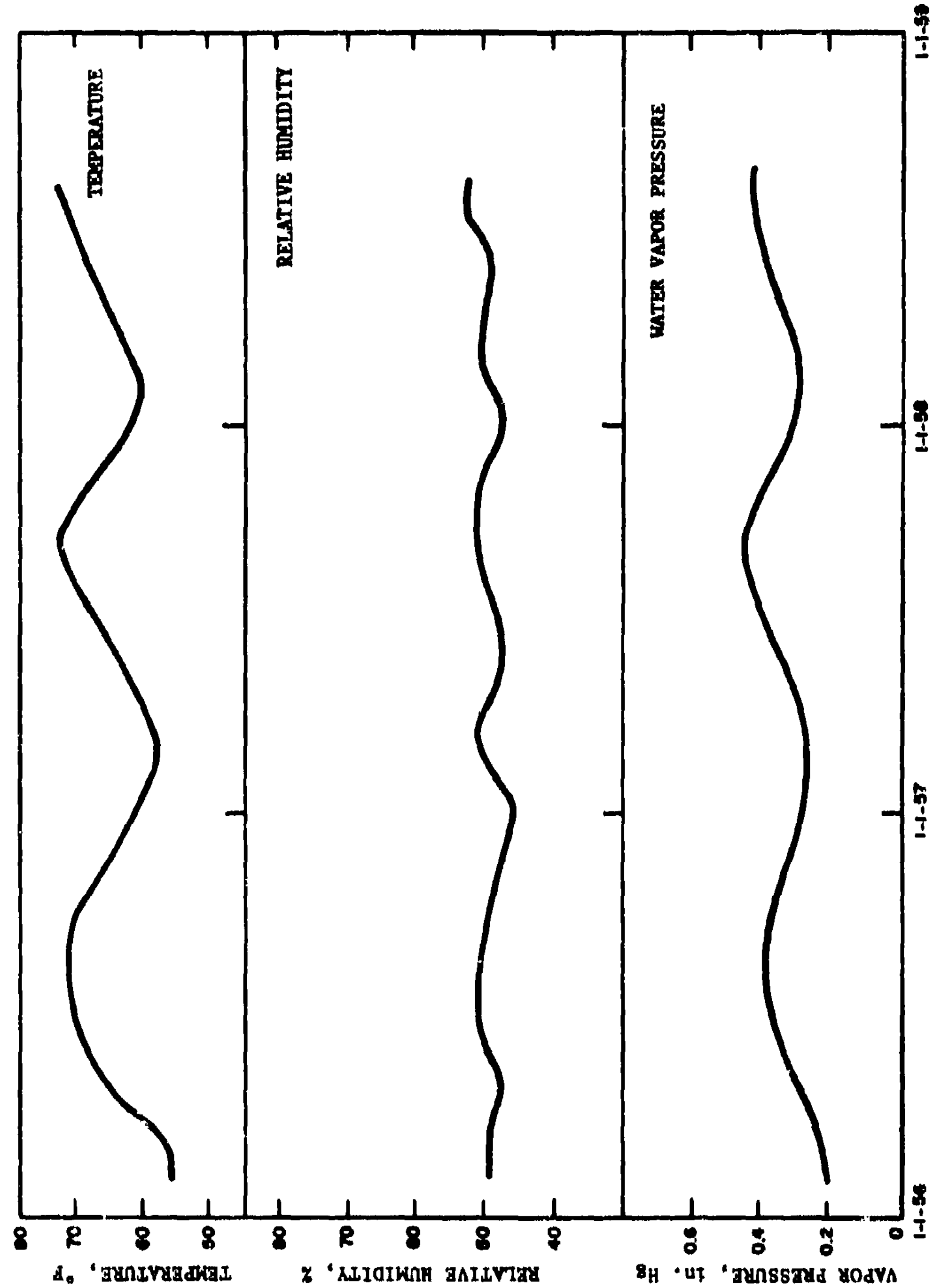


Figure 5-7. Environmental Conditions in 50% Relative Humidity Warehouse (Ref. 11)

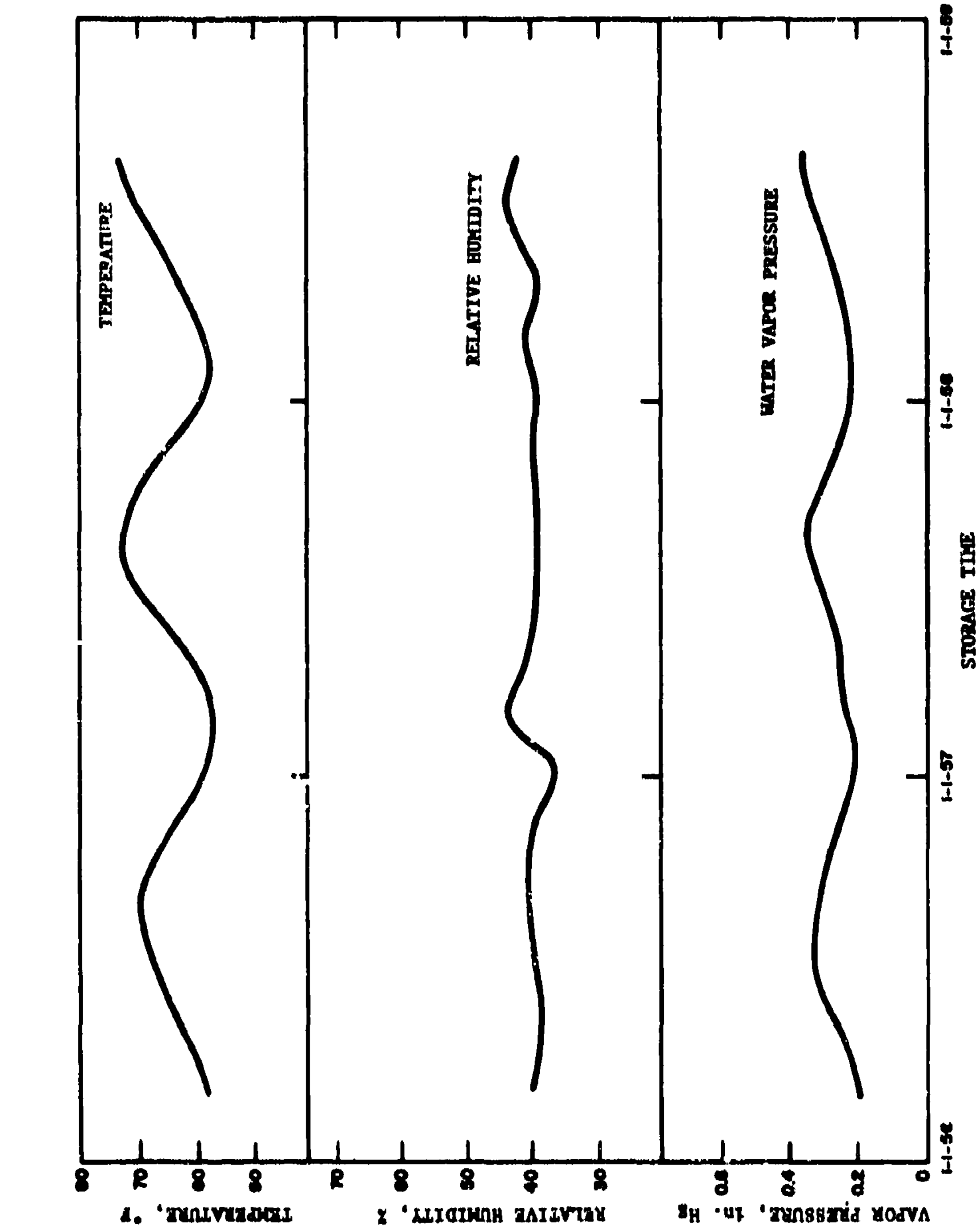


Figure 5-8. Environmental Conditions in 40% Relative Humidity Warehouse (Ref. 11)

TABLE 5-3.
ENVIRONMENTAL CONDITIONS IN STORAGE FACILITIES (Ref. 11)

Environment	Temperature, °F	Relative humidity, %	Water vapor partial pressure, in. Hg
Open slab & shed	61.1	68.9	0.378
Standard warehouse	66.0	55.0	0.363
50% RH warehouse	66.5	49.0	0.327
40% RH warehouse	67.3	39.7	0.272

humidity than in the 50 percent relative humidity building.

The relative humidity in each building was held to within ±3 percent relative humidity of the designated level. The water vapor partial pressure curves are sinusoidal and vary mostly with the temperatures since the relative humidity in each environment is essentially constant. The vapor partial pressure in the 40 percent relative humidity warehouse varies from approximately 0.20 to 0.4 in. of mercury and in the 50 percent relative humidity warehouse from approximately 0.24 to 0.42 in. of mercury. The overall arithmetical averages of the temperature, relative humidity, and vapor partial pressure for each type of storage are given in Table 5-3.

5.4.4.1.3 *Effects on Materiel.* Rust and deterioration encountered during each inspection were classified and recorded. Rust classification was in accordance with the following terminology.

(1) *Class I, Stain.* Discoloration or staining with no evidence of pitting, etching, or other surface damage visible to the naked eye.

(2) *Class II, Light Corrosion.* Surface Corrosion. Loose rust or corrosion, no tight rust or scale. When removed by wiping, it leaves a stain but no evidence of pitting, etching, or other surface damage visible to the naked eye.

(3) *Class III, Medium Corrosion.* Loose or granular rust or corrosion, together with visible evidence of minor pitting or etching.

(4) *Class IV, Heavy Corrosion.* Powdered scale or tight rust or corrosion, together with deep pits or irregular areas of material removed from the surface.

During the final inspection, it was evident that the same components were rusting regardless of environment and with little regard for preservation methods. It also was found that the deterioration was somewhat similar in each environment. Five components were involved predominantly: internal combustion engines, gear boxes, fuel injector sets, hydraulic brake systems, and cooling systems.

The nature of the deterioration of internal combustion engines consisted almost entirely of top cylinder rust including cylinder walls, valves, and head surfaces. This rust usually occurred when the valves were in a closed or nearly closed position. Very little rust was found in the cylinders when the valves were open enough to permit air to circulate through the cylinders, except in a few instances in which heavy rust was caused by water seeping into cylinders through a leaking head gasket. Nearly all of the gears and gearboxes (including transmissions), differentials, power-takeoff units, and transfer cases of a 2-1/2-ton dump truck and the 1/4-ton jeep were heavily stained. The sole exception was a 2-1/2-ton dump truck, located in the standard warehouse, whose gears were in excellent condition. In this instance, a light oil preservative had been fogged into the transfer case, and the transmission differential and power-takeoff unit had been protected with a lubricant.

A 30-kW diesel generator was the only item with fuel injectors. These injectors, irrespective of preservation level, all had corrosion on such parts as the plunger, sleeve, and spring. In the hydraulic brake systems, rust was predominant in the wheel cylinders and the master cylinder. It is likely that the brake fluid had been contaminated by water since the fluid was hygroscopic. A high incidence of rust occurred in the water pumps of engine cooling systems, caused by water that had pocketed when the system was drained. The remaining rust and deterioration encountered at the final inspection appeared to occur randomly and to be caused by environment.

In the initial portion (first 2-1/2 yr) of the study (Ref. 11), it was concluded that corrosion is the most costly form of deterioration of equipment in storage. The primary factors contributing to corrosion are oxygen and alternate wetting and drying; sunlight and variable weather are secondary. Oxygen is always present, while the wetting and drying action comes largely from nighttime condensation and daytime evaporation. Condensation in areas with high dewpoint temperatures may be visible as a film or as drops of water. In dry climates, it may be an invisible, microscopically thin film. Temperature stability, the partial pressure of the water vapor in the air, and the mass-area ratio of the object all influence the amount of condensation. Corrosion accelerates if condensation includes dissolved mineral salts such as those present in ocean air and certain industrial atmospheres. Dust particles settling on the metal from the air also markedly accelerate corrosion.

Measurement of the corrosion-producing potential of each environment was made with an instrument called the corrosometer. The unit consists of a probe or probes and a special meter. The probe is essentially a taut, metal, sensing element 4 in. in diameter and 3 in. long which is connected electrically to the meter during readings. The extent of probe corrosion is determined by measuring the changes in electrical resistance as its cross section is reduced by corrosion.

A steel, an aluminum, and a copper probe were placed in each of the five storage environments. Corrosometer readings were made periodically. Table 5-4 gives the corrosometer readings for each of the environments during the first 2-1/2 yr of the test. From these data it is clear that open-air storage provides the least protection from corrosion with the shed being second, the standard warehouse third, and the controlled relative humidity warehouses providing the most protection.

General observations on the effect of corrosion on equipment in the various storage structures were obtained at the end of the test (Ref. 10).

In the open-air storage, items that were uncrated or in open crates had extensive exterior rust on places such as control panels, switches, pulleys, flywheels, exposed shaft ends, and universal joints. Boxed items were better protected and had much less exterior rust. For example, the sheet metal hood over a crated floodlight-trailer engine was irreparably damaged, whereas a similar hood that was boxed was in good condition. Interior surfaces, such as those found in a boiler, a heater, a bake oven, and a diesel generator, had considerable rust.

In the shed storage, the exterior condition of uncrated or open crated items was poorer than those that were boxed, much like those

TABLE 5-4.
CORROSOMETER READINGS (Ref. 11)
(Penetration in mils)

Date	Probe type	Storage facility				
		Open air	Shed	Standard warehouse	50% RH warehouse	40% RH warehouse
1 July 1957	Steel	0.000	0.000	0.000	0.000	0.000
	Copper	0.000	0.000	0.000	0.000	0.000
	Aluminum	0.000	0.000	0.000	0.000	0.000
19 Aug 1957	Steel	1.326	0.230	0.014	0.000	0.004
	Copper	0.032	0.012	0.018	0.022	0.038
	Aluminum	0.064	0.000	0.006	0.030	0.008
30 Sept 1957	Steel	*	0.450	0.028	0.032	0.020
	Copper	0.098	0.030	0.036	0.025	0.040
	Aluminum	0.176	0.022	0.046	0.035	0.024
30 Oct 1957	Steel	*	0.542	0.018	0.016	0.010
	Copper	0.092	0.018	0.014	0.034	0.020
	Aluminum	0.196	0.030	0.000	0.022	0.020
1 Dec 1957	Steel	*	0.634	0.036	0.042	0.016
	Copper	0.138	0.044	0.042	0.060	0.046
	Aluminum	0.262	0.070	0.014	0.058	0.034
8 Feb 1958	Steel	*	0.860	0.032	0.020	0.020
	Copper	0.166	0.054	0.040	0.054	0.044
	Aluminum	0.460	0.100	0.040	0.048	0.044
11 Mar 1958	Steel	**	1.056	0.038	0.028	0.024
	Copper	0.208	0.058	0.024	0.052	0.044
	Aluminum	0.583	0.086	0.034	0.044	0.038
29 May 1958	Steel	**	1.460	0.040	0.032	0.028
	Copper	0.250	0.094	0.026	0.036	0.028
	Aluminum	0.780	0.160	0.018	0.052	0.058

*Indicator off corrosometer scale
**Probe completely rusted in two

in the open air except that the rust was less severe. Also, items stored on the open side were generally in poorer condition than those along the wall where they were more shielded from the weather.

In standard warehouse storage, rust occurred that was attributable to environment. This rust, however, was limited to small areas of light rust or stain with a few exceptions such as the combustion chamber and shell of an oil-fired heater and the interior of the compression tanks of compressor sets where rust was more extensive. The general exterior condition of all other items was good with little or no change (except dusty surfaces) being apparent.

In the dehumidified storage warehouses, no rusting attributable to the environment occurred. Some rust occurred on items that were stored temporarily in a shed 4 or more weeks waiting for the warehouses to be erected prior to the initial start of the test. Subsequent storage in the dehumidified atmosphere arrested this rusting. With the exception of the rusting due to the temporary storage and the five components previously discussed, all items were in excellent condition with no apparent difference in the condition of items stored in the 50 percent and 40 percent relative humidity warehouses. All exterior surfaces were in very good condition with very little surface rust. No detrimental effects of the dehumidified environments were detected on seals, rubber, wire harnesses, or gaskets.

Some engines were removed from the 40 percent relative humidity warehouse after 48 mo and stored in open air for the following 12 mo. These had the usual internal rust plus a considerable amount of other rust caused by exposure to the outdoor environment. The pattern of rusting during the final 12 mo followed quite closely that of items that were stored originally in the open air for the same period of time. The general exterior condition of the items deteriorated rapidly during the 12 mo of outside storage.

The effects discussed in this paragraph were those directly concerned with operation of the equipment. The effects of rain, dust, sunlight, and general weathering as they affect the serviceability and life of the equipment were not determined. Table 5-5 shows the time sequence of rust and deterioration of three of the vehicles stored for the 60-mo period in the open shed. Table 5-6 shows a similar time sequence of rust and deterioration for items stored in the standard warehouse, and Table 5-7 shows the effects of storage in the 50 percent relative humidity warehouse. In all these tables the Roman numerals in parentheses refer to the four classes of corrosion discussed earlier. Where gear boxes are listed, it refers to heavy staining caused by the MIL-L-2105 gear lubricant. NC means no change in amount of corrosion from the previous time period in which corrosion was reported.

5-4.4.2 Warehouse Temperature: Various Climatic Environments and Storage Methods

During long-term storage of nonmetallic materials (for which corrosion is not a significant factor), temperature is generally the most severe environmental factor encountered in warehouses. High temperatures are encountered in a wide variety of environments and are characteristic of many types of warehouse storage. For subsistence items—in particular, food, as well as a number of other perishable items—temperature represents the factor most likely to lead to deterioration during long-term storage. As a result of the broad impact of high temperatures on materiel in storage, it is important to consider the relationships among climatic environments, storage methods, and the temperatures experienced by materiel under these conditions of climate and storage. The paragraphs that follow are intended to provide this information.

5-4.4.2.1 *Temperature Distribution in a Typical Army Warehouse.* The temperature regimes at selected points in a typical Army warehouse at Richmond, Va., with and

TABLE 5-5. TIME SEQUENCE OF RUSTING IN SHED STORAGE (Three Vehicles) (Ref. 10)

Vehicle	Exposure time, mo								
	6	12	18	24	30	36	42	48	54	60
Truck, 2-1/2 ton dump (domestic)	Left front brake drum 15% (I)	30% (I)*	40% (I)	80% (II)	NC†	NC	NC	NC	NC	All brake drums 90% (II)
	Left front brake cylinder 1% (I)	NC	NC	5% (II)	NC	NC	NC	NC	NC	All brake cylinders 50% (III)
										Clutch throwout bearing 20% (II)
										Water pump 60% (II)
										Air compressor cylinder 5% (II)
										Camshaft 10% pitted
										Gear boxes‡
Truck, 2-1/2-ton dump (contact)										Gear boxes‡
										Water pump 40% (II)
Truck, jeep (domestic)	Left front brake drum 95% (I)	95% (II)	95% (III)	100% (III)	NC	NC	NC	NC	NC	All brake drums 100% (III)
	Universal joints 10% (I)	15% (II)	20% (III)	50% (IV)	100% (IV)	NC	NC	NC	NC	NC
	Spindle Seal 1% (I)	NC	30% (II)	50% (IV)	NC	NC	80% (I)	NC	NC	NC
	Waterproof shielding 20% (II)	40% (II)	80% (III)	80% (IV)	NC	100% (IV)	NC	NC	NC	NC

*Roman numerals refer to corrosion classes as defined in text, par. 5-4.4.1.3.

†NC = no change in amount of corrosion since previous reporting period

‡Gears in gear boxes were heavily stained, apparently by reactions with the MIL-L-2105 lubricant.

TABLE 5-6.
TIME SEQUENCE OF RUSTING IN STANDARD WAREHOUSE STORAGE (Ref. 10)

Vehicle	Exposure time, mo 12	24	36	48	60
Truck, dump 2-1/2-ton (domestic)	Pressure plate clutch 10% (I)*	NC†	NC	NC	NC
					Brake cylinders 100% (II) Gear boxes‡
Truck, dump 2-1/2-ton (contact)	Rear differential pinnion shaft 1% (I)	NC	NC	NC	NC
				Intermediate differential pinnion shaft 1% (I)	NC
Truck, dump 2-1/2-ton (contact)				Wheel brg. race 1% (I)	NC
					Brake cylinders 40% (II)
Truck, jeep (domestic)	Brake drum 5% (I)	NC	NC	NC	NC
	Front & rear differential bearing straps 5% (I)	NC	NC	NC	NC
					Water pump 100% (III)
					Brake cylinders 60% (II)
					Gear boxes‡
Truck, jeep (contact)					Engine cylinder wall 20% (II)
					Brake cylinders 30% (II)
					Gear boxes‡

*Roman numerals refer to corrosion classes as defined in text, par. 5-4.4.1.3.

†NC = no change in amount of corrosion since previous reporting period

‡Gears in gear boxes were heavily stained, apparently by reactions with the MIL-L-2105 lubricant

TABLE 5-7.
RUSTING IN 50% RH WAREHOUSE STORAGE (60 mo) (Ref. 10)

Item (type of preservation)	Rusted part	Percent of surface rusted, %	Rust classification
Slicer, meat (domestic)	Electric motor	20	I
Slicer, meat (contact)	Electric motor	20	I
Truck, dump 2-1/2-ton, 6 x 6 (domestic)	Engine cylinders	70	II
	Brake cylinders	50	II
	Water pump	100	III
	Air compressor valves	90	III
	Gear boxes*		
Truck, dump 2-1/2-ton, 6 x 6 (contact)	Water pump	20	II
	Gear boxes*		
Truck, jeep 1/4-ton, 4 x 4 (domestic)	Brake cylinders	20	II
	Gear boxes*		
Truck, jeep 1/4-ton, 4 x 4 (contact)	Brake cylinders	20	II
	Water pump	70	III
	Gear boxes*		

*Gears in gear boxes were heavily stained, apparently by reactions with the MIL-L-2105 lubricant.

without insulation and ventilation have been determined by the U.S. Army Natick Laboratories (Ref. 12). Air temperatures and humidity were measured inside food cartons, in the open warehouse, and in the outside air, both under normal operating conditions and under conditions imposed by reflective ceiling insulation with or without moderate forced nighttime ventilation.

In this study it was pointed out that for sterile degradation the logarithm of reaction rates of foods in cans increases in an approximately linear relationship with the increase in storage temperature. It is predicted that a decrease of 5 deg F in storage temperature will result in a 21-percent increase in storage life while a 10-deg F decrease will result in a 47-percent increase. Temperature reduction can be achieved either by constant temperature storage conditions or by lowering the mean temperature of material stored in a fluctuating temperature environment. As a result, any lowering of warehouse mean temperature could result in substantial gains in storage life of canned foods. Figs. 5-9 through 5-12 show the mean daily warehouse and mean daily minimum outside air temperatures for warehouses located at Richmond, Va., Schenectady, N.Y., Fort Worth, Tex., and the Sharpe Depot in the San Francisco Bay area of California. From these figures, it can be seen that large differences occur between the mean daily temperature of warehouse air at the 15-ft level and the nighttime mean daily minimum outside temperature. Table 5-8 gives two indexes of the mean annual humidity in Army warehouses.

Two bays of Warehouse 32 of the Richmond Quartermaster Depot were used in the study. The study consisted basically of three parts:

(1) First, it was planned to measure the differential between temperatures produced in contrasting bays by insulating the ceiling of one bay, the so-called experimental or ventilated bay (bay B) and leaving the control bay (bay A) unmodified.

(2) Second, the temperature differential produced by manually actuated, forced ventilation of bay B between the hours of 2000 and 0800 was measured.

(3) Third, the temperature differential produced between 1700 and 0800 by automatically actuated, forced ventilation of bay B with improved intake areas was measured.

Fig. 5-13 shows the warehouse air temperatures for the hottest day of 1956. On this diagram the ventilating control and outside temperatures were given. In the study, the temperature differential produced by ventilation and insulation generally are low and range between 1 and 2 deg F. Table 5-9 shows the temperature differential between the top carton monthly mean air temperature in a control bay versus that in a ventilated bay for selected periods of ventilation. The effect of insulation is also shown in the mean air temperature differential value of 1.85 deg F for the period April through July 1956. By contrast, the maximum effect of ventilation is shown by the difference between that figure and 4.25 deg F for the similar period in 1957 when both insulation and ventilation were operative. This difference is 2.4 deg F.

As a result of this study, it was concluded that the greatest yearly temperature differential between ventilated and nonventilated bays produced by both insulation and ventilation was equivalent to only an 11-percent difference in reaction rate or increase in storage life for the period from May 1957 to May 1958. During the summer of 1957, from April through July the differential was 4.25 deg F, which corresponds to an 18-percent difference in reaction rate or an increase in storage life of 18 percent for the late spring and early summer months. It was concluded that, although the temperature inside the warehouses can be reduced by ventilation and insulation, the increase in storage life was not sufficient to justify the cost and inconvenience of modification.

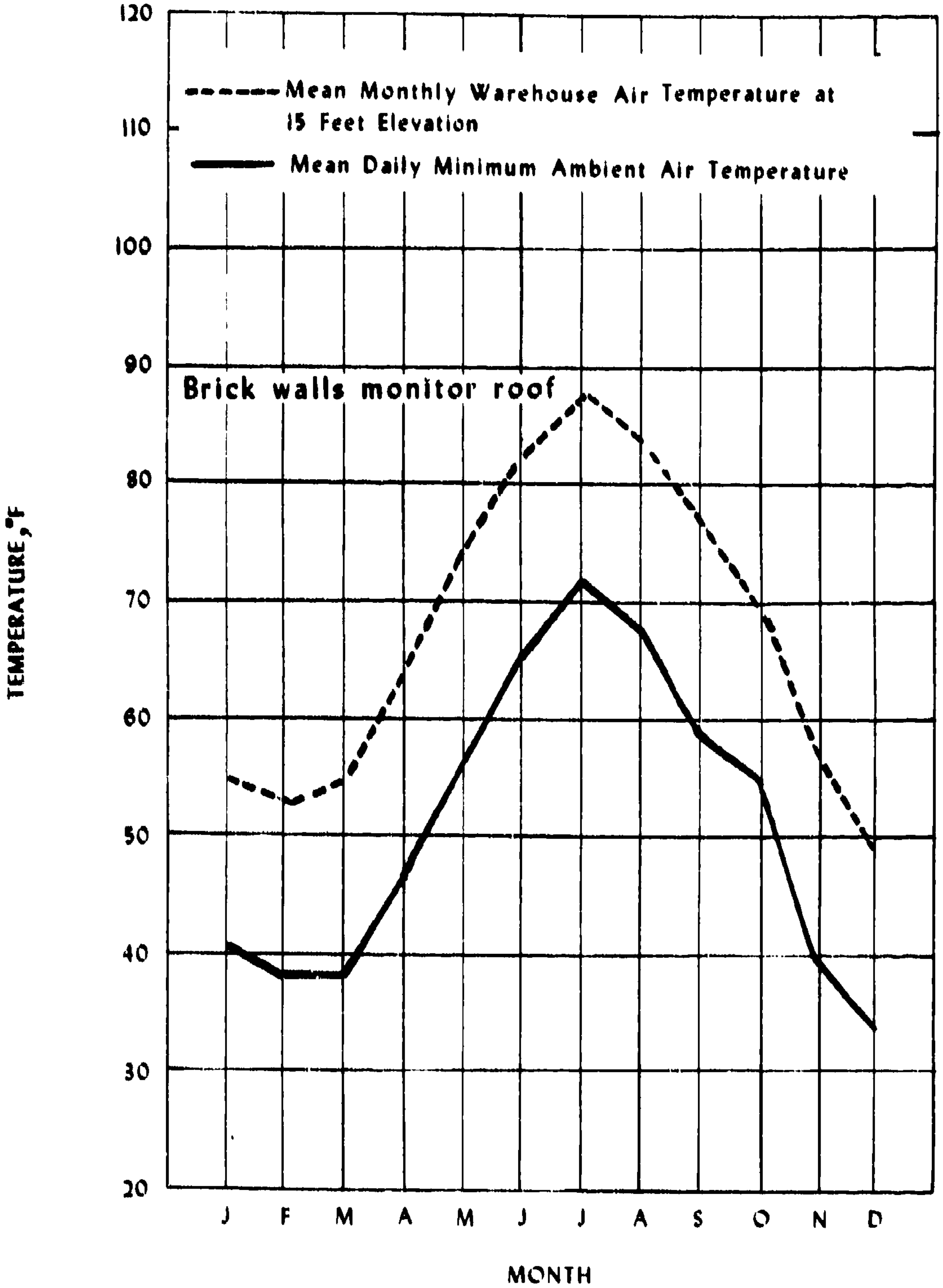


Figure 5-9. Warehouse Temperatures, Richmond Depot (Ref. 12)

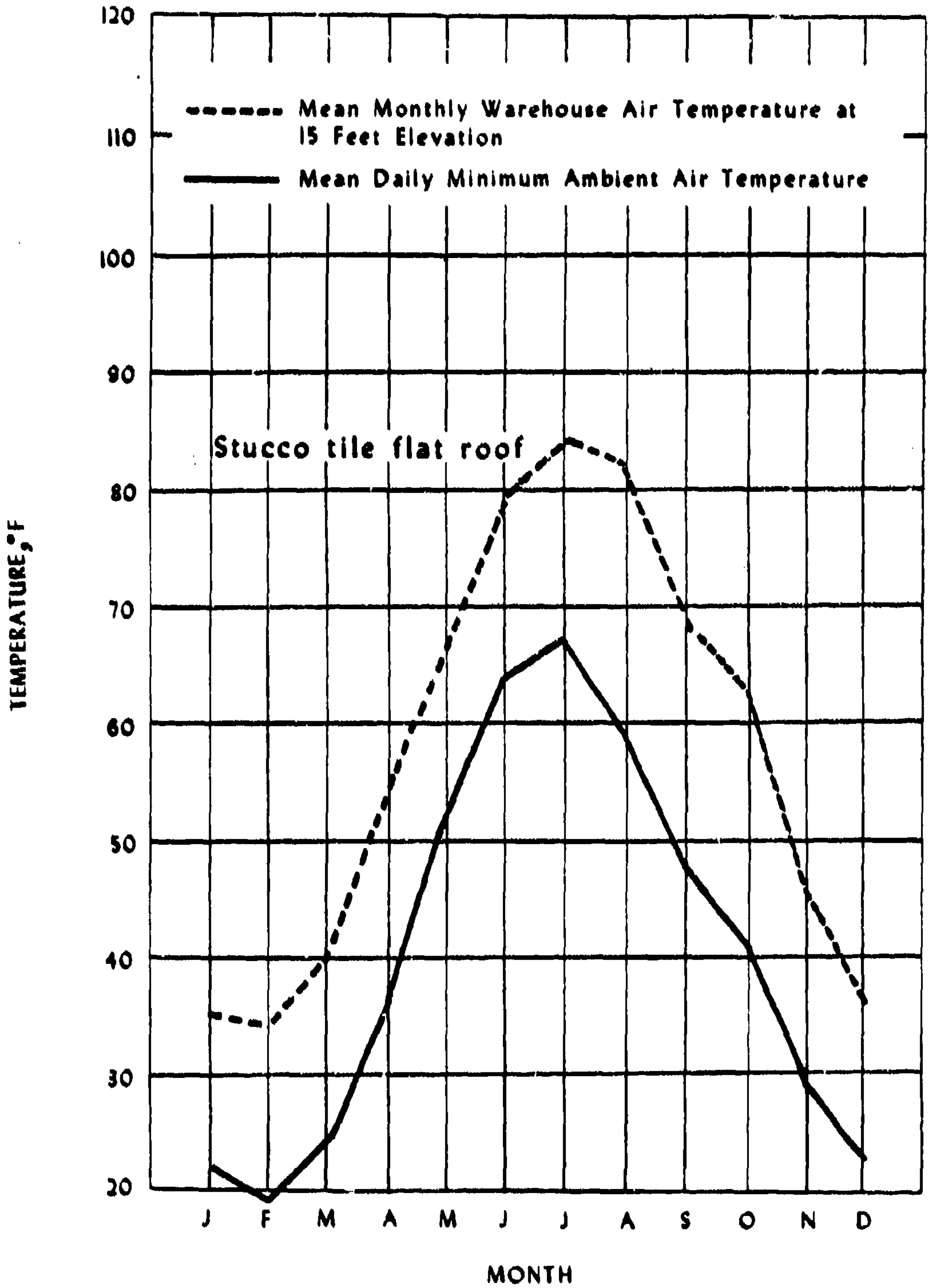


Figure 5-10. Warehouse Temperatures, Schenectady Depot (Ref. 12)

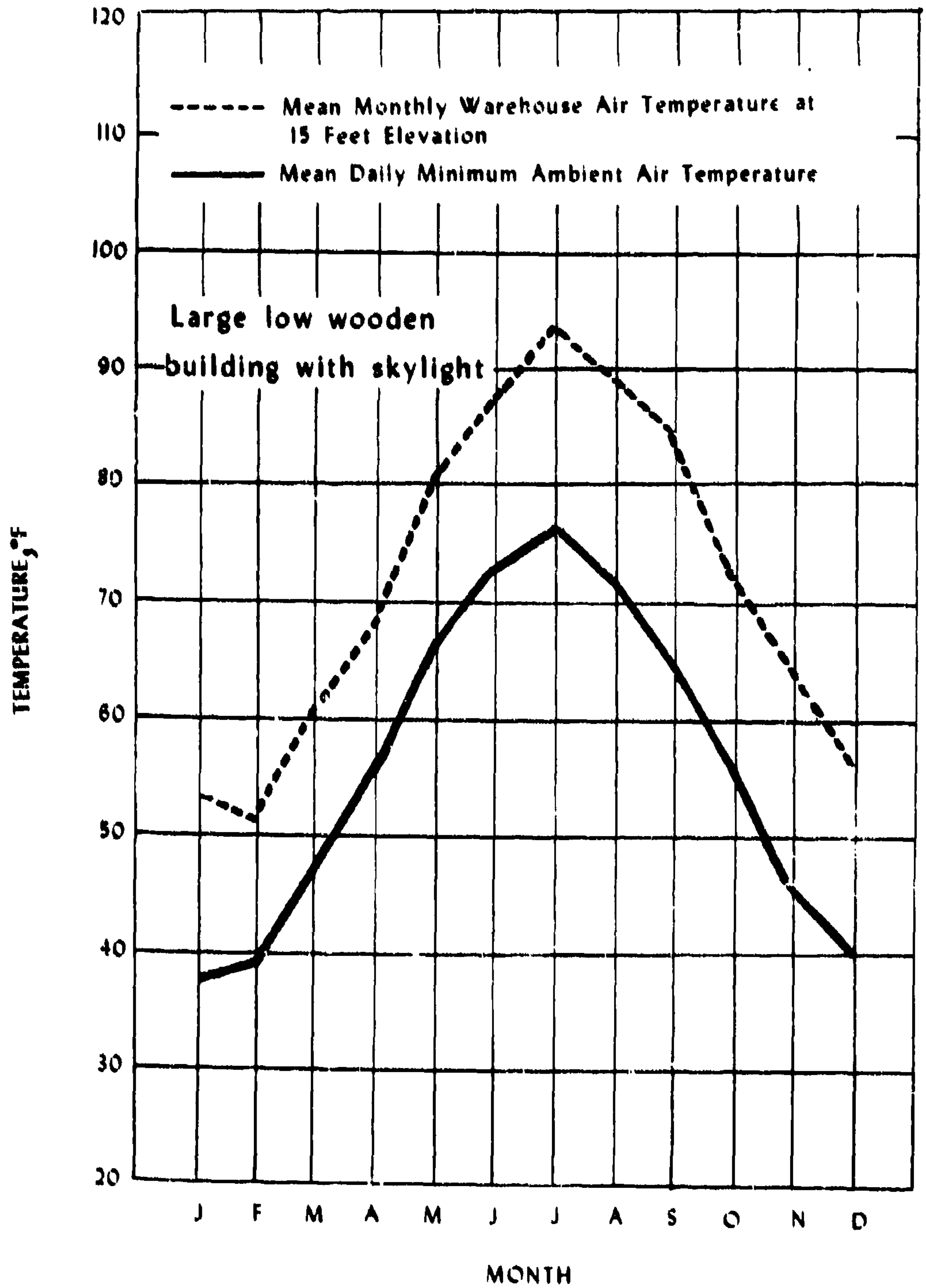


Figure 5-11. Warehouse Temperatures, Ft. Worth Depot (Ref. 12)

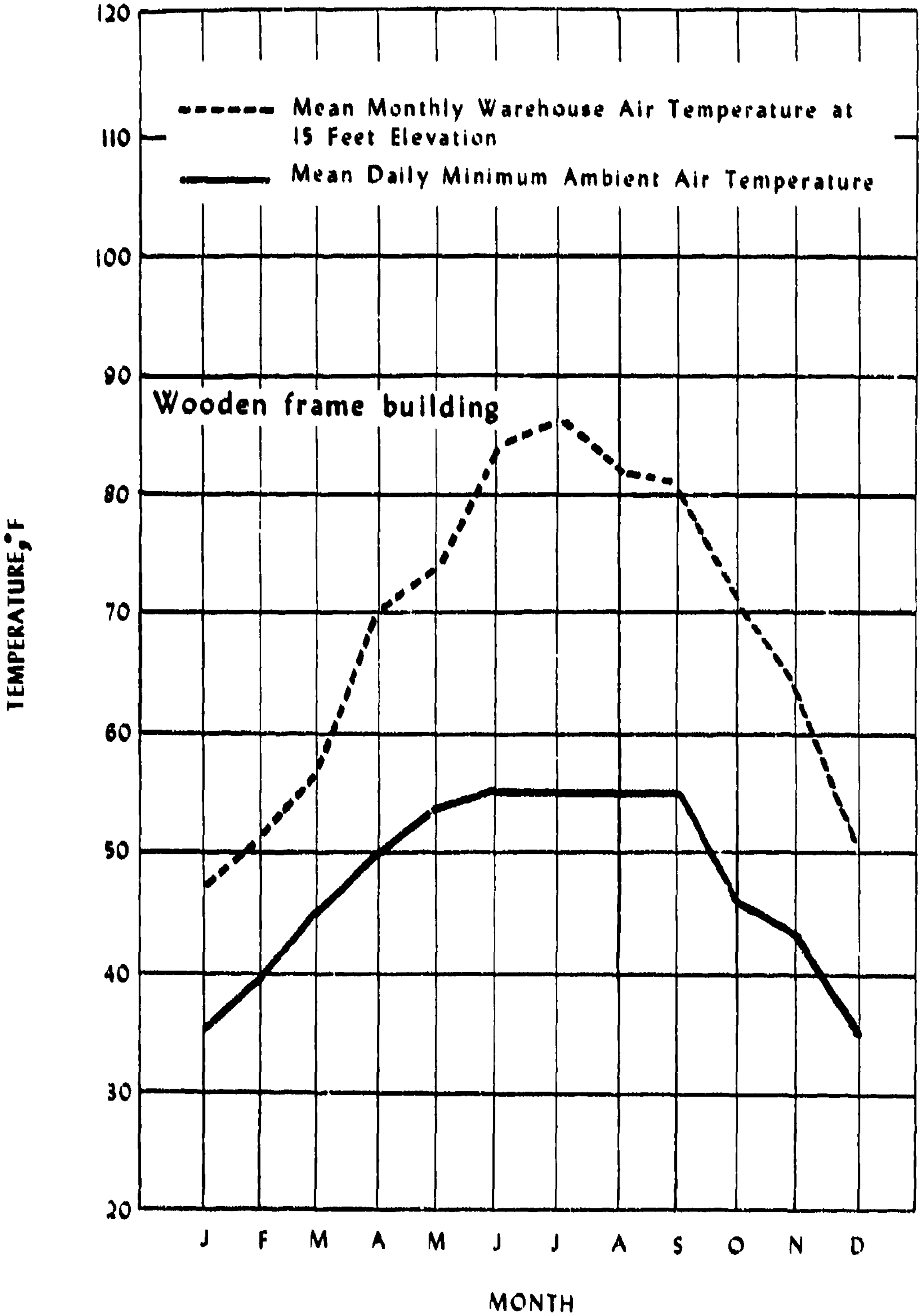


Figure 5-12. Warehouse Temperatures, Sharpe Depot (Ref. 12)

TABLE 5-8.
HUMIDITY IN ARMY WAREHOUSES (Ref. 12)

	Relative humidity, %	Vapor pressure, mm Hg
Belle Meade	80.9	10.7
Corozal	79.3	22.8
Auburn	70.3	8.3
Charlotte	69.0	12.9
Hawaii	67.3	16.4
Richmond	67.0	11.2
Ft. Worth	66.5	13.1
Schenectady	64.0	5.1
Kansas City	63.9	9.8
Columbus	63.7	8.4
New Cumberland	63.4	8.7
Memphis	62.9	11.4
San Antonio	62.6	14.3
Atlanta	62.0	10.9
Cameron Station	61.3	14.5
Chicago	56.0	9.8
Philadelphia	55.0	14.3
Sharpe	53.0	9.3
Jeffersonville	51.0	8.9
Mira Loma	49.3	9.1
Ogden	48.0	6.4

5-4.4.2.2 *Temperature Distribution in Desert Storage Magazines*. The storage temperatures of explosive ordnance have been obtained from Army and Navy facilities located in the desert regions of the Western United States (Ref. 13). The data tabulated included: (1) the number of measured temperatures exceeding nominal temperatures for each month, (2) the average maximum and average minimum temperatures for each month, and (3) the standard deviations of the maximum and minimum temperatures for each month. Data on temperatures exceeding nominal are given in Table 5-10, and average maximum and minimum temperatures are given for various sampling periods in Figs. 5-14 through 5-16.

The storage magazines at Yuma are different from those at China Lake and Hawthorne, and the temperature-measuring devices were located at different points. Thus, accurate comparison of the China Lake or Hawthorne data to the Yuma data is difficult. Analysis indicated that if these differences had not existed, the temperatures at Yuma would have been lower. On the assumption that these data are representative for all desert storage magazines, it is concluded that the temperature of stored ordnance explosives, propellants, and pyrotechnics will probably never exceed 120°F.

Data also were collected at Yuma on an above-ground corrugated steel building without insulation and an outdoor tarpaulin-covered structure. The highest temperatures recorded were 119°F for the steel structure and 121°F for the tarpaulin-covered structure. These are not significantly higher than the highest magazine temperature recorded of 116°F.

5-4.4.2.3 *Temperature Distribution in Tropical Storage Magazines*. The storage tempera-

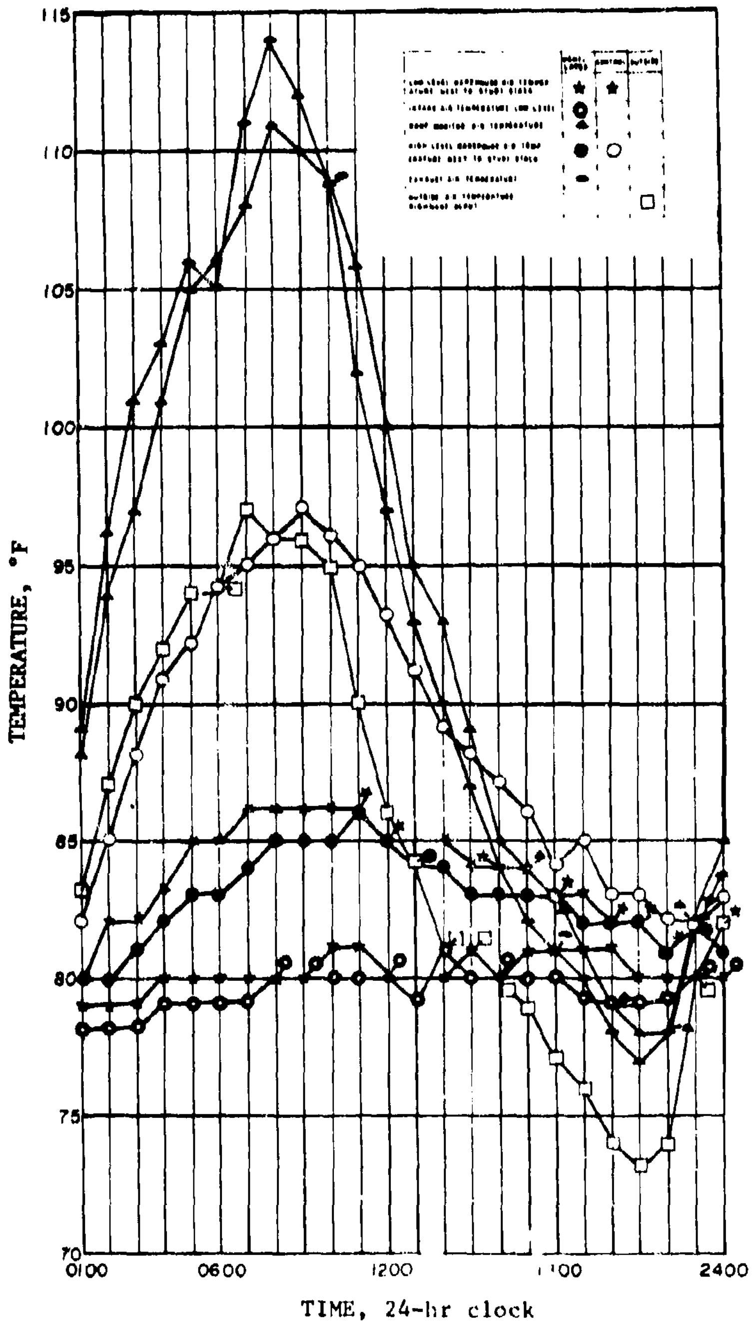


Figure 5-13. Warehouse Air Temperatures for Hottest Day, 1956 (Ref. 12)

TABLE 5-9.
EFFECT OF INSULATION AND VENTILATION ON WAREHOUSE TEMPERATURE (Ref. 12)

Period (inclusive)	Treatment	Temperature differential,* deg F
April - July 1956	Reflective insulation	1.85
Sept 1956 - March 1957**	Manually actuated ventilation and reflective insulation	1.42
May 1957 - May 1958	Automatically actuated ventilation and reflective insulation	2.75
Sept 1956 - March 1957**	Manual ventilation	1.42
Sept 1957 - March 1958	Automatic ventilation	1.88
April - July 1956	Insulation	1.85
April - July 1957	Insulation and ventilation	4.25

*Differential between temperature measured in top center of carton of an uninsulated control bay in warehouse and that in a similarly placed carton in an experimental bay in the same warehouse with the indicated treatment

**January 1957 omitted because data were missing. January 1958 omitted to give comparable means.

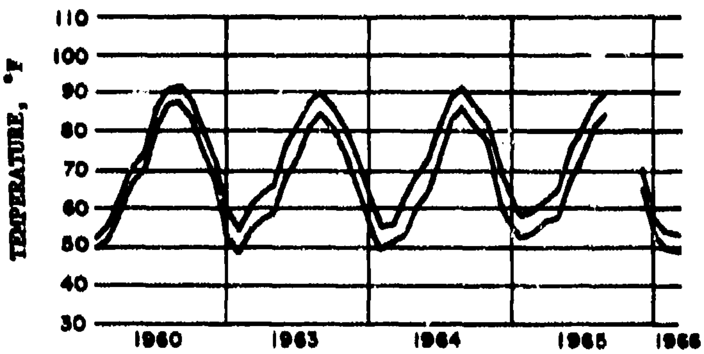
TABLE 5-10.
TEMPERATURE EXCEEDANCES AT DESERT FACILITIES (Ref. 13)

Storage location	Years*	N†	Percentage of maximum temperatures greater than or equal to						
			80°F	90°F	100°F	105°F	110°F	115°F	117°F
China Lake, Calif.	3	22,387	44.3	17.8	0.0	0.0	0.0	0.0	0.0
Hawthorne, Nev.	5	33,881	28.7	0.1	0.0	0.0	0.0	0.0	0.0
Yuma, Ariz.	7	11,208	51.3	33.3	10.3	2.0	0.4	0.03	0.0

*Length of time in complete calendar years

†Number of data points represented in the sampling

ture of explosive hazard magazines in the tropical zone of the western Pacific also have been determined (Ref. 14). The data were accumulated for the air temperatures inside the storage magazines, not for the actual temperature of the stored ordnance. The ordnance temperature lags the air temperature fluctuations within the magazines. Table 5-11 summarizes the data by location and magazine type. The maximum air temperature recorded in the non-earth-covered-type shelter occurred in the maga-



Data were unavailable for the calendar years 1961 and 1962 and for Sept and Oct 1965.

Figure 5-14. Average Maximum and Minimum Storage Temperatures, China Lake, Calif. (Ref. 13)

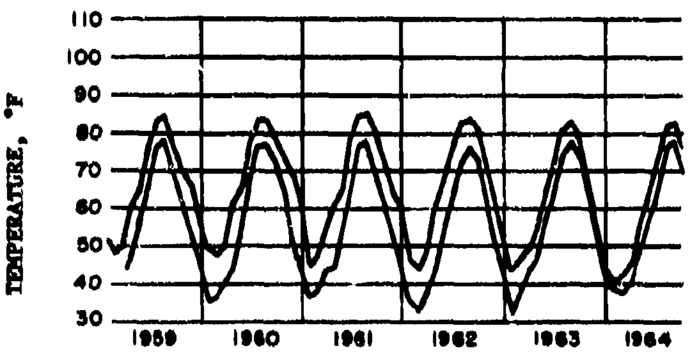


Figure 5-15. Average Maximum and Minimum Storage Temperatures, Hawthorne, Nev. (Ref. 13)

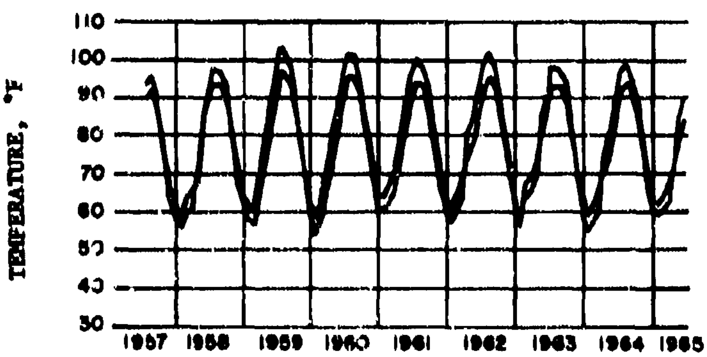


Figure 5-16. Average Maximum and Minimum Storage Temperatures, Yuma Proving Ground, Ariz. (Ref. 13)

TABLE 5-11.
EXPLOSIVE MAGAZINE TEMPERATURES (Ref. 14)

Storage locations	Magazine type	Years*	N†	Number of maximum temperatures equal to or greater than		Maximum recorded temperature
				90°F	100°F	
Naval Ammunition Depot, Oahu, Hawaii	Earth-covered	6	39,155	128	0	98
	Non-earth-covered	6	7,165	2,203	0	99
Naval Air Station, Barbers Point, Oahu, Hawaii	Earth-covered	2	2,146	95	3	101
	Non-earth-covered	2	2,837	141	1	100
Naval Magazines, Guam	Earth-covered	3	6,739	35	0	98
	Non-earth-covered	3	679	471	79	104
Naval Air Station, Agana, Guam	Earth-covered	3	6,518	416	8	108
	Non-earth-covered	2	2,421	311	1	105
Naval Magazines, Republic of the Philippines	Earth-covered	5	9,100	661	1	100
	Non-earth-covered	2	140	69	56	110
Naval Station, Sangley Point, Republic of the Philippines	Earth-covered	1	3,479	476	1	101
	Non-earth-covered	1	383	8	0	98

*Length of time in complete calendar years

†Number of data points represented in the sampling

zine at Subic Bay, Republic of the Philippines. This temperature, 110°F, falls significantly below the existing storage specification requirement for a maximum temperature of 165°F. Thus, it was concluded that air temperatures encountered in explosive storage magazines located in the Tropics will probably never exceed 115°F.

5-4.4.2.4 *Temperature Distribution in Desert Food Storage Dumps.* Data on temperatures in food storage dumps at Yuma, Ariz., have been reported as typical of desert installations (Ref. 15). During a 43-day summer period, temperatures were observed in food storage dumps containing cartons of C-rations and a few cartons of Navy survival food packets (abandon-ship ration cartons). The C-rations were arranged in stacks and exposed with various types of protection (Fig. 5-17).

Yuma has a summer climate with high temperatures and high solar radiation. In addition, in July, Yuma normally experiences a change from dry to a moderately moist airmass, although incoming solar and sky radiations remain high. Fig. 5-18 shows the location of thermocouples used to make the temperature measurements in the stacked cartons. Fig. 5-19 shows the location of the thermocouples in the individual cartons.

Fig. 5-20 gives temperature data for an open stack, Fig. 5-21 for a raised fly stack, and Fig. 5-22 for a tight tarpaulin stack. Fig. 5-23 gives similar data for a raised fly with foil stack. The open stack consisted of unprotected cartons stacked on a pallet. The raised fly stack is a stack of rations protected from solar radiation by a raised tarpaulin permitting ventilation from the sides and ends. The tight tarpaulin stack is protected by a tarpaulin that is lashed tightly around the stack with no provision for ventilation. Finally, the raised fly with foil stack is similar to the raised fly stack except for an additional foil covering over the stack.

In Table 5-12 data abstracted from these measurements are presented showing the absolute maximum surface air temperature in a carton for the various storage conditions. Table 5-13 gives absolute maximums, means, and standard deviations of hourly temperatures at representative interior and exterior positions in stacks of cartons and survival ration cartons for the total period.

Analysis of these data indicates that the highest mean temperatures are found in the air of the top center carton. However, the top southwest corner carton air reached greater absolute maximum temperatures as shown in Table 5-12 and Figs. 5-17 through 5-20. Carton air temperatures normally were measured within one of the six ration packages; however, thermocouples located outside and between the packages showed higher absolute maximum air temperatures. Table 5-13 clearly shows that the stack covered with a tight tarpaulin had the highest mean temperatures, even in the bottom center carton. The other three stacks have surprisingly little mean temperature gradient between the surface and interior cartons. Also, little difference occurs from stack to stack at comparable positions in each of the three types of stacks other than that of the tight tarpaulin-covered stack. The latter had a 10-deg F gradient of mean temperature between top center and bottom center cartons, compared with the nearly isothermal conditions of the other stacks. Mean temperatures at all positions listed in Table 5-13, except those in the tight tarpaulin-covered stack and the survival rations, were equal to or lower than mean outside air temperature.

Differences between temperatures in the dry and moist periods are given in Table 5-14. The data show that mean storage temperatures are higher in moist air. At all thermocouple positions, a 3- to 5-deg F increase in temperature occurred in spite of the fact that solar radiation decreased. This increase in storage temperature in sunny but humid weather is attributed to the reduction of outgoing longwave radiation at night by

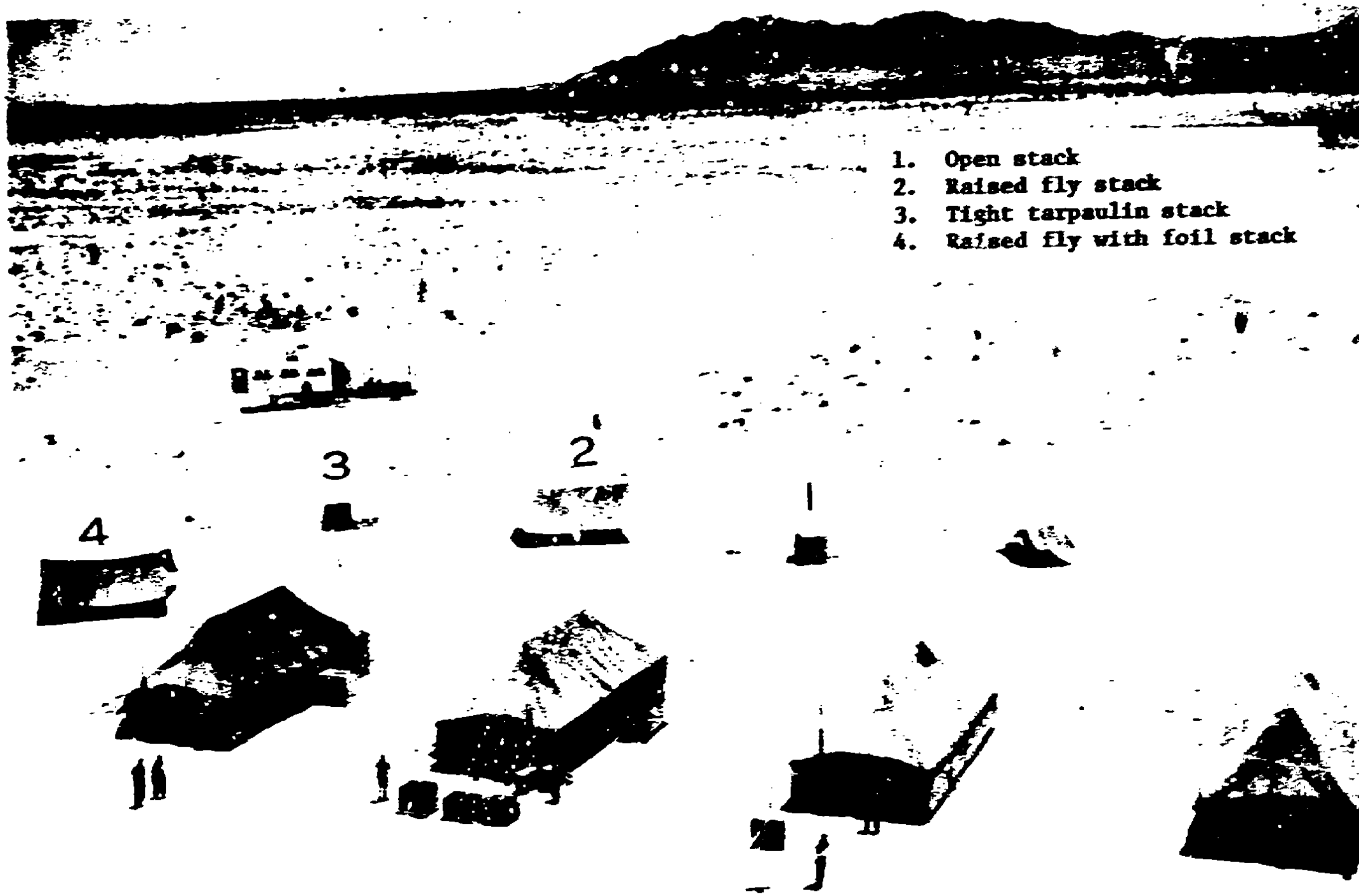
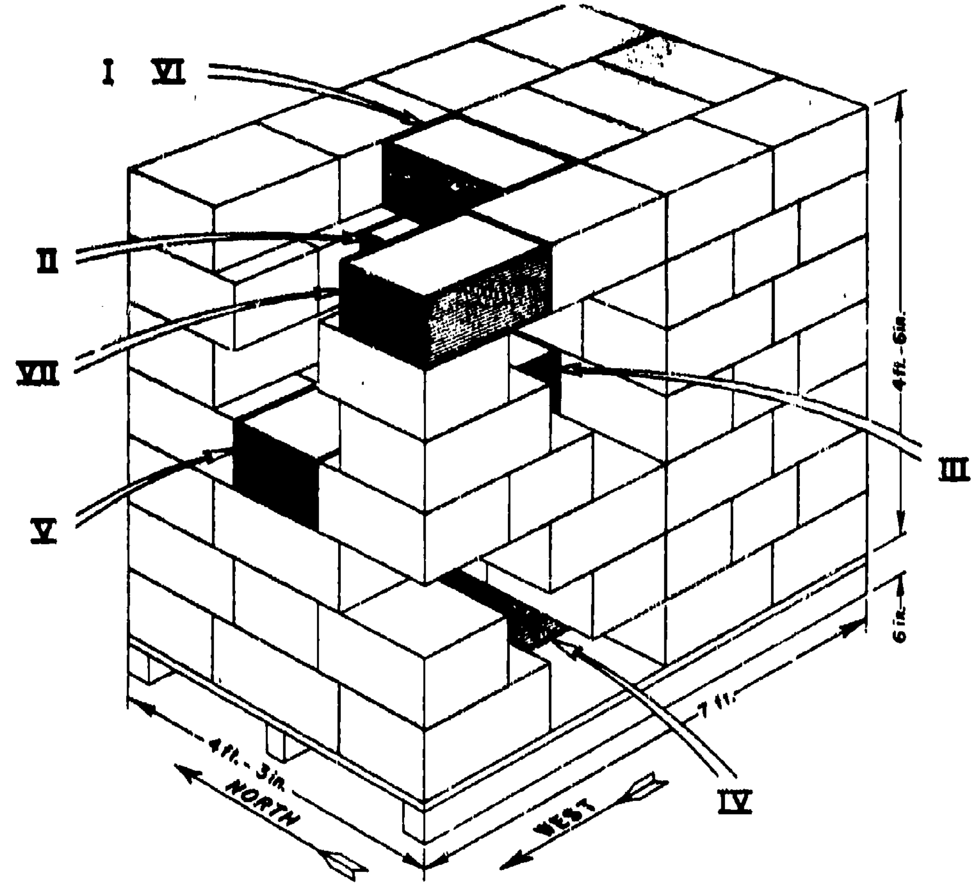


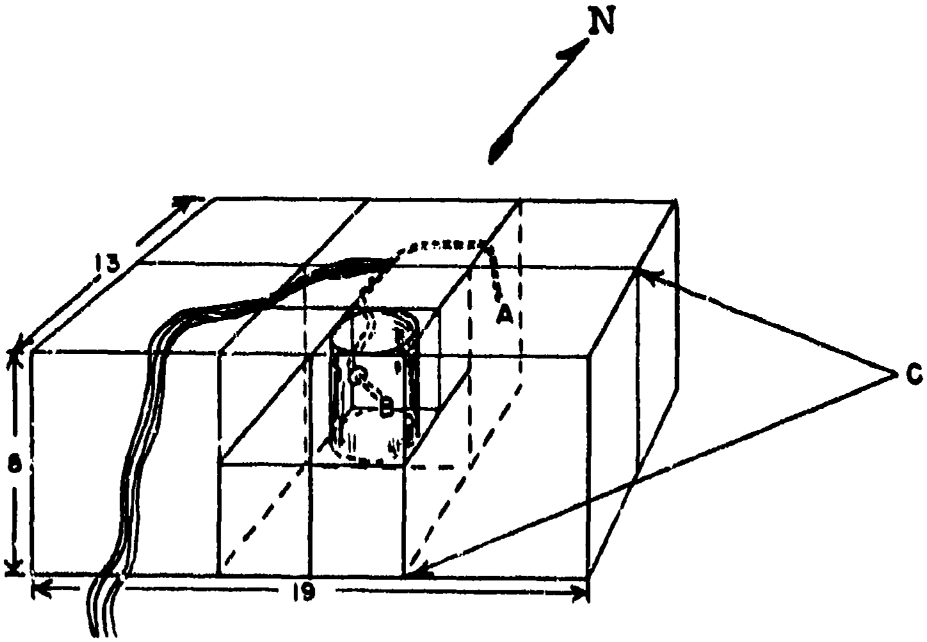
Figure 5-17. Dump Storage Research Site, Yuma, Ariz. (Ref. 15)



I A Top center carton, air
I C Top center carton, food
II A Carton below I, air
III A Carton in diametric center of stack, air
IV A Center bottom carton, air
V A Center west face carton, air
V C Center west face carton, food
VI A Top center carton, air outside ration package
VII A Upper southwest corner carton, air

A = Thermocouple in ration package, air
C = Thermocouple in can in ration package, food

Figure 5-18. Location of Thermocouple Positions in Stacked Cartons (Ref. 15)



(All measurements are in inches.)

A. Carton air thermocouple
B. Food thermocouple
C. Ration package

Figure 5-19. Test Carton Configuration (Ref. 14)

the increased water vapor in the total airmass column. This results in higher minimum temperatures. From these studies, it is concluded that summer storage heat stress will be greater in areas like the shores of the Red Sea, or on large tropical islands where high solar radiation is combined with high atmospheric humidity.

5-4.4.2.5 *Temperature Distribution in a CONEX Container.* The temperature inside enclosed shipping containers such as the CONEX was monitored to develop procedures for predicting temperatures in such containers (Ref. 16). In these tests a CONEX container was left standing in the sun to simulate the conditions on railroad sidings or in temporary storage. Measurements were made at the Tropic Test Center in the Ft. Clayton area of the Panama Canal Zone. A meteorological station located at the test site recorded solar radiation, air temperature, relative humidity, average windspeed and direction, and rainfall. During the period of the test, daytime temperatures were in the high 80's or low 90's and nighttime temperatures were in the 70's. Large amounts of rain fell during the test, but, during the morning, skies were generally clear with development of partly cloudy conditions in the late afternoon.

The container was located in a clear area in a shallow ground depression. During the

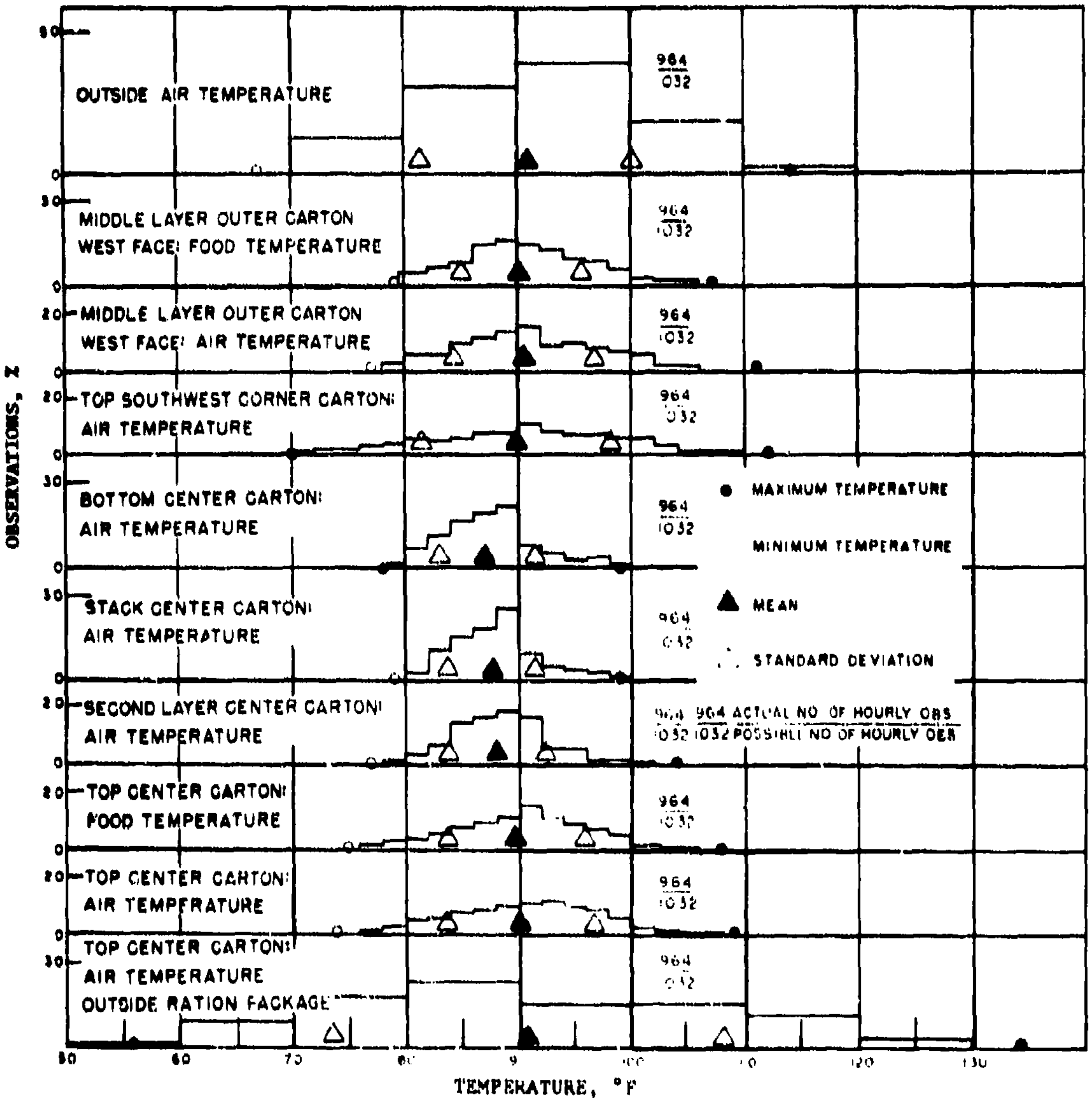


Figure 5-20. Temperature Data for Open Stack of Cartons in Desert Climate (Ref. 15)

early morning a low hill approximately 1,000 yd to the east blocked the sun and delayed the solar radiation heating process for about 30 min. The door of the CONEX container faced approximately north, and eight sensors were placed on and around the container. Fig. 5-24 is a line drawing indicating the location of the various temperature sensors.

Table 5-15 presents the maximum values of temperatures recorded. A peculiarity noted on the hottest day was a series of temperature fluctuations occurring in the early afternoon resulting from a rapidly changing cloud cover. With a 40-min span, the roof temperature dropped 40 deg F, rose 28 deg F, dropped another 44 deg F, and rose again 40 deg F. These variations were

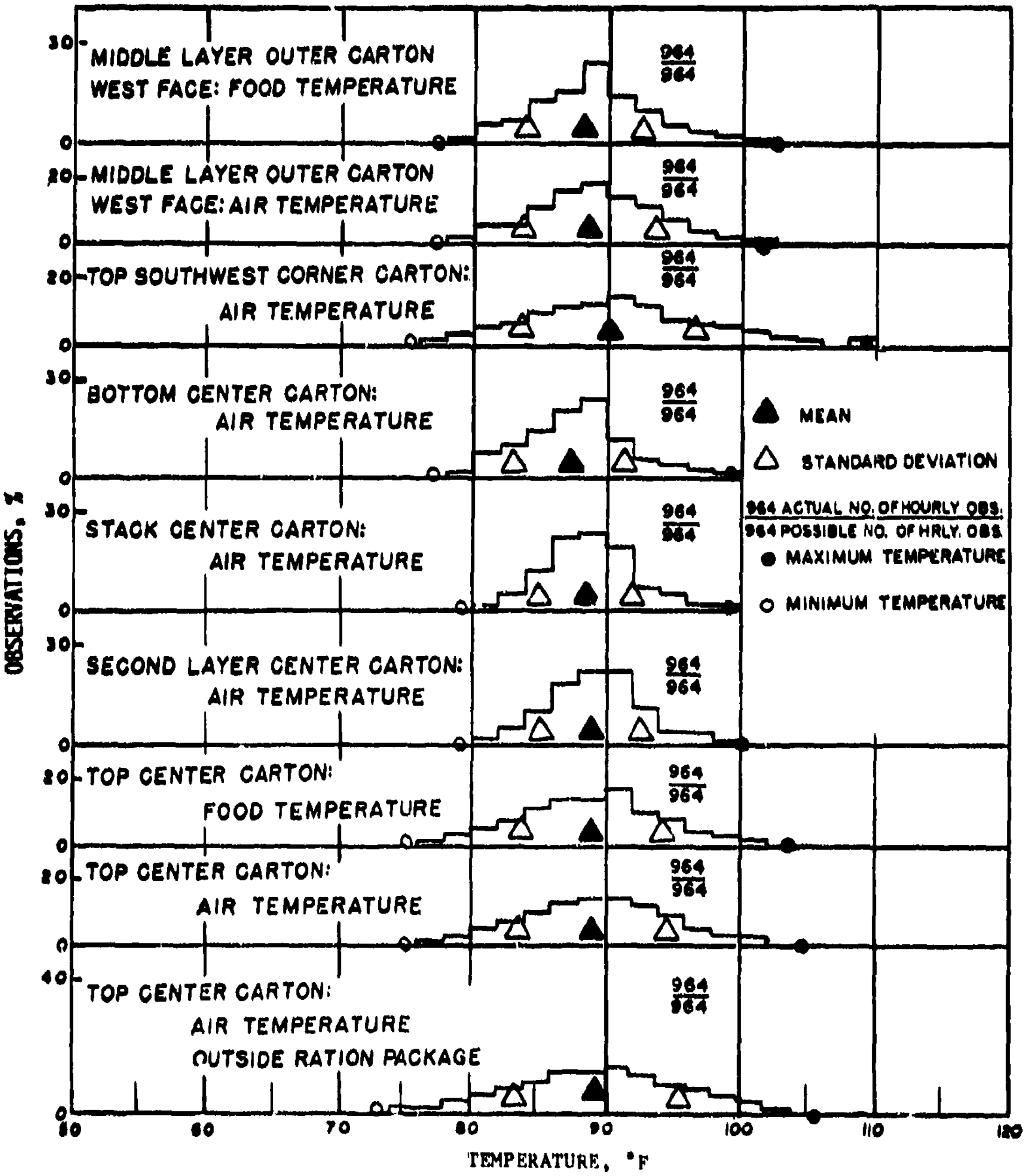


Figure 5-21. Temperature Data for Raised Fly Stack of Cartons in Desert Climate (Ref. 15)

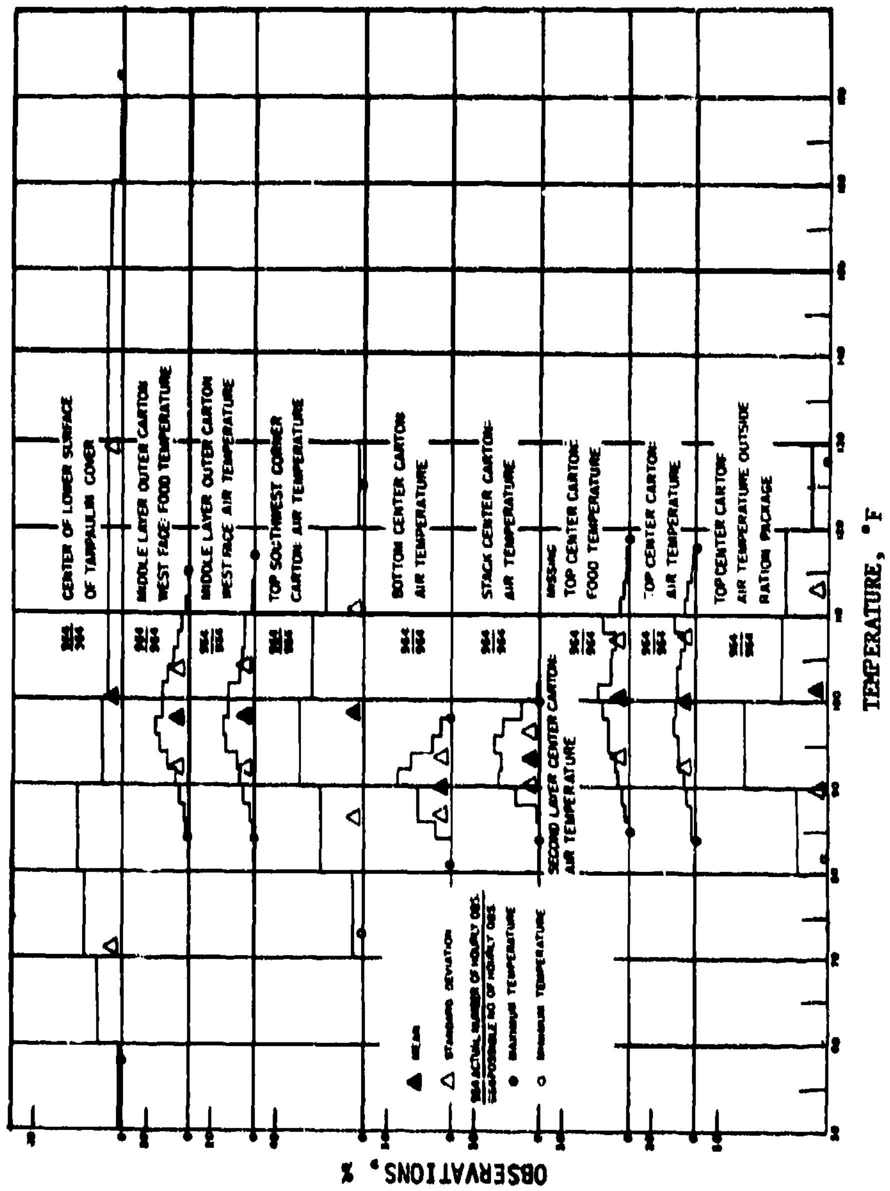


Figure 5-22. Temperature Data for Tight Tarpaulin Stack of Cartons in Desert Climate (Ref. 15)

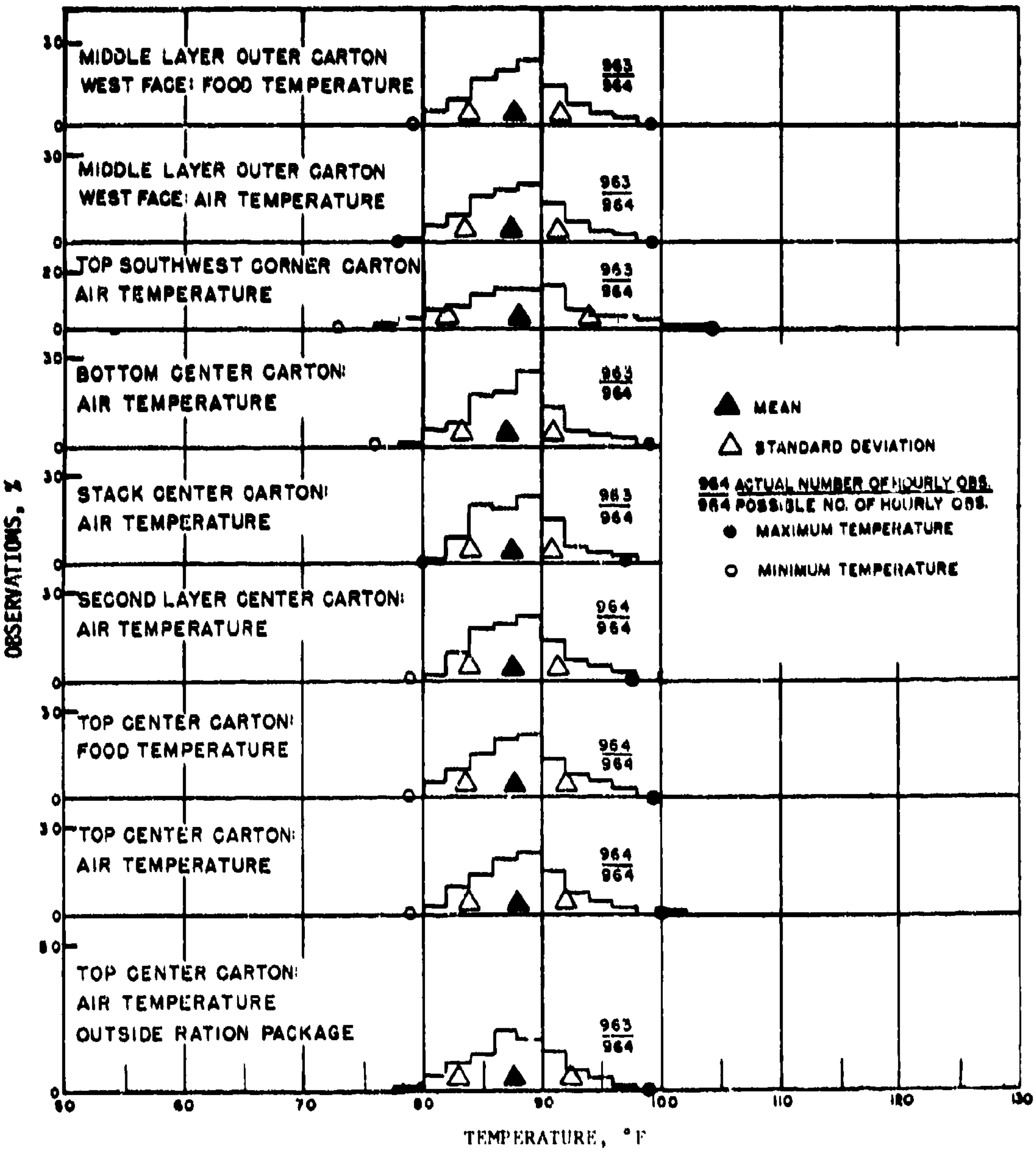


Figure 5-23. Temperature Data fo Raised Fly With Foil Stack of Cartons in Desert Climate (Ref. 15)

TABLE 5-12.
ABSOLUTE MAXIMUM TEMPERATURES IN STACKED CARTONS IN DESERT CLIMATE (Ref. 15)

	Outside air, °F	Abandon ship ration, °F	Open stack, °F	Raised fly stack, °F	Tight tarpaulin stack, °F	Raised fly with foil stack, °F
Top center carton	--	--	109	104	118	100
Middle layer outer carton on west face of stack	--	--	111	101	117	99
Top southwest corner carton	--	--	112	109	125	104
Abandon ship ration with black cover	--	131	--	--	--	--
Abandon ship ration with no cover	--	127	--	--	--	--
Outside air	114	--	--	--	--	--
Top center carton air temperature outside ration package	--	--	134*	106	128	99

*This value seems atypically high and is suspect since the thermocouple may have been touching the upper surface of the C-Ration carton, which was directly exposed to solar radiation.

TABLE 5-13.
TEMPERATURE DATA FOR STACKED CARTONS AND RATIONS (Ref. 15)

Position	Mean °F	Standard deviation, deg F	Absolute maximum, °F
Outside air	90.8	9.4	114
Abandon ship ration, black cover	95.9	17.7	131
Abandon ship ration, no cover	92.4	15.9	127
Top center carton air			
Open stack	90.2	6.5	109
Raised fly stack	89.1	5.5	104
Tight tarpaulin stack	100.2	7.6	118
Raised fly with foil stack	88.0	4.0	100
Second layer center carton air			
Open stack	88.1	4.4	104
Raised fly stack	88.9	3.7	100
Tight tarpaulin stack	M	M	M
Raised fly with foil stack	87.7	3.6	97
Stack center carton air			
Open stack	87.6	3.8	99
Raised fly stack	88.4	3.5	99
Tight tarpaulin stack	93.3	3.3	100
Raised fly with foil stack	87.6	3.4	96
Botton center carton air			
Open stack	87.1	4.2	99
Raised fly stack	87.2	4.1	99
Tight tarpaulin stack	90.1	3.3	98
Raised fly with foil stack	87.2	3.8	99

M = missing data.

reflected throughout the container, but with a lesser degree of change. On this same day, the highest total solar radiation was also recorded. The maximum temperature recorded for the roof was 162°F, for the ambient air, 95°F, and for the center of the container, 110°F. The very high roof temperature compared to the ambient air temperatures indicates the significant effect of solar radiation on material stored in closed containers in the open.

Additional data on extreme temperatures encountered in storage or transit are given in Table 5-16.

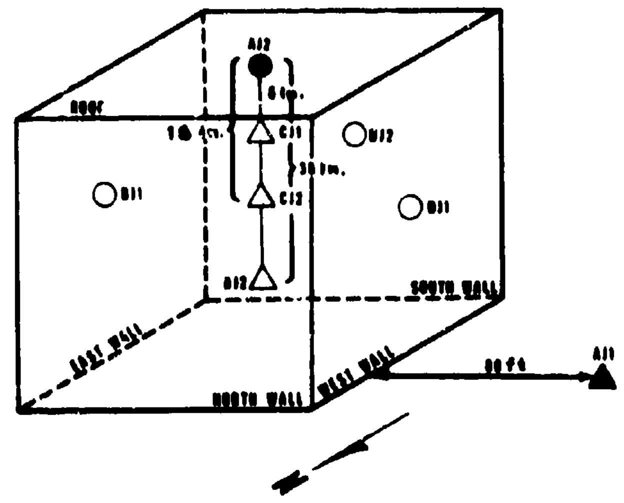
5-4.4.3 Food Storage

5-4.4.3.1 *Storage of Conventionally Processed Rations.* Data on the stability of representative types of Civil Defense shelter rations including cereal items, carbohydrate supplements, and their packaging materials

TABLE 5-14.
STORAGE MEAN TEMPERATURE CONTRAST BETWEEN DRY AND MOIST PERIODS (Ref. 15)

Stack and position	Dry period ending 11 July, °F	Moist period ending 3 Sept, °F	Difference, deg F
Stack center carton air			
Open stack	86.0	89.1	3.1
Raised fly	66.9	89.7	2.8
Tight tarpaulin	90.9	95.7	4.8
Raised fly with foil	85.8	89.4	3.6
Botton center carton air			
Open stack	85.2	88.8	3.6
Raised fly	85.2	89.1	3.9
Tight tarpaulin	87.7	92.4	4.7
Raised fly with foil	85.2	89.2	4.0
Top center carton air			
Open stack	88.2	92.0	3.8
Raised fly	87.0	91.1	4.1
Tight tarpaulin	98.8	101.5	2.7
Raised fly with foil	86.2	89.7	3.5
Second layer center carton air			
Open stack	86.5	89.7	3.2
Raised fly	87.3	90.4	3.1
Tight tarpaulin	M	M	M
Raised fly with foil	85.9	89.6	3.7
Outside air	88.7	92.7	4.0
Abandon ship ration			
Black cover	94.7	97.1	2.4
No cover	90.1	94.6	4.5
Tight tarpaulin stack			
Center of lower surfaces of tarpaulin cover	98.5	101.4	2.9

M = Missing data.



SENSORS		KEY
AJ1——AIR AMBIENT	●	SURFACE PROBE (OUTSIDE)
AJ2——ROOF	○	SURFACE PROBE (INSIDE)
BJ1——EAST WALL (INSIDE)	▲	AIR TEMPERATURE PROBE (OUTSIDE)
BJ2——SOUTH WALL	△	AIR TEMPERATURE PROBE (INSIDE)
CJ1——6 in. UNDER ROOF		
CJ2——18 in. UNDER ROOF		
DJ1——WEST WALL		
DJ2——36 in. UNDER ROOF		

Figure 5-24. Temperature Sensor Locations in the CONEX Container (Ref. 16)

TABLE 5-15. MAXIMUM TEMPERATURES RECORDED IN CONEX CONTAINER IN TROPICAL CLIMATE (Ref. 16)

Time, hour of day	Location/°F							
	AJ1 ambient air	AJ2 roof	BJ1 east wall	BJ2 south wall	CJ1 6 in. under roof	CJ2 18 in. under roof	DJ1 west wall	DJ2 36 in. under roof
0930	92	122	118*	126	115	109	100	93
1000	93	134	118*	127	118	113	97	104
1250	93	162*	111	135*	128*	122*	120	113
1430	93	145	107	122	126	122*	131	116*
1530	95*	133	106	118	126	122*	136*	113

*Maximum temperature recorded by probe.

TABLE 5-16.
EXTREME TEMPERATURES IN STORAGE OR TRANSIT (Ref. 16)

Source	Type storage or transit space	Location	Max. temp. of air at top of space, °F	Max. temp. of air in most critical carton, °F	Max. of hourly food temp. (Not necessarily concurrent with carton air temp. cond. as indicated), °F	Max. Temperature of Outside air, °F
Field tests	Dump covered with tight tarpaulin	Blythe, Calif. and Indian Bay, Fla.	150-160	126 (4 hr over 120)	115 Max. in food at top of stack	113
Questionnaires	Dump covered with tight tarpaulin	Mariana Is., S.W. Pacific	--	125 (5 hr over 120)	110 in food at top of stack at 1345 hrs	89
Questionnaires	Warehouse, cement and asbestos roof	Agra, India	--	107	98 in food at top of stack at 1500 hrs	110
	Warehouse, corrugated iron roof	Pelilieu, Caroline Is., S.W. Pacific	--	107	100 in food at center of stack at 1100 hrs	87
Field tests	Domestic army warehouse, wood frame and walls, asphalt roof	Ft. Wort., Tex.	111 (11 ft from floor) and 5 ft from roof	--	--	104
Field tests	Tents, closed	Ft. Lee, Va.	156 (9 ft from ground and 1-1/2 ft from canvas roof)	--	--	94
Field tests	Moving boxcars loaded to 5 ft with cartons of dried fruit	Near Needles, Calif.	134	102	--	About 111
	Stationary boxcars loaded to 5 ft with cartons containing six No. 10 cans of string beans	Yuma, Ariz.	152	119	113 Max.	111
Literature	Shipholds	Marcus Island, S.W. Pacific	110 upper between decks	--	--	102 (at time of hold temp. max.)

are available (Ref. 17). Rations from different procurement lots were stored for up to 5 yr with various controlled temperature and humidity conditions. Storage conditions ranged from 0° to 100°F and with 57 and 80 percent relative humidities.

Considering packaging observations first, the bursting strength of fiberboard cartons was reduced by storage at 70° and 100°F but increased by storage at 47° and 0°F. Bursting strength was not significantly correlated with moisture content or with relative humidity on which moisture content depends. The general condition of the cartons was satisfactory. Although the bursting strength at high temperatures was reduced, there was no collapse and relatively little distortion, essentially no molding or delamination, only moderate staining, and practically no change in legibility of labels or markings.

Corrosion of metal cans increased during the fourth and fifth years of storage at 80 percent relative humidity. Ten to 20 percent of the external surfaces corroded along seams and on panels. Internal corrosion was relatively slight. No leaks were caused by corrosion.

Cereal items in the rations were in good condition with moderate change in texture as a result of increased toughness or brittleness at higher temperatures and with acceptable-to-good aroma and flavor. Crackers and biscuits stored at 100°F were well below the specified level of quality for continued storage but wafers had changed relatively little during the storage.

Carbohydrate supplements were not severely affected by storage environment but were definitely off-color. However, candy stored at 100°F was rated moderately good to eat.

Another study of long-term food storage was conducted on a total of 93 military ration items more than 26,000 cans and 86,000 flexible packages by the Quartermaster Food and Container Institute (Ref. 18). Forty-three food items, mostly confections, were stored for 2 yr while 50 representative bakery, cereal or coffee, confection, dairy, meat or fish, and vegetable and fruit products were stored for 7 yr. Storage temperatures varied from -20° to 100°F with 50 to 90 percent relative humidity. Both tin cans and flexible containers were used. The most outstanding result from this experiment was the extent by which the storage life was increased at reduced storage temperatures. Each of the qualities appearance, aroma, color, texture, flavor, acidity, drained weight (where applicable), and vitamins of all products responded favorably to refrigeration. For example, the storage life of canned pork steaks was estimated at approximately 20 yr for 0° or -20°F, 15 yr at 32°F, 7 yr at 47°F, 5 yr at 70°F, and 30 mo at 100°F. Corresponding figures for chocolate fudge bars were 40 yr, 17 yr, 6 yr, 2 yr, and 4 mo. The estimated percentages of the rations that would remain acceptable for various durations and temperatures of storage are summarized in Table 5-17.

Undesirable changes also occurred as a result of the freezing and thawing of some products. Products damaged to some extent by freezing were canned beef and vegetables with gravy, bacon, salad, sausage patties, chicken and noodles, frankfurters with beans, ground meat with spaghetti, pork and gravy, beefsteak, tuna and noodles, beans with pork, and tomatoes. Only beans and tomatoes were damaged completely beyond an acceptable grade.

From other storage studies at the Quartermaster Food and Container Institute, it has been demonstrated that almost all canned and dehydrated foods keep well at 40°F and in many instances for short periods at 70°F (Ref. 19). At 100°F, however (a temperature often reached in ordinary warehouses), deterioration is rapid, in some cases occurring within 12 mo. One type of ration was subjected to storage for 2 yr at 70°F and for 2 yr at 100°F. At the end of 1 yr of

TABLE 5-17.
ESTIMATES FOR SURVIVAL OF RATIONS FOR VARIOUS COMBINATIONS OF STORAGE DURATION AND TEMPERATURE (Ref. 18)

Temperature, °F	Percent of rations acceptable after indicated storage duration									
	Years									
	1/2	1	2	3	5	7	10	15	20	30
0 to -20						94	91	77	65	41
32					98		90	78	62	22
47					90		54	22		
70					52	38	28			
100	68	54	34	20	<5					

storage, there was no marked difference in the rations. At the end of 2 yr at 70°F, the ration had not deteriorated significantly, but that stored for 2 yr at 100°F showed such extreme deterioration that the ration was unacceptable for consumption. Deterioration included browning of cereal bars, giving them a distinctly mottled appearance, and a black tarry appearance of tea and coffee products (probably caused by absorption of moisture). The bouillon powder was described as being similar to charcoal, gum pellets had become cream-to-tan in color, chocolate bars were dry, almost powdery, and fruit bars had a mottled black and brown appearance. Flavors had transferred from one item to another, and chemical analysis disclosed that moisture invasion had occurred.

Navy survival rations have been subjected to storage for 3 mo at 70°F, 100°F, and 140°F. Distinct changes were observed for those stored at 100°F and 140°F. Deterioration effects included the inversion of sucrose, leakage of fats, and browning of fruit bars. Indications are that a majority of survival food items would keep in good condition for a minimum of 5 yr at 40°F.

In other tests, the Quartermaster Food and Container Institute selected 35 canned and 15 flexible-packaged products from Quarterma[…]r operational rations for storage tests. The lowering of temperatures again proved most effective in preventing deterioration. For example, cereal bars reached the limit of acceptability when stored at 100°F for 5 mo, when stored at 70°F for 14 mo, and when stored at −10°F for 40 mo. Other foods showed similar trends. In general, edible components remained acceptable about one-third as long at 100°F as at 70°F, about two and one-half times as long at 10°F as at 70°F, and about six times longer at 10°F than at 100°F. Other effects noted were that migration of fats was prevented, the interchange of moisture and corrosion of interiors of cans were reduced, and insect damage was prevented by refrigerated storage.

Not all foods deteriorate at the same rate under a given set of conditions. This poses a problem when a ration contains, in the same package, items of good as well as some with poor stability because of the possibility that the more rapidly deteriorating items will spoil the remainder. Another factor to be considered in storage of rations is relative humidity. Whenever changes in temperature occur, internal redistribution of moisture must be possible within a package as well as exchange with the moisture content of ambient air for nonhermetic packages.

The effect of freeze-thaw cycling, such as can occur in the logistic cycle, on the vitamin content of prepared food in pouches has been studied (Ref. 20). The particular ration studied is one designed to simplify combat feeding by the use of convenience foods It is composed of 12 flexible-packaged menus, plus two alternative menus, each of which is a complete meal and provides at least 1,200 calories and one-third of the daily nutrient requirement. All items are packaged in Mylar-foil-polyethylene laminated bags or pouches. Samples were subjected to one, three, and six freeze-thaw cycles. Vitamin content was analyzed prior to and after cycling. Test results showed that nine of the menus significantly decreased in vitamin A and carotene 44 percent and 28 percent destruction of vitamin A and carotene, respectively. Initial content of reduced ascorbic acid decreased one-fourth after one cycle and one-half after six cycles. For most menus, the thyamine content decreased approximately 20 percent during the first cycle, and no further loss was encountered. The vitamin B_6 content decreased during cycling at the end of the third cycle, a 13-percent reduction: by the end of the sixth cycle, an additional 7-percent loss.

5-4.4.3.2 *Storage of Specially Processed Rations.* The type and extent of deteriorative reactions that occur in precooked, freeze-dried food in adverse storage environments have been studied (Ref. 21). Freeze-dried beef, chicken, carrots, and spinach were employed as the study materiel. The variables monitored were residual moisture level, headspace oxygen concentration, and duration of storage at elevated temperature. Of the variables studied, exposure to oxygen appeared to be the most significant factor in degradation of freeze-dried products stored at elevated temperature.

Since freeze-dried foods are extremely porous, large surface areas are exposed to whatever atmosphere surrounds them. As a result, the volume and composition of the container headspace atmosphere determines the extent of exposure of the product during storage. The container headspace employed in this investigation varied from 70 to 90 percent of the total volume of the container. The substantial volume, coupled with large surface area of the dried food products, provides an appreciable exposure of these products to oxygen, even with a moderately low oxygen partial pressure. As a result, oxidation can proceed at a rapid rate, unhampered by penetration barriers.

Another means by which oxidative damage can occur to freeze-dried products is exposure to air during the interval between removal of the product from the freeze dryer and sealing in the package container. Molecular oxygen is rapidly and tightly bound by these products and is desorbed slowly, if at all, during storage. The test conditions in this study were such that the relative effects of prepackaging air exposure and storage atmosphere could not be differentiated. Packages were sealed with 2, 4, and 20 percent oxygen atmospheres and stored at temperature of 100°F for a 6-mo period. Considering the freeze-dried beef only, the items stored under 2 percent initial oxygen atmosphere were considered acceptable for use after storage. Although some of the other products tested were not completely unusable when stored for 6 mo with higher oxygen concentration, the quality of the product was significantly better with a lower oxygen concentration.

Moisture was the second most significant parameter monitored in this series of tests. Generally, the lower residual moisture levels yielded better products at the end of the storage period.

In another study, the effect of storage temperature on dehydrated lima beans was examined (Ref. 22). In these tests dehydrated lima beans that had been prepared for storage using different techniques were subjected to various temperatures of storage:

40°F, 70°F, and 100°F. Results indicated that storage temperatures significantly affect the texture regardless of preparation method. Lima beans stored at 100°F exhibited a tougher texture than those stored at 40°F or 70°F.

5-4.5 PRACTICAL CONSIDERATIONS ON ENVIRONMENTAL STORAGE OF SUBSISTENCE AND EXPENDABLE ITEMS

TM 10-250–a manual on storage of supplies–discusses the storage of materiel (including items of materiel unusually susceptible to attack by environmental factors), the identification of environmental factors considered most likely to cause deterioration of susceptible items, and some practical general observations on storage of materiel (Ref. 23). A summary of these observations is given.

When materiel is placed in storage, the following practices should be observed for its care and preservation:

(1) All supplies should be protected from damage by moisture, extreme changes in temperature, vermin, and rodents.

(2) Proper ventilation should be maintained at all times.

(3) Good housekeeping practices should be used to insure order and cleanliness.

(4) Periodic inspections should be made of all supplies in storage.

The major causes of damage or deterioration of subsistence during storage periods are improper handling, insects and rodents, bacteria, molds, temperature, moisture, and foreign odors. Molds are especially prevalent in dried fruits and vegetables; preserved fruits; jams, jellies, and syrups; seeds, grain, and cereal products; sauerkraut; pickles; catsup; and sausage. Some subsistence items, particularly cereal and dairy products, are susceptible to absorption of odors from oil, paint, naphthalene, and similar products.

The causes of spoilage in canned foods are the same as for fresh foods; mainly microbes (which include bacteria, molds, and yeast), chemical reactions, and physical damage. In some instances, only one factor is the cause, but more frequently spoilage occurs as the result of a combination of these conditions.

Wool and mixed wool clothing in storage must be protected from damage by moths. The methods of protecting clothing include:

(1) Initial treatment of such clothing with mothicide or insecticide by the manufacturer with additional treatment at the depot when the clothing is repacked or baled

(2) Use of mothicide or insecticide in the bins of a loose issue room to protect unpackaged clothing

(3) Periodic spot checking of wool or mixed wool items, particularly during the summer months

(4) Items susceptible to insect infestations should be fumigated. Mildew (fungous attack) is another means of damage that develops on clothing stored in a warm, moist climate. When sufficient moisture and warmth are present, mildew will grow and spread very rapidly within a period of a few hours. It first appears as brown, black, green, or gray patches. These patches then become dense, developing powdery spores which spread and start new growth.

The major cause of damage to equipment items in storage is moisture. Clean, dry, well-ventilated storage will assist greatly in the preservation of equipage items for long periods of time. The following items should be given particular attention, however:

(1) Lockers, subject to warpage when exposed to moisture

(2) Brass musical instruments, susceptible to corrosion by moisture

(3) Canvas, subject to mildew in a warm, moist climate

(4) Leather goods, subject to becoming moldy or excessively dry unless properly stored and cared for

(5) Metal products, subject to rust and corrosion when exposed to moisture

(6) Rubber goods

(7) Silk flags

(8) Tent pins and poles (untreated wood), subject to rot if not protected from moisture by dry storage

(9) Webbed equipment, subject to mildew

(10) Woodwind musical instruments, subject to splitting and corrosion by moisture.

When placing items in shed storage, supplies that are less subject to damage from the elements should be stored in the outer shed area. When necessary, tarpaulins or other coverings should be used to protect items in outer shed areas. Because of the lack of full protection against the weather, items in shed storages should be inspected periodically for corrosion and deterioration.

Dunnage or pallets must be used to protect all stock placed in open storage. If the storage area is unsurfaced, 6 in. of dunnage should be placed between the ground and the first tier. All items requiring tarpaulins must be covered as soon as the stack is completed, and the tarpaulins should be fastened securely to prevent shifting and tearing when the wind blows.

A number of supplies require special consideration because of low ignition temperature; poisonous nature; or susceptibility to corrosion, contamination, spontaneous ignition, or decomposition. These hazardous commodities include acids, brooms, candles, liquid and rubber cement, textile preservative compounds, gasoline, kerosene, insecticides with kerosene bases, cleaning solvents, diesel fuel, lubricating oils, gear lubricants, cleaning fluids, duplicating fluids, alcohol, ration heating fuel, methanol (wood alcohol), chlorinated lime, lye, lumber, matches, methyl bromine, naphthalene, paint, varnish, lacquer, enamel, shellac thinner, fumigant dust, and rodenticide.

5-5 TRANSPORTATION ENVIRONMENT

5-5.1 AVAILABLE TRANSPORTATION SERVICES

Everything that sustains the activities of a logistic system and the organizations it supports flows through the transportation system. Transportation services create place-utility (by moving an item from an area where it has little value to another where it is useful) and time-utility (by insuring an item is at a given place at the time it is needed). All modes of transportation—air, motor, rail, water, and expedient methods—can be and are used to transport personnel and cargo. Each has certain inherent capabilities and limitations (Ref. 2).

Motor transportation is a flexible, versatile mode of transportation. For many loads in many areas of the continental United States and of the world, motor transport is the only possibility. Materiel environmental requirements and path of movement restrictions may impose overriding limitations on the use of motor vehicles. For example, the loaded weight may be within vehicle gross load limits, but axle and wheel loads may preclude movement by certain routes. The range of shock and vibration values encountered during off-road movement may be a limiting factor for truck movement. General purpose military vehicles are designed to withstand the severe shocks of off-road movement, but the soft ride required for sensitive materials such as some missile system components cannot be obtained from the suspension system of military vehicles. Movement of such items by truck, therefore, may require special cushioning and packing techniques such as inflated rubber dunnage, nylon webbing, or similar material. Weather conditions, types of road surface, load capacities, and dimensions of bridges, tunnels, and underpasses provide other limitations of motor vehicle movement.

Rail transport is characterized by a capability for moving large tonnages of cargo and large numbers of personnel over long distances at higher speeds than can be obtained with inland waterways or motor transport. Of all the transport modes, rail transport is least affected by adverse weather but is less flexible than other modes because of its dependence on a fixed roadbed.

Ocean surface transport is characterized by flexibility, low cost, high tonnages, and wide availability. Limitations on ships may include the necessity of special handling procedures for some items of dangerous cargo; restrictive hatch openings; a lack of adequate bracing, shoring, lashing, or special cargo tiedown equipment; a possibility that over-the-beach discharge may be required; and other factors such as customs requirements, port restrictions, and beach or port clearance limitations.

Inland waterway systems can also transport great quantities of cargo and can move heavy and outsized cargo not easily transported by other modes. Disadvantages of inland waterway transport include slow speed and, in the combat zone, vulnerability to weather and enemy action plus difficulty in repairing damage to facilities such as docks and piers.

The advantages of airlift lie in its speed and security of movement, straight-line travel, and the avoidance of congested roads and terrain obstacles. Factors affecting the use of air transportation include weather conditions, the range and carrying capacity of aircraft, the availability of landing facilities, the degree of air superiority obtained by friendly forces, and cost. Of these factors, weather presents the most unpredictable hazards in the use of air transport.

Pipelines are the preferred mode for moving bulk fluids. Pipelines have the advantages of dependability, high volume capability, and minimum susceptibility to enemy action if concealed. Other less conventional modes of transportation include overland conveyor belts that can be used for bulk commodities such as coal and ore, surface-effect vehicles (air-cushion vehicles) that can move over water and swampy terrain, and animal transport.

5-5.2 TRANSPORTATION POLICY

5-5.2.1 General

The transportation environment experienced by materiel differs, depending upon the mode of transportation. The variation in kind and severity of environmental factors among the various modes of transportation can be significant. As a result, whatever affects the choice of transportation mode also affects the transportation environment to which the materiel will be subjected. In many cases the environment experienced by materiel in transport is influenced by regulations designed to standardize shipping and transportation procedures, to formulate military policy with respect to commercial transportation systems, and to safeguard cargo and prevent hazards to other cargo and personnel during transport.

Since choice of the mode of transportation for military materiel is determined by national transportation policy and since the transportation environment is affected indirectly by the regulations and codes that have jurisdiction over interstate commerce, it is pertinent to consider these aspects of the transportation system whenever attention is focused on the transportation environment. In the paragraphs that follow, the agencies within the United States that prescribe transportation policies are reviewed briefly, and illustrative examples of codes regulating transportation are given. National transportation policy with respect to the military materiel and personnel within the continental United States is outlined, along with the military common user transportation agencies and their functions. Finally, a discussion of major environmental hazards encountered during transportation is given.

5-5.2.2 Agencies Prescribing Transportation Policies

Within the continental United States, military freight shipments normally are made by commercial carriers in accordance with the directives and policies of appropriate regulatory agencies—Federal, State, or local (Ref. 24). Departments and agencies of the U S Government formulate and prescribe interstate commerce regulations pertinent to the carriers under their respective jurisdictions. Such regulations are published in permanent form in the Code of Federal Regulations (CFR) (Ref. 25). Amendments to the CFR are compiled and published annually as a pocket supplement to the basic CFR. These regulations are mandatory for many commercial carriers (including carriers of explosives and other dangerous articles) and are made applicable to military transportation activities by *Military Traffic Management Regulations* AR 55-355, par. 2-002 (Ref. 26). Intrastate regulations are prescribed by State and local agencies. The object of these multiple safeguards is the protection of life and property and the prevention of damage to the national transportation system and facilities. If military necessity requires departure from established regulations, waivers may be obtained as outlined in AR 55-355.

The authority of the Federal regulatory agencies is derived from laws such as the Interstate Commerce Act, which gives the Interstate Commerce Commission (ICC) jurisdiction over surface transportation by motor, rail, and waterways within the continental United States and the Civil Aeronautics Act, which regulates air transportation by commercial carriers. The Dangerous Cargo Act of 1940 authorizes U S Coast Guard regulation of movement of explosives and other dangerous articles by vessel. Other laws, such as the Transportation of Explosives Act and its subsequent amendments, cover specific matters.

Many manuals and regulations provide guidance for shippers and transportation officers. For example, the principal military one, AR 55-355, *Military Traffic Management Regulations* contains the general requirements for the transportation of military goods and implementation of ICC and other regulatory body directives (Ref. 26). Guidance on many specific items is provided by Technical Manuals of the 9-39 series which contain detailed procedures for loading and storing of special weapons, and for shipping containers in aircraft, trucks, railway cars, and naval vessels.

The transportation procedures for nuclear weapons materiel in the Defense Atomic Support Agency supply system are published in TM 39-100-5 *Nuclear Weapons Materiel Shipping Guide* (Ref. 27). The Atomic Energy Commission (AEC) prescribes rules and regulations governing the use, handling, transportation, and storage of nuclear material (radioactive materials that are fissionable). The AEC policies and regulations applicable to transportation of classified materials are contained in the AEC publications and in the Code of Federal Regulations. Pertinent CFR references include 10 CFR 20, *Standards for Protection Against Radiation;* 10 CFR 70, *Special Nuclear Material;* and 10 CFR 71, *Packaging of Radioactive Material for Transport* (Refs. 28,29,30).

The commandant of the U S Coast Guard establishes and enforces regulations applying to safety, transportation, and storage of explosives and other dangerous articles (including radioactive materials) aboard all vessels, domestic or foreign (except public vessels not engaged in commercial service) operating into or from U S ports and on inland waterways. These regulations are embodied in 46 CFR 146.29-1 to 146.29-100 (Ref. 31).

The transportation of explosives and other dangerous articles including radioactive materials by aircraft in the United States is regulated by the Federal Aviation Agency under its Federal Aviation Regulations (FAR) published as 14 CFR 103, *Transportation of Dangerous Articles and Magnetized Materials* (Ref. 32).

The Interstate Commerce Commission is responsible under the provisions of the Transportation of Explosives Act (18 USC: 831-835) for regulating the safe transportation within the United States of explosives and other dangerous articles (Ref. 33). These regulations are applicable to such shipments moving by surface in interstate commerce by common surface carriers: rail freight, rail express, rail baggage, highway, or water.

The Association of American Railroads (AAR), an organization of the commercial rail carriers of the United States, is not a regulatory body per se but exercises such jurisdiction over its members. The AAR publishes rules governing the loading of various commodities in open and closed cars. Compliance with these rules is requested for all shippers of freight by member railroads; otherwise, freight cars will not be accepted for movement.

The American Trucking Association (ATA) is an organization composed of the principal motor transport common carriers within the continental United States. The ATA is not a regulatory agency, being somewhat similar to the AAR in purpose. It publishes tariffs containing ICC regulations for the transportation of explosives and other dangerous articles by motor carriers. These tariffs are guides for all participating motor carriers and the shippers who use them. The ATA publishes a chart containing, by State, a table of allowable highway loads and a table of vehicle height, length, and width limitations.

TM 55-602, *Movement of Special Freight*, defines the term, "special freight shipment" to include all commodities that by their very composition are inherently dangerous or difficult to handle or transport (Ref. 24). This broad terminology includes acids and other corrosive liquids, munitions, compressed gases, explosives, flammable liquids, flammable solids, oxidizing materials, poisonous articles, nuclear weapon materials, radioactive materials or waste, and other items requiring special attention in processing due to transportability factors. It also includes oversize and overweight articles.

5-5.2.3 National Transportation Policy

All areas of the continental United States are served by commercial transportation systems from one or more of the modes. Generally, air and surface transportation systems are a combination that can reach any desired destination. Water transport, of course, is limited to areas adjacent to the coasts and the canals, lakes, and rivers of inland waterway networks. National transportation policy prescribes that commercial transportation services will be employed by the military departments for the movement of personnel and materiel between points within the United States when such service is available or readily obtainable and satisfactorily capable of meeting military requirements. Military-owned transportation such as motor vehicles, military air transport service, or other military aircraft may be used when the urgency of military necessity requires. However, the Department of Defense traffic management policy as outlined in AR 55-355 states that military-owned transportation will not be employed in such a manner as to affect adversely the economic well-being of the commercial transportation industry (Ref. 26). All modes of transportation must receive equal consideration services. The mode selected will be that which produces the lowest overall cost consistent with military requirements, contingent upon the carrier's ability to provide the desired transportation service in a safe, adequate, and efficient manner.

5-5.2.4 Military Common User Transportation Agencies

Single-service managers are designated for operation of modes of transportation common to the services (Ref. 2). These common modes are airlift, sea transportation, and continental U S surface transportation.

The Military Traffic Management and Terminal Service, operated by the Army, is the single-service manager for surface transportation and the operation of ocean terminals in the continental United States. The Military Airlift Command operated by the Air Force is the single manager for airlift service. The wartime mission of the command is to provide air transport forces, specialized technical services, in-route support, and air routes to meet emergency requirements of the Department of Defense. The Military Sea-Transportation Service operated by the Navy is a single-manager operating agency for sealift services. The major portion of the passenger sealift requirement is transported on Military Sea Transportation Service passenger vehicles. The bulk of the cargo, however, is transported in commercial ships that are chartered by the Military Sea Transportation Service. In addition, the Air Force Strike Command has an organic strategic airlift capability that is used to provide assault airlift.

5-5.2.5 Most Severe Environmental Factors During Transportation

The most severe environmental factors encountered by packaged items during transportation are shock and vibration. Because of the severity of shocks and vibrations to cargo induced by the transportation environment, the majority of military cargoes require packaging or cushioning for shock and vibration attenuation. Of all the transportation environments encountered involving shock or vibration, the most extreme (with a possible exception of airdrop) are rail impacts that occur during switching, highway transport on unpaved roads that are nearly impassable, and terminal handling such as corner drops on a hard surface of 12-in. height for cargoes over 2,000 lb (Ref. 34).

For detailed information on shock and vibration effects and fundamentals, the reader is referred to Chap. 4, "Vibration", and Chap. 6, "Shock", in Part Three, *Induced Environmental Factors*, of this Environmental Series of Engineering Design Handbooks (Ref. 35).

5-5.3 MOTOR TRANSPORT

5-5.3.1 Types of Motor Transport Routes

Many of the problems associated with environment in the use of motor transportation involve the type of roadway on which the motor vehicle must operate. Routes are classified according to their ability to withstand the effects of weather (Ref. 36). Route type in any given delivery or transportation mission is determined by the worst section of the route. Routes as classified by type are:

(1) *Type X*. All-weather route is any route that, with reasonable maintenance, is passable throughout the year for traffic densities never appreciably less than maximum capacity. The roads that form this type of route normally have waterproof surfaces and are affected only slightly by precipitation or temperature fluctuations. At no time is the route closed to traffic by weather effects other than temporary snow or flood blockage.

(2) *Type Y*. All-weather route (limited traffic due to weather) is any route that with reasonable maintenance can be kept open in all weather but sometimes only at traffic densities considerably less than maximum capacity. The roads that form this type of route usually do not have waterproof surfaces and are affected considerably by precipitation or temperature fluctuations. Traffic may be halted completely for short periods. Heavy, unrestricted use during

adverse weather may cause complete collapse of the surface.

(3) *Type Z.* Fair-weather route is any road or route that quickly becomes impassable in adverse weather and cannot be kept open by maintenance short of major construction. This category of route is affected so seriously by weather that traffic may be brought to a halt for long periods.

Other obstructions and restrictions that occur on various routes include weight and lane limitations on bridges; overhead obstructions such as bridges, tunnels, underpasses, overhead wires, and overhanging buildings; reduction in width of route as a result of bridges, tunnels, craters, lanes through mined areas, and projecting buildings or rubble; gradients or slopes of 7 percent or greater; curves whose radius of curvature are less than 100 ft; and ferries and fords.

5-5.3.2 Advantages of Motor Transportation

Transportation by motor truck enables the shipment in most instances to take place directly from point to point with little or no interchange of freight between carriers. It not only results in fast and convenient service, but also reduces the possibility of loss or damage resulting from repeated loading and unloading. The motor truck, moving as an independent unit and therefore not being subject to the rigors of coupling and hooking as are rail cars, permit less costly expenditures for loading and unloading, packing, dunnage, and bracing. The fact that trucks are not loaded as heavily as rail cars also contributes to the existence of less stringent and less costly packing requirements. Motor freight is rapid for a comparably short distance because of the directness of route and the avoidance of lengthy and tedious terminal delays.

5-5.3.3 Shock and Vibration Environment

Vibration frequencies in motor trucks are dependent upon the natural frequency of the unsprung mass on the tires, the natural frequency of the spring system, and the natural frequencies of the body structure. The vibration amplitudes are dependent upon the road condition and the speed of travel. Intermittent road shocks of high magnitude can occur, with resultant extreme body displacements. These large displacements may result in a severe shock environment for unlashed cargo as it bounces about the truck floor. Vibrations caused by the truck engine and transmission system are relatively insignificant in the cargo area. The predominant natural frequencies of various military transport vehicles, as measured in the cargo space, are given in Table 5-18. Table 5-19 shows the cargo acceleration in a 2-1/4-ton truck, M104 Trailer combination over various types of terrain.

The vertical motions of truck beds are essentially transient vibrations. Their character is intermediate between periodic vibrations and high intensity shock; e.g., between the low level vibration on railcars—generally not included in the rail environment at all—and the shock of the switching impact of railcars. The transient vibrations are due to the condition of the road surface which may contain all sorts of irregularities. Of course, impact loads as a result of accident or collision cannot be considered a part of the normal ground transportation environment and are not included herein.

For both unit vehicles and tractor-trailer combinations, vertical translations (bounce) and pitch are dominant motions. The natural frequencies are of the order of 3.5 and 4.5 Hz, respectively, for typical highway vehicles loaded to the gross weight limits. The effect of the suspension under normal operating conditions is to damp cargo bed motions to about 10 percent of the amplitude experienced at the wheel-terrain interface. Accelerations measured on a highway trailer axle assembly were 1.5 and 3.0 G for average and extreme conditions, respectively, while the corresponding readings on the trailer frame were 0.1 and 0.3 G (Ref. 6). The dominant frequency of motion on the trailer frame is

TABLE 5-18.
PREDOMINANT VIBRATION FREQUENCIES IN CARGO SPACES OF MILITARY TRANSPORT VEHICLES (Ref. 1)

Type of vehicle	Direction of acceleration	Predominant frequency, Hz		
		Springs	Tires	Body
Truck (2-1/2 ton)	Vertical	2 to 4	8 to 13	70 to 180
	Longitudinal	-	10 to 20	70 to 100
	Lateral	2	10 to 20	100 to 200
Truck (3/4 ton)	Vertical	2 to 3	5 to 10	60 to 110
	Longitudinal	-	-	70 to 100
	Lateral	-	-	60 to 70
Trailer (1 ton)	Vertical	3 to 5	8 to 10	50 to 100
	Longitudinal	-	-	50 to 100
	Lateral	2	-	50 to 120
M14 Trailer	Vertical	1 to 4	7 to 10	50 to 70
	Longitudinal	3 to 4	8 to 10	200 and greater
	Lateral	2 to 4	-	-
M1, 2T Trailer	Vertical	2.5 to 5	7.75 to 10.5	100 to 150

TABLE 5-19.
CARGO ACCELERATION IN TRUCK-TRAILER COMBINATION (Ref. 1)

Operation over	Maximum acceleration, G			
	Longitudinal	Lateral	Vertical	Vector total
Sandy beach	2.5	1.0	4.5	5.3
Ungraded road (30 mph)	0.5	1.0	1.5	1.9
Graded road (30 mph)	1.0	0.25	1.0	1.4

in the range of 2 to 4 Hz, reflecting the influence of the suspension, while the axle motion measured 14 to 15 Hz due to the forcing effect of the vehicle-to-road contact. These values are sufficiently low and uniform in frequency so as not to constitute any long-term, cumulative hazard to containerized materiel.

Off-road and rough highway conditions produce motions at more severe levels than encountered in normal commercial highway operations. Off-road operations cause an increase in severity of motion by a factor of 2 to 3 for a diverse collection of vehicles (Ref. 6). Experimental values of acceleration measured on cargo platforms of trucks were as high as 5 G in the low frequency region of the spectrum. These values were obtained, however, at excessive speeds at which damage would be expected for the particular driving surfaces of the test.

For a more detailed discussion of the motor transport shock and vibration environment, the reader is referred to Chap. 4, "Vibration", and Chap. 6, "Shock", in Part Three, *Induced Environmental Factors*, in this Environmental Series of Engineering Design Handbooks (Ref. 35).

5-5.3.4 Other Environmental Factors

As mentioned in the preceding discussion, many environmental factors are not considered to be important during transport because transportation requires much less time than other activities during which exposure to these environmental factors occurs. Motor transport probably allows more exposure to environmental extremes due to climatic conditions than do other forms of transport such as rail, air, and ship because open shipment (without any covering or protection from the elements other than that provided by the packing or packaging of the materiel) is more likely to occur on trucks than with other transportation modes.

Corrosion is an example of an environmental effect that takes place over an extended period of time so that under normal circumstances it is not considered an important factor during transportation. Relative humidity, in the sense that it contributes to corrosion, is also not particularly significant in transportation. Precipitation in the form of rain, ice, hail, and snow are of little significance in transportation except for open transport in which the materiel is exposed to the environment.

Transportation by open truck over an unsurfaced road in dry areas is possibly the worst exposure to sand and dust that can be experienced by materiel. The truck speed adds to the damaging effects of sand and dust on exposed materiel.

Temperature is an important environmental factor in transportation because of the sensitivity of some materiel to extreme temperatures. Sensitive materiel includes certain ordnance items, electronic equipment, and perishable foodstuffs.

A temperature profile for truck-transported ordnance was determined for a standard loaded ordnance truck traveling in areas sought out for their extreme hot and cold temperatures (Ref 37). The temperature profiles obtained as a result of this study probably represent the extremes of temperature exposure for truck transportation within the continental United States. These measurements demonstrated that truck-transported ordnance is not subjected to the extreme temperatures of the surrounding environment. For example, during cold weather, the lowest outside air temperature measured was −20°F; however, the lowest ordnance temperature measured was −3°F. In like manner, during hot weather, the highest outside air temperature measured was 128°F, but the highest ordnance temperature was 116°F.

5-5.3.5 An Example of the Motor Transport Environment

An example of the motor transport environment experienced by 18 ready-for-issue missiles in a cross-country trip by motor transport from Charleston, S.C., to Concord, Calif., has been reported (Ref. 38). The missiles consisted of TARTARS, TERRIERS, and STANDARDS in MK-199 and MK-372 shipping containers (Fig. 5-25). Environmental factors that were monitored included shock and vibration, road conditions, temperature, relative humidity, and pressure. The transport vehicle was a standard suspension semitrailer, pulled by an over-the-road tractor. No movement of the load was noticed throughout the 2,899-mi trip. The average speed including stops was approximately 32 mph. The pavement varied from fair to very good, but most sections rated as good. Large shocks—two exceeding 15 G—were associated with stopping off the paved roadway. These shocks were reduced by the shock-mitigating systems built into the missile containers. The highest shock level recorded for any missile was 7.6 G which is believed to have resulted from pitching of a missile cradle within the container. Ambient pressure ranged from 11.4 to 14.9 psi. The temperature ranged from 37.4° to 60.3°F, and the relative humidity varied from 11.1 to 15.9 percent. Although two of the 18 missiles failed

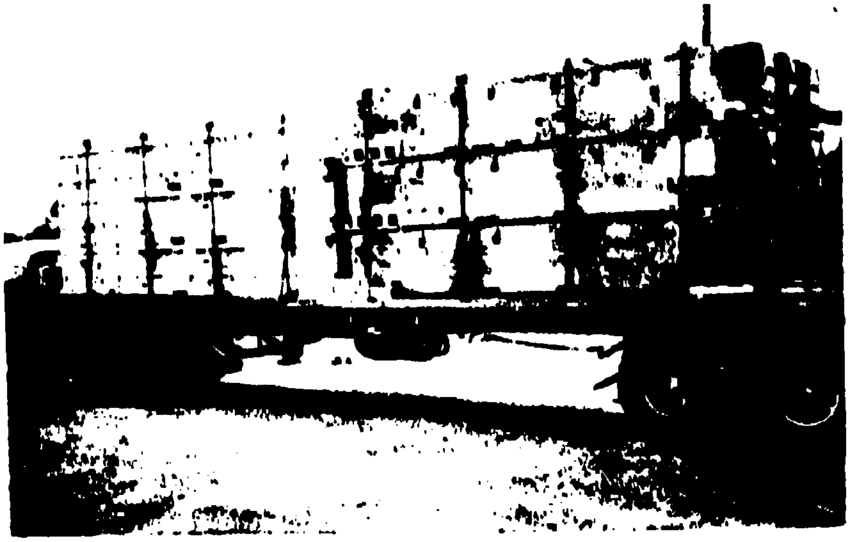


Figure 5-25. Loaded Truck Ready to Depart Naval Station (NWS), Charleston, S.C. (Ref. 38)

acceptance tests at the end of the trip, the failures were not associated with the transportation environment. As a result of this test, it was recommended that missiles/weapons packed in such containers be transported over improved roads on trucks with standard suspensions. Past practice had been to transport such weapons only on vehicles with air-ride suspension.

5-5.3.6 Combinations of Transport Involving Motor Vehicles

The transport of military supplies by motor vehicle can be combined with other modes—rail, water, and air—to reduce the handling of cargo and thus the time en route from origin to destination (Ref. 39). Examples include:

(1) *Piggy-back or trailer on flat car.* This is the term given to the combination of rail and motor transport. Semitrailers are loaded and sealed at point of origin, placed on rail cars, and moved forward as far as possible. They are then off-loaded, coupled with suitable towing vehicles, and delivered to their destinations over the highways.

(2) *Roll on/roll off.* This is the term given to the combination of water and motor transport. Semitrailers are towed onto specially constructed vessels at the port of embarkation and transported to another port. There they are coupled to tractors while still aboard ship and then are moved by highway to their destination.

(3) *Lift-on/lift off.* In this operation, loaded semitrailers are moved to port, uncoupled from their tractors and loaded aboard ship. Upon arrival at an overseas area, these trailers are off-loaded, coupled to tractors, and moved to destination by highway.

(4) *Air.* With the increased employment of air transport for both tactical and strategic mobility of troops and supplies and the concurrent development of aircraft of greater capacity, the movement by air of motor vehicles loaded with high priority cargo has become possible, thus allowing immediate distribution of these critical supplies on landing.

An example of transportation combining motor transport with air transport has been reported for a TITAN missile (Ref. 40). In this study a test was made to determine the vibration levels, shock levels, and pressure effects on an operational TITAN II missile during transport from the factory to the launch complex and during silo emplacement. The missile was loaded on a C-133-B aircraft and flown to its destination. At the end of the flight, the missile was unloaded, convoyed to the launch complex, then lowered into its silo by crane.

During road travel the missile was transported at speeds up to 35 mph. Curves were negotiated normally; dips and chuckholes were not purposely traversed, but when encountered, recordings were immediately annotated and the readings noted with a description of the events. Gravel roads were traveled at speeds up to 15 mph. During this portion of road travel, no shocks in excess of 2 G were imparted to the missile. During the flight, no pressure differential was found on the missile tankage. The peak acceleration measured, including taxiing, takeoff, and touchdown, was 2.82 G. The maximum overall sound pressure level obtained during flight was 127 dB. During transport from the aircraft to the missile launch complex, no shocks in excess of 1-1/2 G were imparted to the missile. During lowering of the missile into the silo by crane, virtually no shocks were obtained, all accelerations being less than 1/2 G. The results of this test indicated that a missile, while being transported from the manufacturing facility to an operational base in a normal manner, sustains no damage.

5-5.4 RAIL TRANSPORT

5-5.4.1 Advantages of Rail Transport

Rail transport represents the best mode of overland transportation for very large items and for large quantity shipments. Rail shipments are particularly suitable for shipment of bulk commodities such as grain, coal, and petroleum. Rail systems are affected little by climatic factors in contrast to the sometimes severe effects of snow and rain on motor transport. Disadvantages associated with rail transport include the frequent necessity for using trucks to bring materiel to and from the rail line. This entails additional handling which increases both the cost and the likelihood of damage during transit. Further, when full advantage is taken of the larger boxcar capacity for rail transport, then stronger and more costly packing techniques are required. When these factors become significant, rail transport is at a significant disadvantage. Rail transportation does decrease exposure to climatic elements compared with motor transport since most items shipped by rail are in closed boxcars.

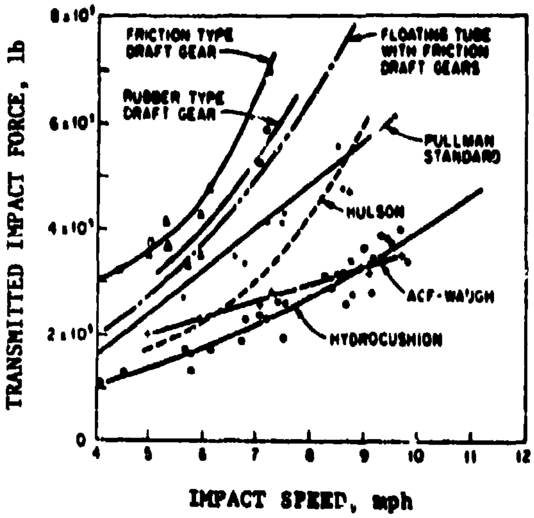


Figure 5-27. Effectiveness of Cushioning by Various Types of Draft Gear (Ref. 6)

5-5.4.2 Shock and Vibration Environment

The most significant environmental factors in rail transport are those resulting from motion. While motion is experienced by railcars during travel, impacts that occur during switching in yards are the major source of stress on cargoes. The various types of draft gear on railcars provide different degrees of cushioning in such switching impacts.

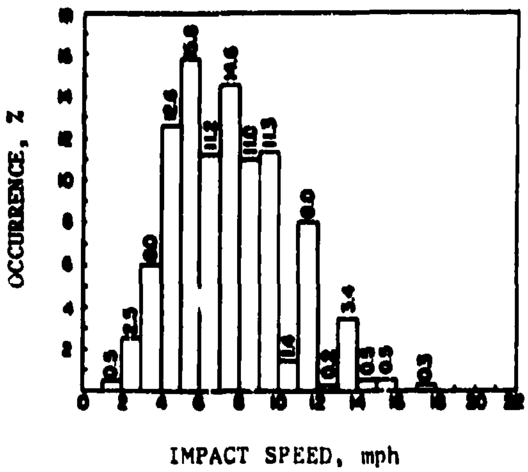


Figure 5-26. Impact Speed During Freight Car Switching Operations (Ref. 1)

Data on impact velocity indicate that impacts at a speed of 14 mph are present (Ref. 6). In Fig. 5-26, the distribution of impact velocities observed during switching operations is shown. Fig. 5-27 shows the effectiveness of cushioning by various types of draft gear. It is estimated that 90 percent of existing rail freight cars have either friction-type or rubber-type draft gear so that, for impact speeds in the range of 12 to 14 mph, a railcar loaded to a gross weight of 300,000 lb would experience an acceleration of 4 G.

Vibrations in moving freight cars arise from track and wheel irregularities and occur principally in the lateral and vertical directions (Ref. 1). The excitation frequencies caused by rail joints and wheel imbalance vary from 0 to 13 Hz. The resonant frequencies of railcar frames are in the range of 50 to 65 Hz. Shock and transient vibration during coupling and during starting and stopping are generally the most damaging phases of rail shipment.

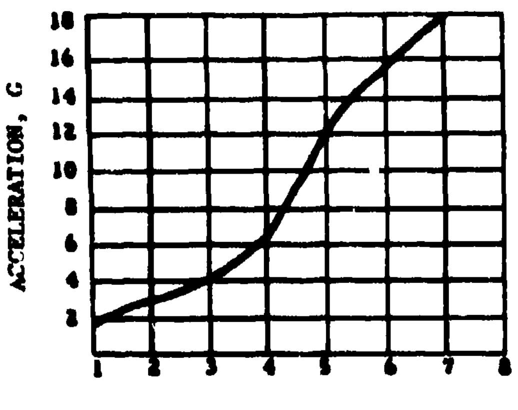


Figure 5-28. Maximum Longitudinal Acceleration of Freight Car During Switching (Ref. 1)

Longitudinal accelerations of a freight car body that can be expected for impact speeds of 1 to 7 mph are shown in Fig. 5-28. The method of bracing greatly affects the maximum acceleration of stored cargo. Although a free-floating cargo is desirable, it is not practical since it requires large space for the movement of the load. Furthermore, it does not provide protection against several successive impacts in the same direction. Controlled floating, in which movement is controlled by means of snubbers that center the load after each impact, is the most practical. Fig. 5-29 shows comparative results for one such controlled-floating arrangement and a blocked arrangement.

For a more detailed discussion of the rail transport shock and vibration environment, the reader is referred to Chap. 4, "Vibration", and Chap. 6, "Shock" in Part Three, *Induced Environmental Factors*, of this Environmental Series of Engineering Design Handbooks (Ref. 35).

5-5.4.3 Other Environmental Factors

Rail transport affords protection from most climatic elements so that they are of little significance during transport. Temperature is the most important environmental factor because of the many materiel items affected by extreme temperatures. Because of the extreme temperature exposure possible during rail transport—particularly where loaded boxcars can remain immobile on sidings for as much as several weeks—the potential temperature exposure of materiel in boxcars under these circumstances is of interest.

Temperature distributions in boxcars while not in motion on sidings in a desert, subtropical climate (Yuma, Ariz.) and in a humid location (Cameron Station, Va.) have been recorded (Ref. 41) (Fig. 5-30). Inside temperatures were sampled hourly. Outside air mean temperatures were normal for both locations so that representative conditions prevailed. The highest cargo temperature was measured in the top center carton in the boxcars, while the roof air was significantly hotter. Table 5-20 presents a comparison of the hottest day temperatures at Yuma and Cameron Station. A pronounced effect of location of measurement on the temperature measured was evident; for example, a 45- to 60-deg F difference between the maximum at different locations within the same car.

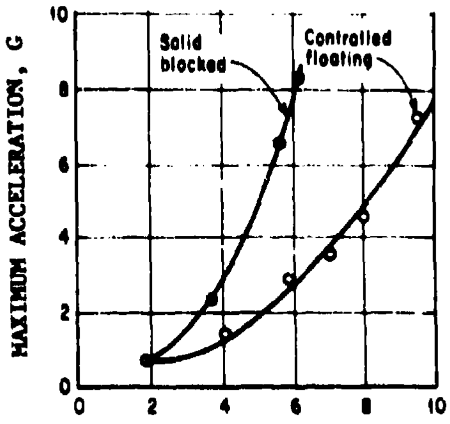
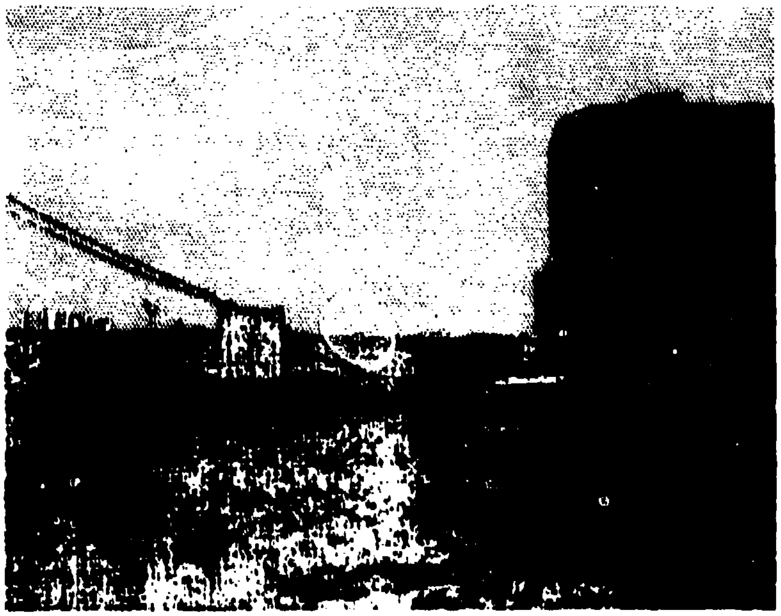


Figure 5-29. Acceleration of Solid-blocked and Controlled-floating Cargoes (Ref. 1)



(A) Facing North

Figure 5-30. View of Yuma, Ariz., Freight Car Study Site (Ref. 41)

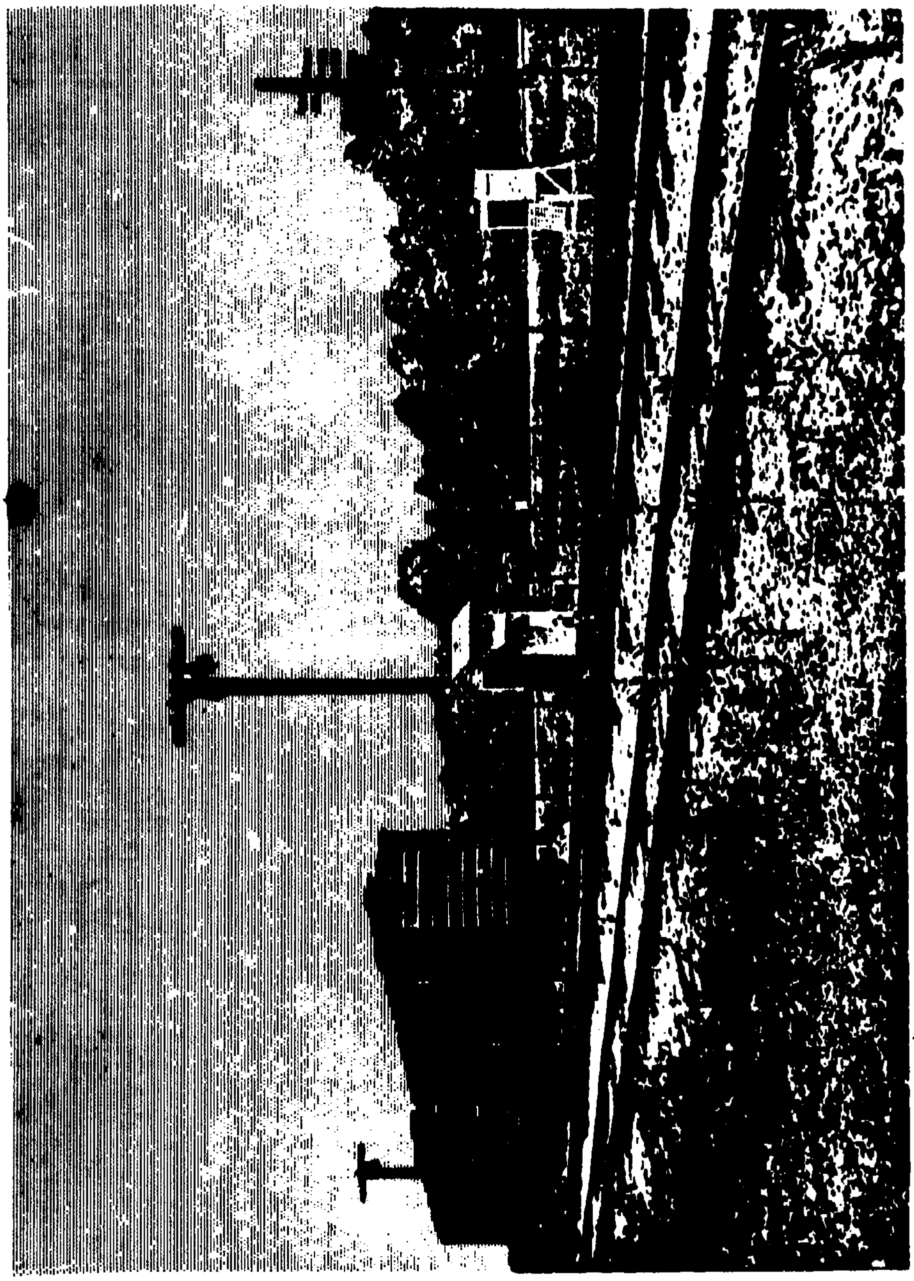
and, indeed, within 7-1/2 ft in actual distance. Figs. 5-31 and 5-32 present weekly means of temperature, windspeed, and solar radiation.

Subsistence in the cars was examined at the end of the test period. Effects on canned snap beans at the Yuma site were stated as, "Loss of vacuum and some chemical decomposition seems to have taken place in this product in the desert heat. The product is sound, however, and is fit for issue." In the same manner, cans of beans sampled from the Cameron Station site received the following evaluation: "The product examined is commercially sterile. Gas analysis and physical inspection of the sample, compared with normal optimal growth rates and biochemical reactions of organisms isolated, indicate that these organisms are metabolizing very slowly. A decrease in the vacuum of sample cans and corresponding increase in carbon dioxide and bacterial counts reveal that deterioration by bacteria may accelerate with continued storage. It is recommended that this product be issued immediately while the bacterial counts remain at their present level." C-rations did not fare as well. Inspection revealed that some ration components were unfit for issue. It is concluded that the absolute maximum temperature given in Table 5-21 may be taken as realistic upper limits for boxcar temperatures, except in such unique environments as Death Valley, Calif., where temperature extremes may be significantly higher.

5-5.5 SHIP TRANSPORT

5-5.5.1 Advantages of Ship Transport

Whenever transport of materiel is required for long distances and where possible, transport by ship is most economical for large or bulky items. The only alternative to ship transportation for long overwater routes



(B) Facing East

Figure 5-30 (Continued). View of Yuma, Ariz., Freight Car Study (Ref. 41)

TABLE 5-20.
COMPARATIVE HOTTEST DAY TEMPERATURES AT YUMA, ARIZ., AND CAMERON STATION, VA. (Ref. 40)

Position	Temperature*, °F		
	Maximum	Minimum	Mean†
Yuma, Ariz., 13 August			
Roof air	149	86	117
Ambient air	110	82	96
Top center carton air	117	94	106
Top center carton food	112	97	104
Buried load food‡	98	97	98
Cameron Station, Va., 30 July			
Roof air	139	76	108
Ambient air	100	70	85
Top center carton air	101	82	92
Top center carton food	91	85	88
Load center carton food	81	79	80

*Derived from hourly observations. Inter-hourly values may differ slightly.

†Derived from (Maximum + Minimum)/2.

‡Derived from middle-layer outer-carton food temperatures at west door and south end, both of which showed the same values.

is air transportation which is significantly more expensive. The great bulk of all materiel flow between continents separated by large bodies of water is water surface transportation.

The great advantage of water transportation is low cost. In general, water rates tend to be so low as to preclude rail, motor, and air transport from competing for traffic moving by water. The low cost of water transportation results from the facts that (1) water carriers have no maintenance or capital charge for use of the waterways, and (2) the tractive effort required to move a given weight in floating equipment is far less than that required to move the same weight on wheels. The disadvantages of water transportation are (1) slowness, (2) the sometimes seasonal character of the service, and (3) the necessity for transfer of freight (Ref. 42). During winter months, water transportation is not possible in northern regions due to freezing, and spring and summer operations are sometimes interrupted by floods or drought. Moreover if it is necessary to transfer freight from rail to the water carrier, handling costs and the possibility of damage are increased. The low initial cost of water transportation may be offset by these additional costs.

Most materiel for overseas use is carried by ship. For example, in the Vietnam conflict roughly 98 percent of all materiel was transported by sea (Ref. 43). This

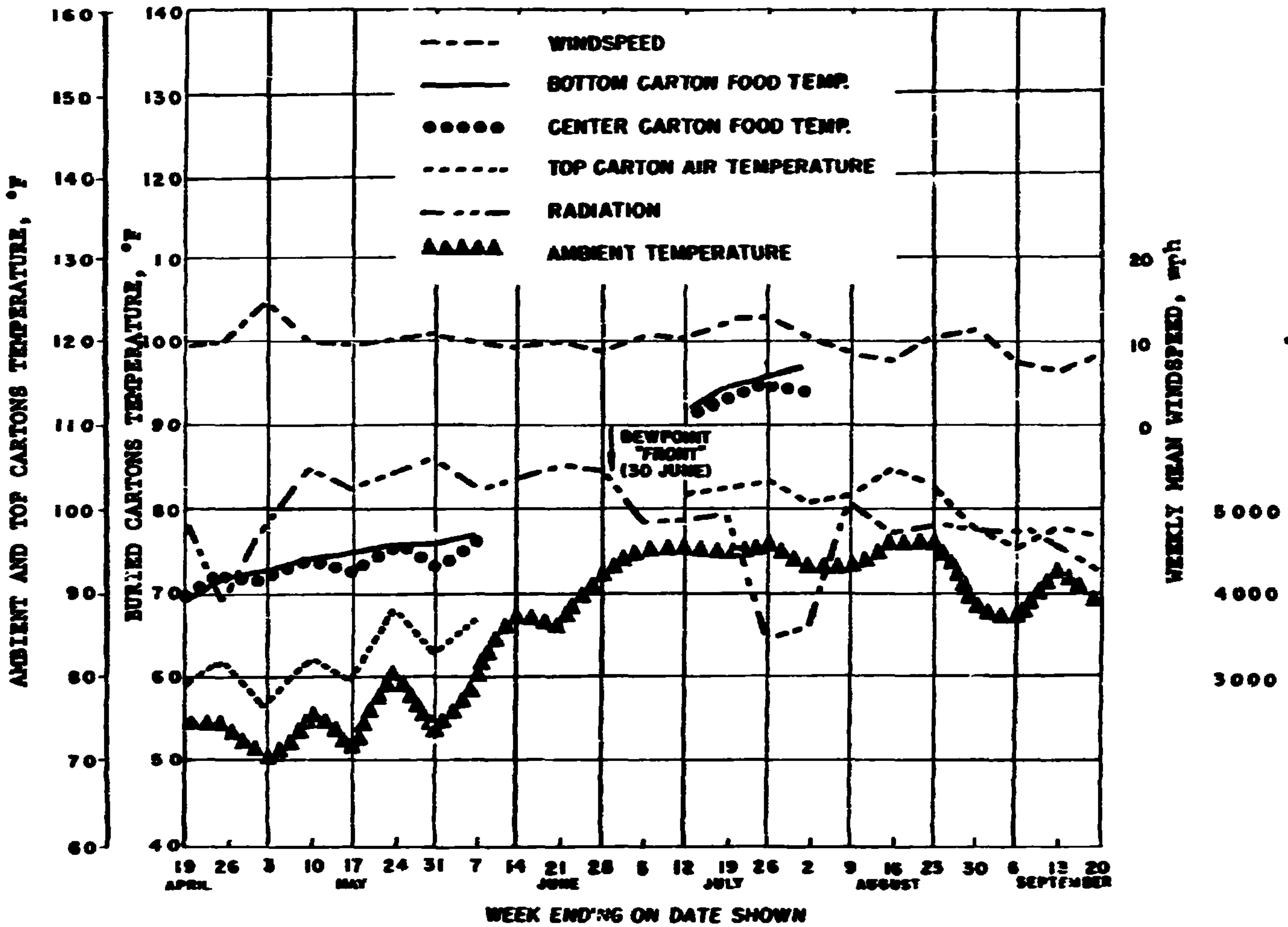


Figure 5-31. Weekly Means of Temperature and Windspeed, and Weekly Total of Solar Radiation, Yuma, Ariz. (Ref. 41)

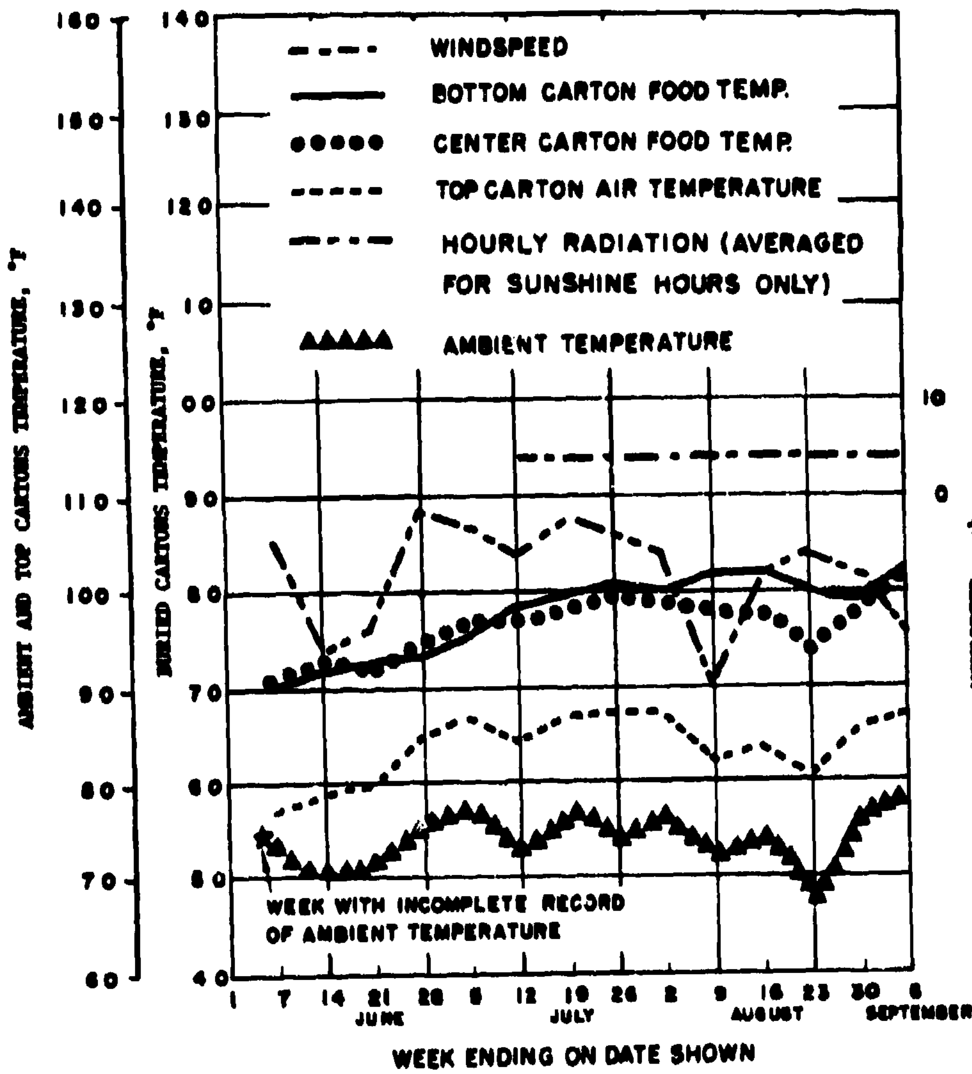


Figure 5-32. Weekly Means of Temperature, Windspeed, and Solar Radiation, Cameron Station, Va. (Ref. 41)

required transport of approximately 800,000 tons mo^{-1} in an almost around-the-clock operation for a minimum distance of 6,000 mi. As an example, one aircraft carrier required as high as 4,478 tons of munitions in one month compared to World War II aircraft carriers which dropped 2,000 tons of bombs in the entire war -a startling higher expenditure of this materiel.

Environmental factors have little deleterious effect on materiel when stored in the hold of a ship but they can and do have important effects during loading and unloading operations. Rain, snow, wind, high and low temperatures, salt air and salt fog, high relative humidity, icing, and blown sand and dust can be present during loading and unloading and can cause damage to materiel

TABLE 5-21.
ABSOLUTE MAXIMUM TEMPERATURES
REACHED IN BOXCARS (Ref. 40)

Position	Temperature, °F		
	Yuma, Ariz.	Cameron Station, Va.	Difference
Roof air	150	145	5
Top center carton air	119	101	18
Top center carton food	113	91	22

if it is not properly packaged. The likelihood that loading and unloading of ships will take place in unprotected areas is significantly higher than for other forms of transport.

In addition, the storage of materiel on open deck with little or no protection other than packing crates is not unusual. This type of exposure can cause severe deterioration by corrosion, accelerated by salt air and salt water exposure.

Another problem associated with water transport is the high probability of materiel damage by rodents and insects. It has been demonstrated adequately that rodents and insects are difficult to exclude from ships; therefore, susceptible materiel must be packaged so as to prevent such damage if it is to survive ship transport without deterioration.

The peculiar problems of water transport and its interaction with environmental factors are illustrated by some experiences in the Vietnam conflict (Ref. 43). The fall and winter seasons are extremely difficult for supply operations in Vietnam. This results from a combination of factors, foremost of which is the weather. The northeast monsoon starts in October and lasts until April. During this period, cooling of the landmass of the Asian continent produces a deep, high pressure area with air circulating clockwise around the continent. The winds drive across the full reach of the South China Sea, causing waves to build up and pound the coast of Vietnam from the east and northeast.

In addition to the sea, the warm, moist air deposits layer after layer of clouds on the coast. Long periods of torrential rains produce deep mud everywhere, flood vast areas, and change quiet streams into torrents. From time to time, conditions are worsened by the surges of cold fronts from the continental landmass down to the latitude of Da Nang and sometimes farther. In addition to producing heavy rains, the pressure gradient tightens as the front approaches and the winds intensify. Off-loading of cargo from the holds of merchant ships to landing craft becomes very difficult and hazardous under these circumstances, and it is sometimes necessary to abandon such activities for as long as 5 days at a time. Roads and staging areas become a morass, and the building and maintenance of roads and staging areas becomes a high priority item.

TABLE 5-22.
PEAK SHIPBOARD ACCELERATIONS
ENCOUNTERED IN NORTH ATLANTIC RUN
(Ref. 6)

Location	Acceleration, G	Sea state
Stern	1.0	10
Midship	0.37	8 and 9
Bow	1.5	8

Poor packaging caused serious problems as cartons dissolved in the heavy rains, making the loose contents difficult to handle or rendering them useless. On the other hand, in the hot season, cans of asphalt burst during handling. The necessity for removing cargo from ships and transporting it to pier areas in smaller, shallow draft ships caused additional difficulties, resulting in much loss and deterioration of materiel.

5-5.5.2 Shock and Vibration Environment

The principal excitation forces for shipboard vibrations are caused by interaction of the structure of the ship with the flow of water from the propellers and by the imbalance or misalignment of the propulsion system. The frequency range of these vibrations is about 5 to 25 Hz, with attendant accelerations reaching a maximum of about 1 G. During normal service, ship cargoes do not experience shock loads of any significant magnitude except during loading and unloading operations. Typical data were obtained for a 523-ft container ship during eight representative North Atlantic crossings (Ref. 6). It is interesting to note that extreme cargo motions are not associated necessarily with the worst sea conditions because the speed of the ship is varied with sea conditions. An attempt is also made to reduce water washing over the deck of container ships by avoiding head seas and accepting high roll excursions.

Peak values of vertical accelerations are given in Table 5-22. It was found that peak accelerations occur at sea state 8 as indicated in the table and not at the most severe sea conditions. On the other hand, the average accelerations continue to rise up to sea state 10. Another point of interest apparent from the raw data is that high seas in excess of sea state 6 are not rare. Approximately 9 percent of the data intervals represented sea states of 10 or greater.

Horizontal motions, including sway, roll (in proportion to the distance from the roll axis on which the observation is made), yaw, and hull bending in the horizontal plane, were also measured. The horizontal peak accelerations in either direction for the forward location at the main deck were 0.16 G for sway acceleration, 0.02 G for acceleration due to roll, 0.37 G for acceleration due to yaw, and 0.55 G for total horizontal acceleration.

For a more detailed discussion of the water transport shock and vibration environment, the reader is referred to Chap. 4, "Vibration", and Chap. 6, "Shock", in Part Three, *Induced Environmental Factors*, of the Environmental Series of Engineering Design Handbooks (Ref. 35).

5-5.5.3 Other Environmental Factors

Water transport generally can be differentiated from rail, motor, and air transport by the time required in transit. Water transportation is very slow when compared with any of these other modes of transportation. As a result, those factors that require long periods of time to cause deterioration of materiel can become effective during ship transport, although they normally are not effective during transport by other means. In addition, exposure to salt air is significantly greater because, in most cases, the ship and its cargo are in contact with a maritime atmosphere of high humidity and high salt content at all times. Items stored above deck are particularly susceptible to rapid corrosion as a result of exposure to salt air and salt water. The bulk transportation of grains and other food stuffs has resulted in many freighters becoming infested with insects and rodents, thereby increasing the possibility of materiel deterioration from macrobiological attack. For above-deck storage, exposure to high ambient solar radiation, snow, ice, rain, changes in atmospheric pressure, sleet, hail, wind, as well as the previously mentioned salt spray and salt water is significant. For materiel stored below decks, exposure to these elements is of much less importance.

5-5.6 AIR TRANSPORT

5-5.6.1 Advantages of Air Transport

For any transportation need in which extreme speed is required and long distances are involved, air transport is the obvious choice. During conventional air transport, cargo is carried within the fuselage; however, a number of aircraft carry external canisters, tanks, or other special containers fitted to the wings and fuselage. Fig. 5-33 shows various means of loading and unloading three different types of cargo aircraft. Air transport also includes transport by gliders towed by aircraft. Helicopters have become versatile transportation vehicles for small cargoes over difficult terrain. Helicopters are employed in close support and resupply operations for operational units where conventional aircraft landing fields are not available. Indeed, the prime advantage of the helicopter is its ability to land cargo even when an area large enough to land the helicopter is not available. In this case, cargo can be winched down from the helicopter while it is in a hovering mode. This kind of air transport finds wide application in the tactical environment. Finally, another technique that has been employed for the landing of cargo in areas in which insufficient airfield capabilities exist is the airdrop from low-flying cargo aircraft. A variety of techniques have been developed to permit the accurate delivery of cargo or materiel from aircraft in flight to a point on the surface of the earth.

Although the aircraft has some clear advantages, it also has some rather obvious disadvantages as a transport mode. The requirement of a large landing field for conventional cargo aircraft is a significant limitation. Of perhaps more importance is the fact that air transport is more sensitive to climatic factors than are most other modes of transportation. In addition, aircraft cover extremely long distances in a very short time and therefore are subjected, in many cases, to a rapidly changing environment because of the wide variety of the climatic environments that can be encountered in a single flight. Some of the common variables that affect the performance standards of aircraft are:

(1) Range and payload

(2) Speed

(3) Altitude

(4) Air density and temperature

(5) Wind

(6) Other environmental factors.

Range, payload, speed, and flight altitude are primarily characteristic of individual

(A) Cargo loader in mating position

(B) C-124 being unloaded in Greenland

Figure 5-33. Loading and Unloading Modes of Cargo Aircraft (Ref. 44)

(C) Palleted materiel being unloaded from C-5 aircraft

Figure 5-33 (continued). Loading and Unloading Modes of Cargo Aircraft (Ref. 45) aircraft. The other items are natural environmental factors and are considered in turn:

(1) *Air density and temperature.* These factors determine the ability of an aircraft to lift weight. The density of the airmass, in turn, is affected by, and is inversely proportional to, temperature, humidity, and altitude above sea level. For example, the U-8F (Seminole), weighing 7,700 lb and operating from a point at sea level where the temperature is 59°F, requires 2,200 ft from the start of its takeoff run to clear a 50-ft obstacle (Ref. 36). The same aircraft operating at the same weight from an airport 5,000 ft above sea level where the temperature is 95°F requires over 2,985 ft to clear a 50-ft obstacle. The capability of a helicopter with an externally slung load can be reduced as much as 80 percent between sea level at 0°F and 6,000 ft at 95°F.

(2) *Surface winds.* These affect both fixed-wing and rotary-wing aircraft. If utilized in conjunction with available runways, a surface wind has a pronounced beneficial effect on the takeoff and landing characteristics of an aircraft, since lift capability is directly proportional to the speed of air passing over the lifting surfaces.

(3) *Other environmental factors.* The amount of oxygen available in the air decreases as altitude increases. Flight above 10,000 ft for an extended period can be extremely dangerous unless personnel are supplied with oxygen or unless the aircraft is pressurized so that the atmosphere within corresponds to a lower level. A minimum of 1,000 ft should be allowed for clearing obstacles; therefore, when the terrain altitude is over 9,000 ft, only aircraft with oxygen should be programmed for flight. Aircraft flight altitude is determined by the characteristics of the aircraft and by air traffic considerations.

When flight is under visual flight rules (VFR), the underside of cloud ceilings must be at least 1,000 ft above the terrain for the entire route, and the visibility should be at least 3 mi in controlled zones around airfields and 1 mi outside controlled zones. All other weather conditions require operation by IFR (instrument flight rules). VFR aircraft normally cannot be flown in IFR weather. The availability of all-weather aircraft and qualified aviators does not always guarantee the start of a mission; an aviator may refuse to attempt a mission if extreme weather is anticipated. If air turbulence or other conditions are such that an aircraft cannot remain airborne, it is foolhardy to attempt a mission. The high speed and long range of modern aircraft require adequate weather intelligence for the entire route before the start of any mission. The weather to be encountered in route may not be, and very frequently is not, apparent at the airfield from which the flight originates.

5-5.6.2 Shock and Vibration Environment

5-5.6.2.1 *General.* Mobility requirements of the modern Army have created a demand for resupply that can be obtained only through the use of aircraft. Due to the large quantities of supplies and equipment requiring delivery by aircraft, it is no longer practical to modify an item for air transport or airdrop after the designed item has been completed. The necessary field modifications and the loading problems inherent in that method create excessive man-hour requirements and serve to limit the mobility. It has become necessary, therefore, that air transport and airdrop knowledge be incorporated in the basic design of materiel having an air transport or airdrop requirement.

Materiel developed for air transport in Air Force aircraft must meet the limitations imposed by the characteristics of aircraft used in these types of operations. Materiel developed for air transport by Army aircraft must meet the requirements imposed by the characteristics of Army aircraft and helicopters as well as those imposed by Air Force aircraft. Materiel developed for airdrop must be designed to meet the requirements imposed by the characteristics and capabil-

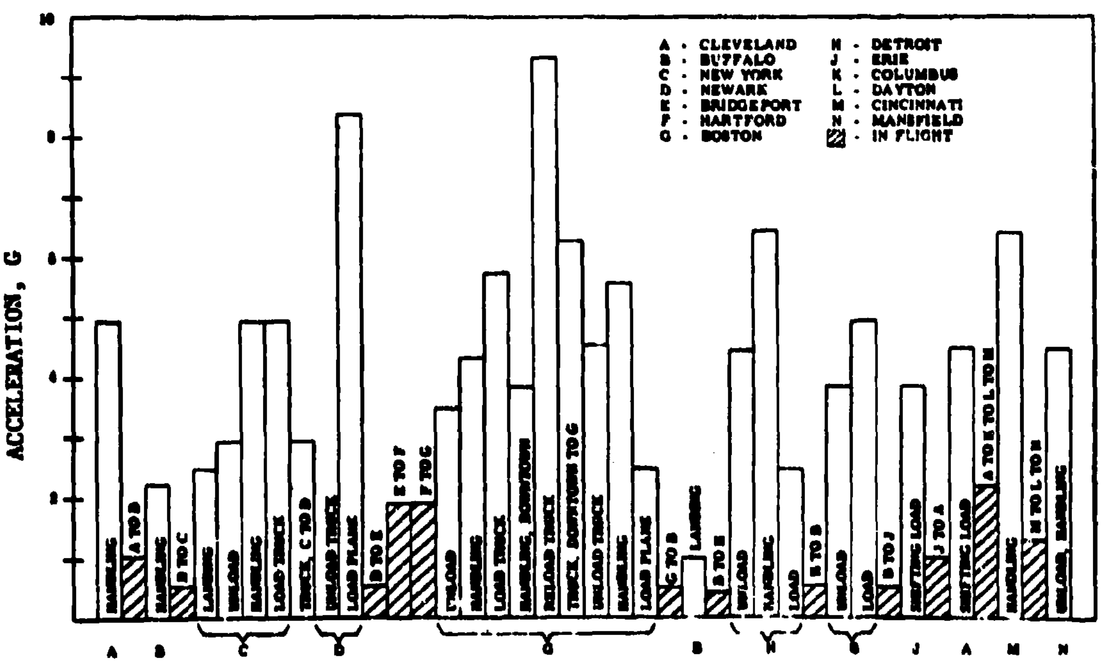


Figure 5-34. Maximum Shocks Recorded During Airline Test Shipment (Ref. 1)

ities of the airdrop system with which they will be used. These include size and weight requirements and requirements for tiedown, extraction, and suspension provisions. The materiel must be able to withstand the environments created during each phase of airdrop and the sum of the environments created by all phases. Materiel that is airdropped to combat forces must be capable of immediate effective employment.

5-5.6.2.2 *Internal Air Transport.* The important loadings during air transport are dynamic loadings occurring during flight in rough air. These are differentiated from shock loadings in that they consist of fairly high magnitude accelerations imposed for a prolonged period of time. These accelerations can be as high as 2 to 3 G during normal operation of transport aircraft. The most damaging conditions encountered during air shipment are the shocks resulting from handling operations. Fig. 5-34 shows the maximum shocks recorded during a test shipment by a major airline. For that test, two impact recorders were placed in a wooden box having a total weight of 73 lb. Both longitudinal and vertical shocks were recorded.

For air transport by Air Force cargo planes, the following G loads are permitted in the C-130 and C-144 airplanes: forward 8.0 G, side 1.5 G, vertical up 2.0 G, aft 1.5 G, vertical down 4.5 G (Ref. 34). Larger articles requiring transport in C-5 airplanes must withstand the following G-loads: forward 3.0 G, side 1.5 G, vertical up 2.0 G, aft 1.5 G, and vertical down 4.5 G. Materiel must be capable of surviving an acceleration of 3 G for a minimum of 3 s during flight and taxiing when applied independently along each of the longitudinal and vertical axes in each direction and 1.5 G for a minimum of 3 s applied independently along the lateral axis in each direction. In emergency landings, a minimum of 9 G in either direction applied independently along each horizontal axis for a minimum of 3 s is the specified stress level.

TABLE 5-23.
CARGO RESTRAINT FACTORS (CREW PROTECTED BY AIRCRAFT STRUCTURES)
(Ref. 33)

Direction	Fixed-wing aircraft, G	Helicopters, G
Forward	2.5	2.0
Aft	1.5	2.0
Vertical down	5.25	4.0
Vertical up	2.25	2.0
Side	1.5	1.5

For Army aircraft, the cargo restraint criteria for air transport that indicate maximum accelerations are:

(1) If personnel are protected by aircraft structures and/or other barriers, restraint factors are as outlined in Table 5-23.

(2) Where personnel are not protected by aircraft structures and/or other barriers, restraint factors are as given in Table 5-24.

For more detailed discussion of the air transport shock and vibration environment, the reader is referred to Chap. 4, "Vibration" and Chap. 6, "Shock", in Part Three, *Induced Environmental Factors*, of the Environmental Series of Engineering Design Handbooks (Ref. 35).

5-5.6.2.3 *External Air Transport and Air-landed Cargo*. External transport port of materiel has become more important with increased deployment of helicopters. One innovation accompanying this has been the increase in "air-landed" external cargo. The term "air-landed" is distinguished from "airdrop" in that the unloading of material occurs while the transporting aircraft is in a landed or hovering position. Unloading of

TABLE 5-24.
CARGO RESTRAINT FACTORS (CREW NOT PROTECTED BY AIRCRAFT STRUCTURES)
(Ref. 33)

Direction	Fixed-wing aircraft, G	Helicopters, G
Forward	8.0	4.0
Aft	1.5	2.0
Vertical down	5.25	4.0
Vertical up	2.25	2.0
Side	1.5	1.5

cargo or personnel in an airdrop operation occurs during the actual flight of the aircraft. External transport is limited to the use of racks on fixed-wing aircraft and the use of suspended slings on helicopters. The choice of internal or external transport depends on several factors (Ref. 46):

(1) Light, bulky cargo always should be loaded internally.

(2) Heavy cargo items should be loaded externally.

(3) When it is essential that aircraft be in the loading or unloading area for a minimum time, load should be carried externally.

(4) If the cargo could be damaged by adverse weather during flight, internal transport is preferred.

(5) For delivery of cargo in rugged areas where motor vehicles cannot function and transport aircraft cannot land, the helicopter external lift is a practical mode to be used because of the hovering capabilities of the helicopter.

(6) External transport is preferred only when the requirement is for rapid shuttle operations over short distances (less than 35 mi), when the takeoff point or landing point is exposed to fire, or when precise placement at the destination is desired.

(7) Internal loading normally will be preferred when long transport distances indicate that greater enroute speed will compensate for the increased loading and unloading time, when load can be driven aboard under its own power, when the load is of extremely light density and therefore will not maintain acceptable stability in external flight, or when it is desired to deny the enemy information about the materiel being transported.

(8) A combination of internal and external loading normally will be preferred when it is necessary to utilize fully the lift capability of a helicopter or aircraft, and when the load constitutes a system that should not be separated.

One of the problems associated with external carriage of supplies by a helicopter is that a helicopter in flight generates and stores a charge of static electricity. When the helicopter lands, this charge is grounded. While the helicopter is in flight, however, this charge remains stored unless a path is provided for it to the earth. A ground crewman can provide this path by contacting the helicopter hook when it is positioned over a cargo hookup or release point. Although this charge cannot cause an electrical burn, it can invoke a muscular reaction that may, if the individual concerned is on an unsure footing, result in injury from a fall. An individual shocked by the electricity may also suffer delayed discomfort from muscular cramps or spasms. To avoid the possibility of ground crew being shocked by the static electricity, a discharge probe is used ordinarily to ground the cargo hook.

In the transport of materiel by helicopter, an inherent characteristic of the helicopter that must be considered is the cyclic vertical motion produced by periodic loading and unloading of the helicopter blades (Ref. 47). This is a low frequency motion and requires special consideration. Vertical motion fluctuations are a function of the number of blades in the rotor and the rotor rotation speed. As a rule the predominant frequency is given by the formula

$$W = B\frac{rpm}{60}\text{, Hz} \qquad (5\text{-}1)$$

where

W = natural frequency, Hz

B = number of blades in the rotor, dimensionless,

rpm = revolutions per minute of the rotor.

Any load containing a spring in the form of a shock mount or padding must be checked for its natural frequency. Under no circumstances should the natural frequencies of the system to be carried match the inherent frequencies of the helicopter. The frequency spectra to avoid for several helicopter types are as follows:

Helicopter model	*Frequency, Hz*
CH-21	11.7-17.5
CH-34	11.3-17.3
CH-37	13.7-17.9
CH-47	10.2-13.1
UH-1	9.8-11.3

Spring-mounted loads with natural frequencies lower than these should also be avoided since lower frequencies will be excited as the helicopter rotor comes up to speed.

Generally, acceleration measurements made on helicopter primary structures lie below the 1-G level (Ref. 6). Rotary-wing aircraft, of course, are equally subject to landing impact as are fixed-wing types, and, in many military operational situations, high intensity landing impacts may routinely be encountered. An additional hazard in the case of rotary-wing aircraft occurs when cargo is carried in an external mode and is subjected to buffeting by air loads.

5-5.6.2.4 *Airdrop Transport.* Airdrop involves air-to-ground delivery of supplies and equipment by dropping them from aircraft in flight. It is used either for mass assaults (where large numbers of personnel, supplies, and equipment are airdropped into enemy-held territory to establish a position) or for resupply to forward bases (where such items as rations, ammunition, water, fuel, and medical supplies are airdropped into territory held by friendly forces in order to replenish dwindling stocks). Current airdrop systems require parachutes for aerial delivery of materiel in operational condition for support of combat operations (Ref. 6). These parachutes are designed for deployment speed, deployment altitude, desirable stability characteristics during descent, rate of descent, and weight of the load to be dropped.

Materiel that is capable of being airdropped by parachute with the use of standard impact energy dissipators must be able to survive a maximum impact speed of 28.5 ft s^{-1} which is based on airdrop system performance at 5,000 ft altitude and 100°F. Nominal rates of descent of airdrop materiel at sea level on a standard day may vary between 22 and 25 ft s^{-1}.

Airdrop techniques include platform airdrop, nonplatform airdrop, low altitude airdrop, retro-rocket deceleration systems, recovery parachutes, rotating decelerators, gliding parachutes of flexible wings, ground-slide airdrop, high altitude airdrop, and paraglider delivery using helicopters. Because of this variety of airdrop methods, it is not possible to detail here the full environments that will be encountered for each type of airdrop. For further information on the design of materiel for air transport and airdrop, the reader is referred to AMCP 706-130, *Design for Air Transport and Airdrop of Materiel* (Ref. 47).

5-5.6.3 Other Environmental Factors

The temperature profiles for air-transported materials, including the maximum and minimum materiel temperatures during actual air transportation conditions, using normal routine flights of the Military Airlift Command have been determined (Ref. 44). Various transport aircraft on flights between the United States and Europe were monitored during the winter season to emphasize cold weather operations. After each aircraft was loaded with cargo and ready for flight, thermocouple probes were installed at various depths in the cargo to determine the thermal profile of that cargo. The cargo consisted of wooden crates, metal or cardboard boxes, and bulk-filled sacks tied down to metal pallets. A total of 93 hr, 55 min of flying time was logged.

The most severe outside temperatures occurred at high altitudes. Fig. 5-35 shows the temperature profile for one such flight in which the outside temperature remained between -60° and -75°F. Note that the aircraft cargo compartment floor itself never reached a temperature lower than 0°F and that the temperature of the cargo was significantly higher. The temperature in the C-141 is held at nominal room temperature under normal situations. Only in the case of pressure loss does the ability to maintain temperature become compromised. However, this is an infrequent happening, and the regulation emergency procedure is to bring the aircraft down to a lower altitude so that, even in the event of pressure failure, the cargo would not be subjected to the extreme cold of high altitudes. For all of the flights and aircraft employed, the minimum temperature for air-carried cargo was in the neighborhood of 20°F. The inside temperature of the aluminum skin of the aircraft is indicated to be about 0°F minimum. In addition, it is concluded that the occurrence of extenuating circumstances would not cause any of the aircraft to surpass this temperature level enough of the time to be significant. During this measurement series, the lowest cargo temperature measured was 19°F, although a minimum true outside air temperature of -82°F was recorded.

When materiel transport by air is contemplated, two additional factors other than shock, vibration, and temperature should be considered. First, packages may be stacked 5 to 6 ft high in cargo planes—to a maximum aircraft floor load of 100 lb ft^{-2}. Second, the atmospheric pressure decreases from 14.7 psi at sea level to 6.82 psi at 20,000 ft so that, for hermetically sealed components, an 8-psi pressure differential would exist at this altitude. Rate of change in pressure will probably be slower during ascent than during descent. Where packs fitted with rubber gaskets are considered, it is conceivable that a leak might occur during ascent as exterior pressure is reduced and that a seal might be reestablished during descent by virtue of increasing pressure on the top of the container.

Because of the rapidity of air transport and the resulting short time that materiel experiences the air transport environment, factors that require a long time to produce deterioration are unimportant. Except for external transport, the materiel is protected from climatic factors such as snow, ice, rain, wind, and sand and dust although airdropped materiel has survived impact, it is exposed to the full terrestial environment. Once materiel has landed, however, it is no longer in the transport environment; it usually is in the operational environment.

5-5.7 ANIMAL TRANSPORT

Dogs, pack mules, and human bearers are used on occasion by the military for the purpose of carrying various types of cargo. Trained dogs may be used individually or in teams to transport cargo in arctic and subarctic areas. They also see limited use in temperate zones to carry messages and small packets of mail—usually in regions inaccessible to other means of transport. The Eskimo dog or husky is used most commonly in arctic and subarctic regions, and the German shepherd usually is used in temperate zones. On packed snow with good traction, an individual dog in a sled team has the cargo-carrying capabilities given in Table 5-25. On soft snow, load and speed must be reduced 50 percent. As can be seen, speed depends on terrain, varying from almost 6 mph in flat terrain to 1 mph in mountainous terrain. On hard surfaces with good traction, an individual dog has the capabilities for carrying cargo packs, messages, and mail as outlined in Table 5-26. The cargo pack weight must be reduced from 35 lb over flat terrain to 25 lb over mountainous terrain and the distance must be reduced by a factor of approximately 2.

For pack mules the average daily distance on rolling or flat terrain is 24 mi while the average daily distance in mountainous terrain is 12 mi. For human bearers, the average

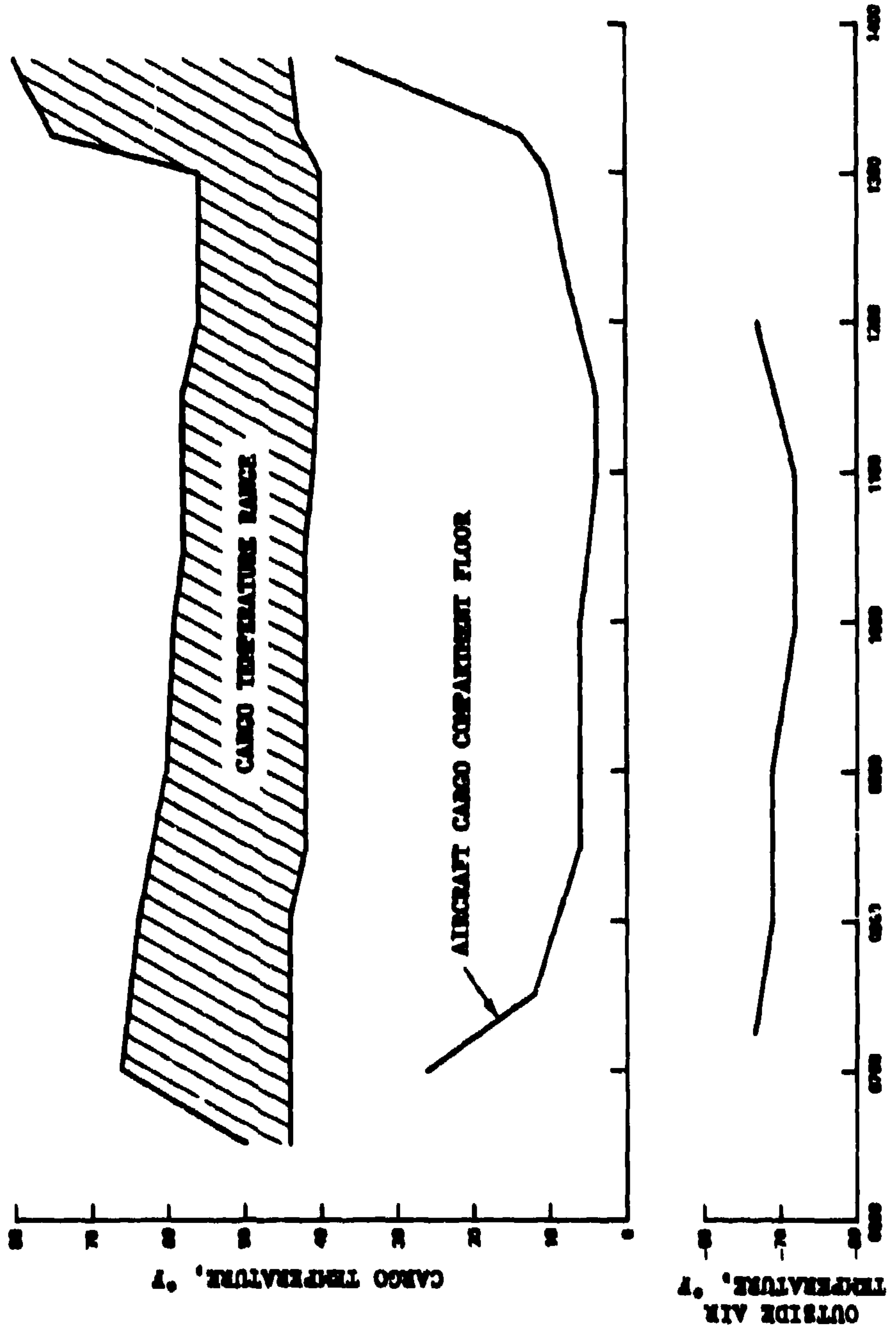


Figure 5-35. Cargo Temperature Profile for C-141 Aircraft Flight (Ref. 44)

**TABLE 5-25.
OVERSNOW TRANSPORT CAPABILITY OF DOG IN SLED TEAM (Ref. 35)**

Terrain	Load, lb	Distance in hr, mi
Flat	50	6
Hilly	50	3
Mountainous	50	1

male can carry 80 lb on level terrain at an average rate of 12 mi per day. The distances covered and the cargo loads are reduced significantly with increasing terrain steepness.

For the most part, however, animal transport seldom is employed except for advanced support within the context of the operational environment. The environment to which animal-transported materiel is subjected is essentially that to which the materiel will be subjected in its operational or service environment except for the fact that animal-transported materiel may be protected by packaging that may later be removed.

**TABLE 5-26.
PACK-CARRYING CAPABILITIES OF DOG ON HARD TERRAIN (Ref. 35)**

Terrain	Load, lb		Distance in hr, mi	
	Cargo pack	Messages or mail	Cargo pack	Messages or mail
Flat	35	5% of dog's weight	2	15
Hilly	30		2	10
Mountainous	25		1	5

REFERENCES

1. AMCP 706-121, Engineering Design Handbook, *Packaging and Pack Engineering*.
2. FM 38-1, *Logistics Management*.
3. TM 38-230-1, *Preservation, Packaging, and Packing of Military Supplies and Equipment, Preservation and Packaging* (Vol. 1).
4. A. Boyd, *Evaluation of MIL-C-81013 (WP) Transparent, Cellular, Plastic Film Cushioning Materials at Different Altitudes*, Naval Air Development Center, Warminster, Pa., August 1968 (AD-841 848).
5. J. A. Hincks, *Outdoor Weathering Effect on Shipping Label Covers*, DSPS Report 42-3, Air Force Packaging Evaluation Agency, Wright-Patterson Air Force Base, Ohio, March 1972 (AD-743 291).
6. S. Berger et al., *Container Development Concepts for Improved Resistance to the Dynamic Environment*, Control Systems Research, Inc., Arlington, Va., for U S Army Mobility Equipment

Research and Development Center, Ft. Belvoir, Va., October 1971 (AD-732 491).

7. FED-STD-101/GEN, *Preservation, Packaging, and Packing Materials, Test Procedures*, 15 January 1969, with Change Notice 2, 8 October 1971.

8. TM 743-200, *Storage and Materials Handling*.

9. H. C. Schafer, *Environmental Criteria Determination for Air Launched Tactical Propulsion Systems*, NWC TP 4464, Part 2, Naval Weapons Center, China Lake, Calif., July 1968.

10. J. C. King, *Rusted Components of Materiel in Storage*, TN N-464, U S Naval Civil Engineering Laboratory, Port Hueneme, Calif., September 1962 (AD-402 376).

11. R. J. Zablodil and J. C. King, *Warehouse and Preservation Methods and Economics for Storing Materiel*, U S Naval Civil Engineering Laboratory, Port Hueneme, Calif., June 1960.

12. W. L. Porter and A. Greenwald, *Temperature Distribution and Effects of Insulation and Night-time Ventilation in an Army Warehouse*, Tech. Report 71-49-FL, 71-49-ES, U S Army Natick Laboratories, Natick, Mass., January 1971 (AD-728 821).

13. I. S. Kurotori and H. Schafer, *Storage Temperature of Explosive Hazard Magazines*, Part 1, *American Desert*, NOTS TP 4143, Part 1, U S Naval Ordnance Test Station (now Naval Weapons Center), China Lake, Calif., November 1966 (AD-805 243).

14. I. S Kurotori and H. Schafer, *Storage Temperature of Explosive Hazard Magazines*, Part 2, Western Pacific, NOTS TP 4143, Part 2, U S Naval Ordnance Test Station (now Naval Weapons Center), China Lake, Calif., June 1967 (AD-820 399).

15. W. L. Porter and A. Greenwald, *The Analysis of High Temperature Occurrences at Selected Internal and Surface Locations in Food Storage Dumps and Isolated Small Cartons at Yuma, Ariz.*, Tech. Report 71-59-FL, 71-59-ES, U S Army Natick Laboratories, Natick, Mass., January 1971.

16. J. H. Grier and V. K. Chan, *Predicting High Temperatures Inside Cargo Containers*, USATEA Report 70-8, U S Army Transportation Engineering Agency, Ft. Eustis, Va., June 1970.

17. S. R. Cecil, *Storage Stability of Civil Defense Shelter Rations*, Tech. Report 156-VI-GES, Univ. of Georgia College of Agriculture Experiment Stations, Experiment, Ga., for Office of Civil Defense, Washington, D.C., June 1968 (AD-673 817).

18. *Long Term Storage of Military Rations*, QM Research and Engineering Command, QM Food and Container Institute, Natick, Mass., 1962.

19. *Establishing Optimum Conditions for Storage and Handling of Semi-Perishable Subsistence Items*, Office of QM General, Washington, D.C., March 1955

20. M. H. Thomas and D. E. Sherman, *Effect of Freeze-Thaw Cycling on the Vitamin Contents of the Meal, Ready-to-eat, Individual*, U S Army Natick Laboratories, Natick, Mass., June 1969.

21. N. Roth et al., *Effect of Exposure to Oxygen in Meats and Vegetables During Storage*, Tech. Report FD-31, Whirlpool Corp., St. Joseph, Mich., for U S Army Natick Laboratories, Natick, Mass., November 1965 (AD-625 484).

22. A. R. Rahman and K. R. Johnson, *Quality of Dehydrated Lima Beans as*

Influenced by Processing Variables and Storage Temperatures, Tech. Report 70-35-FL, U S Army Natick Laboratories, Natick, Mass., November 1969.

23. TM 10-250, *Storage of Quartermaster Supplies*.

24. TM 55-602, *Movement of Special Freight*.

25. *Code of Federal Regulations*, Government Printing Office, Washington, D.C., continuing publication.

26. AR 55-355, *Military Traffic Management Regulation*.

27. TM 39-100-5, *Nuclear Weapons Material Shipping Guide*.

28. *Code of Federal Regulations*, Title 10, *Atomic Energy*, Part 20, *Standards for Protection Against Radiation*, 1972, pp. 123-49.

29. *Code of Federal Regulations*, Title 10, *Atomic Energy*, Part 70, *Special Nuclear Material*, 1972, pp. 286-300.

30. *Code of Federal Regulations*, Title 10, *Atomic Energy*, Part 71, *Packaging of Radioactive Material for Transport*, 1972, pp. 300-14.

31. *Code of Federal Regulations*, Title 46, *Shipping*, Part 146, *Transportation or Storage of Explosives or Other Dangerous Articles or Substances and Combustible Liquids on Board Vessels*, Subpart 29, *Detailed Regulations Governing the Transportation of Military Explosives and Hazardous Munitions on Board Vessels*, 1972, pp. 813-91.

32. *Code of Federal Regulations*, Title 14, *Aeronautics and Space*, Part 103, *Transportation of Dangerous Articles and Magnetized Materials*, 1972, pp. 169-74.

33. U.S. Code, Vol. 4, Title 18, *Crimes and Criminal Procedures*, Chap. 39, "Explosives and Other Dangerous Articles", Sect. 831-5, 1970, pp. 4244-8.

34. AR 70-(Draft), *Research and Development, Transportability Criteria, All Modes, and Worldwide Dimensional and Environmental Limitations*.

35. AMCP 706-117, Engineering Design Handbook, *Environmental Series*, Part Three, *Induced Environmental Factors*.

36. FM 55-15, *Transportation Reference Data*.

37. R. D. Marten and H. Schafer, *Temperature Profiles of Truck Transported Ordnance*, NWC TP 4822, Naval Weapons Center, China Lake, Calif., June 1970 (AD-871 595).

38. F. R. Fisher, *Cooperative Monitoring of a Highway Shipment of Missiles From Charleston, South Carolina, to Concord, Calif.*, USATEA Report 71-9, U S Army Transportation Engineering Agency, Newport News, Va., March 1971 (AD-723 399).

39. TM 55-310, *Truckmaster's Handbook*.

40. A. Andrews, *TITAN II Environmental Study During Transportation and Silo Emplacement - Post Test Report*, CR-63-231.

41. W. L. Porter and A. Greenwald, *Comparison of the Occurrence of High Temperatures in Air and Food in Boxcars in Desert and Humid Sub-Tropical Climates—Yuma, Arizona, and Cameron Station, Virginia*, Tech. Report 71-55-FL, 71-55-ES, U S Army Natick Laboratories, Natick, Mass., January 1971.

42. FM 38-9, *Transportation and Traffic Management*.

43. E. B. Hooper, *Mobility, Support, Endurance*, Naval History Division, Dept. of the Navy, Washington, D.C., 1972.

44. H. C. Schafer and R. A. Dickus, *Temperature Profiles of Air Transported Material*, NWC TP 4828, Naval Weapons Center, China Lake, Calif., October 1970 (AD-878 281).

45. J. D. Ryan, "The Future Air Force", Ordnance, LVI, No. 309 (November-December 1971), pp. 202-5.

46. TM 55-450-8, *Air Transport of Supplies and Equipment: External-Transport Procedures*.

47. AMCP 706-130, Engineering Design Handbook, *Design for Air Transport and Airdrop of Materiel*.

CHAPTER 6

STANDARDS AND SPECIFICATIONS

6-1 INTRODUCTION

The effects of environmental factors on Army materiel is a function of two general factors: (1) the exposure to the environment as determined by the existence and severity of the environmental factors and the life cycle of materiel in the logistic and operational environments, and (2) the design of the materiel and its protective packaging as determined by design engineers in conformance with applicable standards and specifications. The second factor is the subject of this chapter. Standards and specifications provide the method by which accumulated knowledge and experience on how to make equipment resistant to environmental effects is incorporated in materiel design. The nature of the materiel entering the life cycle environment is thus determined. The functions of standards and specifications are much broader than the assurance of environmental protection; these are given in the subparagraphs that follow.

The Department of Defense (DOD) is responsible for the commitment of resources to the defense posture of the United States. The DOD provides the impetus, management, and funding for the production of current needs and for the design, development, production, and logistic support of new weapon systems. The Defense Standardization Program (DSP), established pursuant to the *Cataloging and Standardization Act* (Ref. 1) and implemented by DOD Directive 4120.3-M (Ref. 2), is the principal program utilized in the achievement of these objectives. The DSP provides for the development, coordination, and mandatory use of specifications, standards, and other standardization documents, and produces a profound influence on the life cycle of military materiel.

The life cycle of military materiel encompasses the various stages through which it passes from initial conception to disposal. These phases have been defined as concept formulation, contract definition, development, production, logistics, and operations (Ref. 2). Standards and specifications are the principal medium through which the DOD oversees the official and orderly progression through the life cycle phases. During the concept and definition phases, materiel is usually defined and evaluated in terms of performance specifications that express requirements in the form of output, function, or operation. In the development phase, a complete prototype suitable for operational testing is produced. During this phase, the item is listed in the *Federal Supply Catalog* for identification purposes. Such things as quantitative requirements, probable operational environments, support requirements, etc., are determined. To make these determinations, additional performance and design specifications that further define and control the characteristics of the materiel are required. This is accomplished through the medium of standards, which enhance the design, limit cost, and reduce support requirements through interchangeability.

For the production phase, the materiel to be procured must be completely defined through specifications that in turn fully exploit existing standards. Although specifications are the basic procurement document, reference standards are an integral part of specification. Specifications and standards assure that the procured item will have the desired characteristics and capabilities and that the buyer, user, and seller are in agreement as to what these are. Specifications and standards control competition during the production phase by restricting it to manageable questions such as price of delivery items, by insuring that all competitors are on an even basis at the start of negotiations, and by preventing an unscrupulous bidder from producing an inferior item. The logistic and operational phases of the materiel life cycle—including distribution, storage, handling, and maintenance as well as use—are controlled through the medium of standards and specifications as well.

Standards and specifications can be differentiated by the definitions given in the *Defense Standardization Manual* (Ref. 2). Standards are defined as documents that establish engineering and technical limitations and applications for items, materials, processes, methods, designs, and engineering practices. Standardization documents include specifications, standards, handbooks, qualified product lists, drawings, codes, and such other engineering records as are or may be used for comparable purposes. Specifications are defined as the documents, intended primarily for use in procurement, that clearly and accurately describe the essential technical requirements for items, materials, or services, including the procedures by which it will be determined that the requirements have been met. Specifications for items and materials may also contain preservation, packaging, packing, and marking requirements. In practice, especially in the private sector, the relationship between standards and specifications is confused. In the private sector, the term "specification" is seldom used, and many standards have titles that begin, "Standard Specification for . . . ." (Ref. 3). Specifications are essentially purchase documents and, in the private sector, are replaced by purchase agreements, sales contracts, purchase orders, etc., that in turn refer to standards and standard specifications.

The DOD and the Federal Government develop and publish many standards and specifications. Each, along with the relationship among them, is well defined.

> "Standards function in procurement through the medium of specifications. Thus, they are used to standardize one or more features of an item such as size, value, detail of configuration, etc. In equipment specifications, they are referenced to standardize on those design requirements which are essential to interchangeability, compatibility, reliability, and maintainability. They are prepared to provide the designer with the descriptions and the data normally required for selection and application. Standards disclose or describe the technical features of an item in terms of what it is and what it will do. In contrast, the specification for the same item describes it in terms of the requirements for procurement" (Ref. 2).

The DOD Standardization Program interfaces with other segments of society without significant conflict and in many cases benefits all concerned. Indeed, standardization is essential not only to the military but to the economic survival of any industrial society. Virtually all nations are engaged increasingly in national and international standardization activities. The DOD is also a participant, i.e., a contributor and a benefactor, to the national and international standardization activities.

Military specifications affect cost. Generally, commercially available items can be procured at a lower price than like items designed to meet pertinent military standards and specifications. This is true because military specifications impose additional requirements on the materiel that increase its production cost. Military specifications, although they raise costs, are necessary in many cases involving military operations because of the unique requirements of the military, e.g., the necessity to insure reliability of materiel in the field. Most commercially available materiel is designed to operate within a rather narrowly specified environment. This environment usually is not severe with respect to climate, terrain, or induced environmental factors.

In order for materiel to survive and remain operationally useful under severe climates, terrain, and induced environments, it is necessary to invoke special requirements in the design of materiel subject to these extreme environments. The way in which materiel characteristics are defined for the manufacturer is by means of military standards and specifications. The military standards and specifications inform the manufacturer of the exact, required characteristics of the materiel. For the purchaser of materiel, military standards and specifications ideally will insure that materiel procured under the specifications will function in its assigned task under the conditions it will encounter in the field. It is true that in many applications military materiel is used in the same manner as its commercial counterpart, so that additional requirements on performance, maintainability, and environment are not required. In such cases, commercially available materiel may be used.

On the other hand, it is not infrequent that the military will require materiel with unusually severe requirements. In this case equipment specifications may take exception to generally accepted military specifications and standards, particularly with respect to sensitive components or systems. For example, various items of materiel have been procured by the military that have specifications significantly more stringent than the general military standards and specifications used in procuring normal military materiel. Generally, these special specifications are written and enforced in order to protect sensitive components, to obtain extreme reliability under normal conditions, to obtain reliability under abnormally severe environments, or to assure reliability of very sensitive materiel in which failure might produce catastrophic consequences.

These types of weapon systems and materiel with extremely severe and stringent specifications have been built in the past, and it is recognized that they will continue to be built in the future. However, since each of these weapon systems or items of materiel is considered as a special case, standards and specifications as applied to these special cases will not be discussed herein. Rather, the standards and specifications that are involved in the normal military processes of procurement of materiel are considered to be those of interest in a discussion of the impact of standards and specifications on the ability of materiel to survive environmental effects during its life cycle.

Par. 6-2 contains a limited discussion of voluntary standards and specifications. The general subjects of Federal standards and specifications and military standardization are discussed in pars. 6-3 and 6-4, respectively. In par. 6-5 those standardization documents pertinent to a discussion of the effects of environment on materiel are reviewed. The basic means whereby materiel is proved to meet environmental requirements during the procurement cycle is standardized environmental tests. Essentially, items of materiel are subjected to a series of environmental tests, and, if the materiel can survive these tests and operate according to specifications, the materiel is acceptable and is considered to be capable of meeting the environmental extremes for which the materiel was designed. If the materiel will not perform as specified following or during environmental tests, the equipment will not be accepted by the military until the manufacturer makes the necessary changes in order to meet the specifications. In the final analysis, therefore, the standardized environmental tests determine the capability of materiel to survive environmental exposure. Because of their importance, these standardized environmental tests are discussed separately in par. 6-6.

6-1.1 HISTORICAL PERSPECTIVE

At the beginning of the 20th century, railroads were standardizing track gages; the American Society of Mechanical Engineers (ASME) had a standardization committee at work and had standardized pipe and pipe threads; and the American Society for Testing and Materials (ASTM) had been organized to promote knowledge of the materials of engineering and the standardization of specifications and testing methods. The National Bureau of Standards was established by an Act of Congress in 1901 and has continued to be the focal point in the Federal Government for determining basic measurements and standards.

The American Standards Association (ASA) was founded in 1918 to serve as a clearinghouse for voluntary nationally coordinated safety, engineering, and industrial standards. (The ASA was renamed the United States of America Standards Institute in 1966, and subsequently the American National Standards Institute in 1969.) The American National Standards Institute (ANSI) is the U.S. representative in the International Organization for Standardization (ISO). The ANSI includes industrial firms, trade associations, technical societies, consumer organizations, and Federal Government agencies.

There was a tremendous growth of the standardization movement in the early 1920's which gave rise to a multiplicity of standards of all types. Trade associations, engineering societies, private firms, international and Government groups were engaged in drafting and recommending standards, resulting in a considerable duplication of effort, since many standards were designed to meet the particular needs of the respective groups. Recognition of this fact led to the formation of national standards bodies.

In 1910, the Government established the General Supply Committee as a central procurement activity. This was the first official recognition of the necessity and value of buying in accordance with standards and specifications. In 1921, the Federal Specification Board, whose membership consisted of representatives from each Government department or agency and from industry was formed to compile or adopt and publish Government specifications for materials and supplies and to insure that these specifications were in accord with the best commerical practice. Also in 1921, the Federated American Engineering Societies organized a committee to see how much waste could be eliminated by reducing needless varieties of commodities. This committee stimulated another wave of voluntary standardization which emphasized such matters as dimensional standards, material specifications, and testing, drafting practices, definitions, and symbols used in engineering.

Military standardization, born of necessity, also has a long history. In the early 20th century, several military groups established specifications for items peculiar to their activities. These specifications were necessitated by a lack of standardization within industry. As its standardization activities increased, the military increasingly worked with the Federal Specifications Board, the American Standards Association, the National Bureau of Standards, and with engineering societies and trade associations. The military's interest was twofold: (1) it was concerned about the indiscriminately large range of specifications available for procurement of supplies, and (2) it benefited from the results of many research and engineering problems being investigated and solved by industry. Although the military departments did not formally recognize industrial standards until the late 1940's, they tacitly accepted the benefits resulting from them as exemplified by the frequently specified requirement: "Shall be made in accordance with the best commercial practice". Early nonmilitary standards adopted for use by the War Department include, for example, the acceptance in 1917 of a Color Card developed by the Textile Color Card

Association of the United States and a 1919 specification that required, in part, that motor starters and controllers conform to the standardization rules of the American Institute of Electrical Engineers (AIEE) and to the regulations of the National Electrical Code for electrical wiring and apparatus.

In 1937, the military services organized a joint standardization activity, known as the Working Committee, which became responsible for the preparation of specifications in the aeronautical area. In 1941, the Signal Corps established a Standards Office to develop specifications for electronic parts which, at that time, were critical to expanding communications and to the development of radar. The Army-Navy Joint Specification Council and Board, established in 1945, developed, on a limited scale, Joint Army-Navy (JAN) specifications to support procurement. In 1947, the National Security Act created the Munitions Board which established the Munitions Board Standards Agency. In 1951, the Secretary of Defense directed that all new standards and specifications be issued in either the Federal or Military series, and that all existing service and departmental specifications be converted to the Federal or Military series.

In 1952, the Defense *Cataloging and Standardization Act* (Ref. 1) created the Defense Supply Management Agency (DSMA) as a separate element of the Department of Defense. This Act required use "to the highest degree practicable" of standardized items throughout the Department of Defense by developing and using single specifications; eliminating overlapping and duplicate specifications; and reducing the number, sizes, and kinds of items that are generally similar.

Department of Defense Directive 4120.3, issued in February 1953, established "a single integrated Department of Defense Standardization Program, controlled and directed by the Office of the Secretary of Defense which will include the effective management of specifications, standards, drawings, standardization handbooks, qualified products lists, and engineering records" (Ref. 2).

6-1.2 SOURCES OF STANDARDS AND SPECIFICATIONS

There are numerous sources of standards and specifications in the United States, both private and governmental. A 1971 National Bureau of Standards (NBS) publication, for example, indexes more than 19,000 voluntary engineering and related standards, specifications, test methods, and recommended practices published by some 350 technical societies, professional organizations, and trade associations (Ref. 4). This index of documents does not include Federal and military, food and drug, local government (State, county, and city), foreign, or company standards and specifications. Another NBS publication lists 486 U.S. organizations that consider standardization to be a major or important part of their work (Ref. 5). Another excellent directory of sources for standards and specifications has been prepared by Struglia (Ref. 6).

The Federal Government is a major contributor to national standardization. Governmental involvement with voluntary standards is a public service to manufacturers, distributors, consumers, and others interested in establishing requirements. These standards and specifications are, in general, mandatory only for governmental purchasing; however, they are increasingly imposed as requirements in the private sector in the public interest. The 1970 Occupational Safety and Health Act, for example, effectively ended the voluntary status of many previously voluntary standards and specifications. In the discussions of governmental sources of standards and specifications that follow, the voluntary status of many of these standards and specifications is not clearly defined.

Federal standards and specifications and military standards and specifications are, collectively, the largest single source of standards and specifications with approximately 50,000 currently in effect. Two major indexes are the annual *Index of Federal Specifications and Standards* (Ref. 7) and the annual Department of Defense *Index of Specifications and Standards* (DODISS) (Ref. 8). These Federal Government standards and specifications, whenever appropriate, are mandatory only upon the Federal Government; however, they are frequently adapted or adopted for voluntary private use and some have been coordinated by the American National Standards Institute (ANSI) as voluntary consensus standards; e.g., MIL-STD-105 has become ANSI Number Z1.4-1971, *Sampling Procedures and Tables for Inspection by Attributes* (Ref. 9).

6-2 VOLUNTARY STANDARDS AND SPECIFICATIONS

An industrialized society is vitally dependent upon thousands of nationally recognized and accepted standards. Every segment of society is dependent upon standards and the benefits from them. The Government, in response to the general public welfare, requires standards for sound procurement of goods and services, for implementation of legislated programs for health and safety, and for implementation of service programs, including transportation, communication, and national defense. As commerce and cooperative efforts increasingly transcend national boundaries (e.g., resource development and national defense), international rather than national standards are required.

Voluntary standardization is an old and well-established tradition in the United States. The professional and technical societies and trade associations develop standards, and, when additional recognition or acceptance is needed, coordinating institutions initiate procedures to gain a consensus with consequent national stature for the standard. All segments of the society, including the Federal Government, are free to use these standards. These voluntary standards may also be presented to the international community as National Consensus Standards.

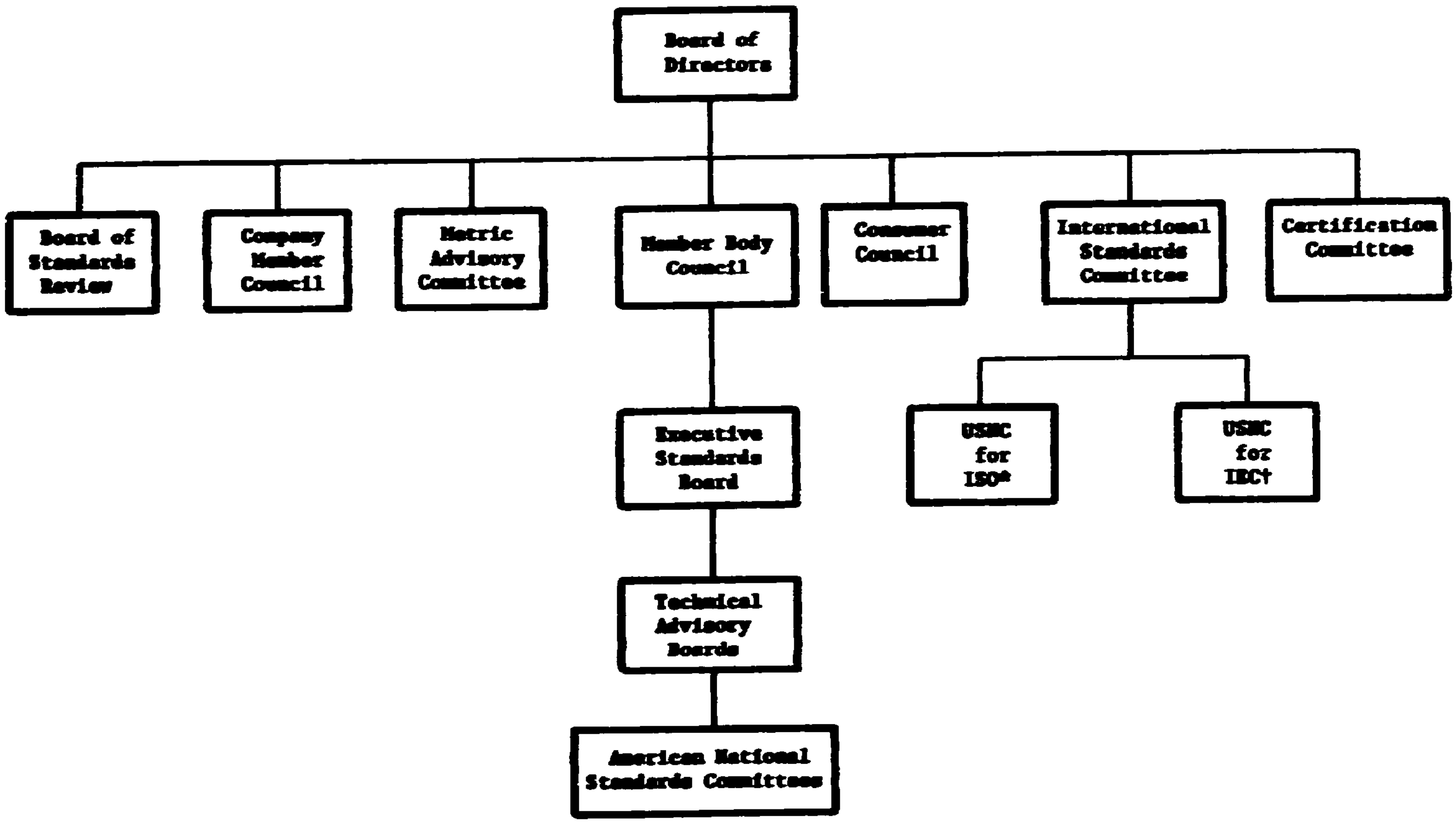
In recent years, congressional legislation has made many voluntary consensus standards, developed in the private sectors, mandatory in certain areas. In implementing the *Occupational Safety and Health Act* (Public Law 91-596), for example, more than 100 National Consensus Standards are cited. Other familiar areas include automobile tires, safety belts, radiation, and flammable fabrics. Also, certain Federal and military specifications that were developed by Government agencies and mandatory only upon the Federal Government have been reviewed and accepted as voluntary National Consensus Standards.

6-2.1 THE AMERICAN NATIONAL STANDARDS INSTITUTE

The American National Standards Institute (ANSI)—a private, nonprofit federation of trade, technical, professional, labor, and consumer organizations, business, and Government agencies—is the major clearinghouse and coordinating agency for voluntary standardization in the United States.

The Institute approves a standard when it receives evidence that all national groups concerned with the development of a particular standard have been given an opportunity to cooperate in its development and have reached substantial agreement on its provisions. ANSI also represents the interest of the United States in international standardization work carried out by such nontreaty organizations as the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the Pan American Standards Commission (COPANT) (Ref. 10). Organization of ANSI is indicated in Fig. 6-1.

ANSI's recognition as the National Standards Organization for the United States is de facto recognition and not official. The United States is the only participant in the International Organization for Standardiza-



*U.S. National Committee for the International Organization for Standardization (ISO)

†U.S. National Committee for International Electrotechnical Commission (IEC)

Figure 6-1. Organization of the American National Standards Institute tion and in other international standards groups without an officially recognized and sponsored member. ANSI's recognition as the U S representative in these international affairs has evolved without significant governmental support or financing. It is significant, however, that legislation has made many ANSI standards and specifications mandatory for the U S industrial community. Many governmental programs have specified adherence to certain American National Standards; e.g., building codes and regulations, information processing, flammable fabrics, radiation, and high-pressure gas pipelines.

ANSI does not develop the standards or specifications itself but utilizes the technical expertise of its member bodies; i.e., the organizations and companies that comprise the federation. ANSI has three methods for evolving standards. In each case interested and affected parties among the public are given ample opportunity to comment on the proposed document at various stages of development. In one method (the canvass method) an interested group writes or commissions the writing of a proprietary standard and submits it to a ballot by knowledgeable individuals and organizations. These individuals and organizations vote by letter ballot on the standard. The ANSI Board of Standards Review examines the completed standard and the results of the ballot. A second method (the committee method) employs a committee representing the interest of substantially affected groups. This committee is established through ANSI with an interested organization designated as secretariat. The committee then writes a standard which is voted on by the members of the committee and examined by ANSI Board of Standards Review. In a third method, organizations that use standard development procedures meeting the ANSI consensus principles may submit their standards directly to the Institute for consideration and potential approval. If the documents are approved, they may be designated American National Standards after review by the ANSI Board of Standards Review. The purpose of these procedures is to insure that any documents given the designation American National Standards is a consensus standard that has received close examination by a broad cross section of concerned and affected parties.

At the present time, almost 5,000 American National Standards are in use and many more are in development. Some typical examples include such things as the consistency and performance of portland cement, safety requirements on elevators, data processing practices, sizes and shapes of electrical plugs and receptacles, and the sizes of screw threads and bolts. A number of American National Standards have been referenced for use as military specifications, and many military specifications have been approved as American National Standards. For example, techniques first devised to test the shock resistance of naval equipment were adapted for wider application and published as an ANSI standard which describes the design, construction, and operation of a Class HI shock testing machine.

Approximately 200 representatives from the Defense Department and the Coast Guard participate in the work of ANSI. DOD participants in ANSI work have experience in areas related to research, engineering, and development of Army, Navy, and Air Force weapon systems and equipment, including specialized research and engineering in flight dynamics, electronics, ship engineering, underwater sound, photography, medicine, construction and civil engineering, and many other scientific and technical fields. Coast Guard personnel have participated in work on merchant marine technology and marine inspection standards.

6-2.2 THE AMERICAN SOCIETY FOR TESTING AND MATERIALS

The American Society for Testing and Materials (ASTM) which is the world's largest developer of voluntary consensus standards, was founded in 1898 "for the

Promotion of Knowledge of the Materials of Engineering and the Standardization of Specifications and the Methods of Testing". It is an international, privately financed, nonprofit, technical, scientific, and educational society. Among its publications is the 33 volume *Book of ASTM Standards* which is published annually (Ref. 3). The 1972 edition comprises over 31,000 pages and includes more than 4,500 standards and tentative standards. Standards developed by ASTM may be specifications, methods of test, recommended practices, or definitions. ASTM standards are known and respected around the world.

ASTM has more than 109 main technical committees covering the entire spectrum of materials research and standards development. These committees, staffed by some 14,000 technical experts drawn from ASTM's 22,000 active members, adhere to procedures and regulations designed to insure balanced representation among producers, consumers, the Government, and other concerned interests, and to achieve impartiality by consensus in the development of standards and specifications. (For ASTM purposes, a consensus is substantial agreement by concerned interests according to the judgment of a duly appointed authority. It implies more than a simple majority, but it does not necessarily mean unanimity (Ref. 11)).

Although somewhat out of date, a 1964 survey found that ASTM had produced 3,253 of a total of 13,675 nationally used standards. The next single largest contributor was the Society of Automotive Engineers (SAE) with 2,129 (Ref. 12).

6-2.3 OTHER NON-GOVERNMENT SOURCES OF VOLUNTARY STANDARDS

Other sources of national voluntary standards and specifications are given in Table 6-1. Addresses and telephone numbers of each source are also included. Additional information about any source can be obtained by communicating directly with the source or by consulting a directory (e.g., Ref. 13). Table 6-1 is not complete; complete indexes of sources of voluntary standards and specifications are available elsewhere (Refs. 4-6). The table includes only sources that have contributed to ANSI's inventory of American National Standards or have developed standards or specifications that are related to military material. Standardization documents developed by sources followed by an asterisk, and those developed by ASTM and ANSI, can be readily adopted for use by the DOD.

6-2.4 THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards (NBS) was established by an act of Congress on 3 March 1901 and charged with the responsibility to cooperate with other Government agencies and with the private sector in the establishment of standard practices incorporated in codes and specifications. Today, in addition to serving as the nation's central measurement laboratory, it is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in four broad program areas—(1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology. The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office of Information Programs.

6-2.4.1 Institute for Basic Standards

The Institute for Basic Standards (1) provides the central basis within the United States of a complete and consistent national system of physical measurements, (2) coor-

TABLE 6-1.
OTHER NON-GOVERNMENT SOURCES OF VOLUNTARY STANDARDS AND SPECIFICATIONS

1. American Society of Civil Engineers (ASCE)
   United Engineering Center
   345 East 47th St.
   New York, N.Y. 10017
   (212)752-6800
   Founded in 1852, 62,000 members

2. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE)*
   345 East 47th St.
   New York, N.Y. 10017
   (212)752-6800, ext. 360 or 361
   Founded in 1894, 25,000 members

3. American Society of Mechanical Engineers (ASME)*
   345 East 47th St.
   New York, N.Y. 10017
   (212)752-6800
   Founded in 1880, 64,125 members

4. American Society of Safety Engineers
   850 Busse Highway
   Park Ridge, Ill. 60068
   (312)692-4121
   Founded in 1911, 91,000 members

5. American Society of Sanitary Engineering (ASSE)
   228 Standard Bldg.
   Cleveland, Ohio 44113
   (216)621-8520
   Founded in 1906, 2,500 members

6. American Society of Traffic and Transportation, Inc.
   22 West Madison St., Rm. 404
   Chicago, Ill. 60602
   (313)263-3818
   Founded in 1946, 2,100 members

7. American Water Works Association, Inc. (AWWA)
   2 Park Avenue
   New York, N.Y. 10016
   (212)686-2040

8. American Welding Society (AWS)*
   345 East 47th St.
   New York, N.Y. 10017
   (212)752-6800

See footnote at end of table.

TABLE 6-1 (Continued).
OTHER NON-GOVERNMENT SOURCES OF VOLUNTARY STANDARDS AND SPECIFICATIONS

9. Conveyor Equipment Manufacturer's Association (CEMA)
1000 Vermont Avenue, N.W., Suite 504
Washington, D.C. 20005
(202)628-4634

10. Edison Electric Institute (EEI)
750 Third Avenue
New York, N.Y. 10017
(212)986-4100

11. Electronic Industries Association (EIA)*
2001 Eye St., N.W.
Washington, D.C. 20006
(202)659-2200

12. Federation of Societies for Paint Technology (FSPT)
121 South Broad St.
Philadelphia, Pa. 19107
(215)545-1506

13. Illuminating Engineering Society (IES)
345 East 47th St.
New York, N.Y. 10017
(212)752-6800

14. Institute of Electrical and Electronics Engineers, Inc. (IEEE)
345 East 47th St.
New York, N.Y. 10017
(212)752-6800

15. Institute of Makers of Explosives (IME)
420 Lexington Avenue
New York, N.Y. 10017
(212)689-3237

*Standardization documents developed by these sources can be readily adopted by the DOD.

dinates that system with measurements systems of other nations, and (3) furnishes essential services leading to accurate and uniform physical measurements throughout the nation's scientific community, industry, and commerce. The broad nature of this responsibility requires work at many levels of technical sophistication; however, the critical contributions in measurement usually lie at the frontiers of science and engineering. Consequently, an important activity of the Institute of Basic Standards is with the International System of Units. This system is based upon six quantities—mass, length, time, temperature, electric current, and luminous intensity. All other physical quantities can be derived from these six.

6-2.4.2 Institute for Materials Research

The Institute for Materials Research conducts materials research leading to improved methods of measurements, standards, and data on the properties of materials needed by industry, commerce, educational institutions, and the Government. It develops, produces, and distributes standard reference materials, relates the physical and chemical properties of materials to their behavior and their interaction with their environments, and provides advisory and research services to other Government agencies.

6-2.4.3, Institute for Applied Technology

The Institute for Applied Technology (1) provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government, (2) cooperates with public and private organizations in the development of technological standards and test methodologies, and (3) provides advisory and research services for Federal, State, and local government agencies.

A significant standardization activity of the NBS Institute for Applied Technology is the development of Voluntary Product Standards. The Institute's Office of Engineering Standards works closely with scientific and trade associations and organizations, business firms, testing laboratories, and other appropriate groups to develop Voluntary Product Standards under procedures established by the Department of Commerce. These standards may include dimensional requirements for standard sizes and types of various products; technical requirements; and methods of testing, grading, and marking. The objective of a Voluntary Product Standard is to establish requirements that are in accordance with the principal demands of an industry and at the same time are not contrary to the public interest.

NBS provides editorial assistance in the preparation of Voluntary Product Standards, supplies assistance in review to enhance the technical soundness of a standard, and publishes the standard. In the role of an unbiased coordinator, NBS determines that the standard is representative of the views of all concerned interests and seeks satisfactory adjustment of valid points of disagreement. Industry customarily initiates the development of a standard, participates in its development, provides technical counsel, and promotes the use of and support for the standard. When general industry agreement is obtained on a standard and when there is no substantive objection deemed valid by NBS, approval of the Voluntary Product Standard is announced and published by NBS. Although the adoption and use of the standard is completely voluntary, it may be used in conjunction with legal documents (e.g., as sales contracts, purchase orders, and building codes) making compliance with the standard enforceable.

Department of Commerce procedures also require that all Voluntary Product Standards be reviewed within 5 yr after issuance or last revision. Standards will be revised or withdrawn if obsolete, technically inadequate, no longer acceptable to or used by the industry, or not in the public interest.

Revised procedures for the development of Voluntary Product Standards were printed in the *Federal Register*, and copies are available from NBS (Ref. 14).

Voluntary Product Standards were previously called Simplified Practice Recommendations and Commercial Standards. As these two types of standards increasingly overlapped, the term Voluntary Product Standards was selected to identify future standards developed through this program. As existing Simplified Practice Recommendations and Commercial Standards are reviewed, they become Voluntary Product Standards (Refs. 5,15).

In FY 69 the NBS, through its Office of Engineering Standards, took a step toward improving communication among the nation's standards-writing groups by announcing the availability of information on engineering and related standards and specifications. A Key-Word-In-Context Index was compiled which lists 19,000 voluntary engineering and related standards from 353 national trade, professional, and technical societies alphabetically by each key word in their titles, and lists the sponsoring group for each standard (Ref. 4). This index will aid individuals in determining if standards exist in their areas of interest and in locating groups that could answer questions on specifications and standards. A need for this type of information is evidenced by the 5,600 inquiries regarding standards and standardization activities received in FY 69.

Other standards activities at NBS include the development of Federal standards for automatic data processing equipment, the operation of the National Standard Reference Data System, publication of many standards-related documents, and participation in many other standards activities.

6-2.5 OTHER GOVERNMENT STANDARDIZATION ACTIVITIES

The Range Commanders Counsel, Interrange Instrumentation Group, is active in standardization of systems, equipment, and processes in fields related to missile test range instrumentation. Specific areas of concern to this group include electronic tracking systems, telemetry systems, time generation and distribution systems, frequency regulation, computers and related data conversion and formatting equipment, and meteorological systems.

Other Government agencies involved in the development of standards and specifications that are likely to be of less general military interest are tabulated in Table 6-2 (Ref. 6).

6-2.6 INTERNATIONAL STANDARDS

World War I and rapidly expanding world trade following the war gave impetus to international standardization efforts in the early 1920's. At that time private industry made some significant standardization progress through routine commercial and engineering interchanges. In 1922, for example, an estimated 90 percent of all ball bearings were being manufactured to dimensions that were standard internationally, and there was international accord on the width and flats of nut and bolt heads and on dimensions for wrench openings (Ref. 16).

The Allied Powers of World War I, frustrated and hampered by a lack of standardization during the war effort, met in New York in 1926 and formed the International Federation of National Standardizing Bodies (ISA). Though short lived, the ISA made several significant contributions to international standardization, e.g., the ISA made the inch-millimeter conversion ratio a world standard, adopted a system of preferred numbers, and standardized the location of sound tracks on 16 mm film.

6-2.6.1 International Organization for Standardization

The most important organization in international standardization is the International Organization for Standardization (ISO), made up of the national standards bodies of 70 countries. ANSI represents U.S. interest in this body and is a source for ISO standards. The purpose of ISO is to promote international agreement on standards in the interest of trade expansion, increased productivity, and improved quality and lower prices of goods and services. When first created, ISO's efforts were concentrated in attempts to harmonize the national standards of its member countries. Recent years have seen a dramatic increase in interest in international standardization and a growing demand for international standards. The factors that have accelerated this interest include the removal of many tariff barriers to trade and the development of multinational companies which find their commercial activities hampered by conflicting national standards.

Currently, there are approximately 2,000

TABLE 6-2.
OTHER GOVERNMENT AGENCIES INVOLVED IN THE DEVELOPMENT OF STANDARDS AND SPECIFICATIONS

Small Business Administration (SBA)
Navy Standardization Board (NSB)
Public Health Service (PHS)
Department of Agriculture
Federal Radiation Council (FRC)
Federal Housing Authority (FHA)
Bureau of Public Roads
National Research Council (NRC) of the National Academy of Sciences
Atomic Energy Commission (AEC)
Federal Aviation Administration (FAA)
Office of the Federal Register
Food and Drug Administration (FDA)
Bureau of Mines (Navy)
Bureau of Ships (Navy)
Interstate Commerce Commission (ICC)

ISO Standards and recommendations plus another 2,000 in preparation. The work of ISO is carried out by some 1,200 technical groups working through their ISO member bodies. This work is highly decentralized with secretariats of the 1,200 technical groups located in 28 countries. A central secretariat, located in Geneva, is responsible for the planning and coordination of ISO activities (Ref. 17). Prior to January 1972, ISO documents were published as Recommendations to the ISO member bodies to use as the basis for a national standard. The currently published ISO International Standards are intended to be used as a substitute for the different national standards. (Seventy-five percent approval of the member bodies is required for qualification as an International Standard.)

6-2.6.2 International Electrotechnical Committee

The International Electrotechnical Commission (IEC) is a parallel organization to ISO, which prepares international standards (recommendations and reports) in the electrical and electronic fields. The U S representatives to IEC are under the direction of ANSI's International Standards Committee (Refs. 18,19).

6-2.6.3 Pan American Standards Commission

Another international organization of importance to the United States is the Pan American Standards Commission (COPANT). Founded in 1961, COPANT comprises the national standards bodies of the United States (ANSI) and 11 Latin American countries. COPANT is a coordinating organization concerned with the implementation of ISO and IEC Recommendations and Standards in the Western Hemisphere (Ref. 19).

6-2.6.4 American-British-Canadian Conference of Unification of Engineering Standards

The American-British-Canadian Conference on Unification of Engineering Standards (ABC) is a standardization organization of much importance to the U.S. military. ABC is comprised of standards bodies of America, Britain, and Canada with leading Government representatives participating in meetings. It was founded near the end of World War II to standardize basic engineering standards of importance to military supplies and industry. The ABC standardization program was initiated to resolve standardization difficulties and thus enhance the ability of the armies of the three countries to fight together in any future war. Standardization of materiel and nonmateriel items has progressed notably through this program during the past two decades. Effort is directed toward the greatest possible economy for armies of the governments concerned through the use of combined technological and scientific resources. Exchange of information among the ABC allies includes sharing of procedures governing tactical doctrine, organization, intelligence, operations, administration, logistics, research and development, and the design of weapons and equipment of common interest. The broad aim of the ABC standardization program is to minimize operational materiel, and technical obstacles to full cooperation and collaboration among the American, British, and Canadian armed forces. None of the ABC armed forces is compelled legally to agree to a standard or to join in collaboration leading to a possible standard. Once a member nation has approved a standard, however, it is obligated morally to conform unless released by agreement of the other members or unless the standard item is replaced by a new development.

Insofar as manufacturing techniques permit, ABC materiel and nonmateriel items will be identical. As a minimum, items of equipment will have interchangeable parts and assemblies. In the materiel field, over 100 ABC Army Standards are active and 40 more are in the process of completion. In addition, several hundred specific agreements have been reached that did not require publication of a formal ABC Army Standard. The standards list includes such items as spark plugs, telephone cables, radio sets, trucks, aircraft, and ammunition. In the nonmateriel field, approximately 100 active procedures have been approved for standardization. These procedures include such diverse items as operation orders, techniques for minefield laying and recording, adjustment of artillery fire, relief of combat troops, and military mapping.

A keystone of the ABC program is the principle that information and opinion among the armed forces can be exchanged with a minimum of formal procedure. Within the limits of national policies, information on the status of all development projects, current doctrine, and tactical concepts is made available. Consequently, a great volume of information is moving continually among the armies on a variety of subjects. Standardization would be virtually impossible without this exchange. Differences over standardization or collaboration are referred to higher levels as early as possible for mediation. In the interests of economy, each armed force has agreed that it will make maximum use of existing agencies and procedures.

The possibility of sharing the work of research and development is under constant ABC review. Collaboration in research is directed toward solution of mutual problems by pooling knowledge and combining talents of each of the member nations in a spirit of mutual trust and cooperation.

6-2.6.5 North Atlantic Treaty Organization

The North Atlantic Treaty Organization (NATO) also has a standardization program of importance to the U.S. military. The NATO program generally has been confined to areas of practical importance, such as the octane rating of gasoline in NATO's pipeline, tactical and operational terminology, and road sign designation. One of the most significant achievements is the development of the 7.62 mm rifle cartridge for use in different weapons of NATO countries. It was adopted by NATO under the Mutual Weapons Development Program (MWDP) (Ref. 20).

6-2.6.6 Miscellaneous

Other international standards organizations include the Asian Standards Advisory Committee (ASAC), the International Commission on Rules for the Approval of Electrical Equipment (CEE), the European Committee for Standardization (CEN), the European Electrical Standards Coordinating Committee (CENEL), and the International Special Committee in Radio Interference (CISPR).

6-3 FEDERAL STANDARDS AND SPECIFICATIONS

The *Federal Property and Administrative Services Act* of 1949 (Public Law 152, 81st Congress, 63 Stat. 377, as amended) established the General Services Administration (GSA) to provide the Federal Government an economical and efficient system for the procurement and supply of property and services (Ref. 21). The GSA consists of six operating services. Of these, the Federal Supply Service (FSS) is of particular interest because it is responsible for the Federal Standardization Program in compliance with the *Federal Property and Administrative Services Act*. These standardization activities encompass standards and specifications for real and personal property, materials, supplies, and equipment, as well as management practices and procedures. Specifically, they include development and maintenance of Federal standardization documents, standardization of commodities procured by the Government, coordination of governmental standardization activities, development and maintenance of the Federal Catalog System, inspection and testing of supplies procured under GSA contracts, and coordination of participation by GSA technical personnel in activities of nationally recognized technical societies and standardizing bodies.

When a Federal standard or specification is published by GSA, it takes the place of all antecedent specifications or standards for the same material, product, or service. When applicable, its use is mandatory. A Federal specification is used primarily in the procurement of commercial items of general application by at least two Federal agencies, one of which has to be an agency other than the Department of Defense. For example, a desk used by the Army and by the Department of Agriculture would be procured using a Federal specification. DOD policy prohibits the issuance of a military document that duplicates a suitable Federal document, but rather provides for military participation in the development and coordination of Federal standards and specifications. When an item is peculiar to the military, its procurement and uses are governed by military standards and specifications.

When initiating a standardization project, the GSA includes a statement of the scope and objective of the project, a statement of the specific requirement, reasons for the initiation of the project, a desired date of completion, and a list of agencies and segments of industry with which the document is to be coordinated. Once an assignment has been made, the assignee is responsible for the development of the new standard or specification. It also must coordinate the document with interested agencies or activities and with segments of industry, convert interim Federal documents to fully coordinated Federal documents, and amend or revise the document when the need arises.

The DOD relies completely upon the GSA for the issuance of adequate standards and specifications governing materiel for which GSA provides sole purchase support. Only when justified by special requirements of a military mission does the DOD prepare or coordinate a Federal standard or specification in which it has an interest. It also informs GSA of any new or changing requirements for items under this policy and of any unsatisfactory supplies received. When there is military interest in a Federal specification or standard, it may be coordinated by the DOD in accordance with the *Defense Standardization Manual* (Ref. 2).

The procedure for developing Federal standards within the Department of Defense is the same as for military projects. However, additional coordination is required with other Federal agencies. The final draft of the specification, with appropriate comments received from Federal civil agencies, is forwarded to GSA through the assignee activity for approval, reproduction, and issue (Ref. 16).

A close parallel exists between Federal and military standardization documents. A document in either of the two series could be entered into the other with only minor changes, and documents in either series, if applicable, are mandatory upon all Federal agencies. It is not intended that any duplication exist between the two series. The similarity between the two series is reflected in the discussion of Federal standardization documents that follows. The military series is of more interest for the purposes of this handbook, and information common to the two series is discussed in a subsequent paragraph on military standards and specifications.

It is essential to the GSA standardization program that Federal standards and specifications reflect the best technical knowledge and experience of the Government and industry, be responsive to technological advances, provide an efficient and economical medium for filling the procurement needs of Federal agencies, and enhance the ability of manufacturers to fill Government orders from their normal commercial production. A GSA *Federal Standardization Handbook*, which includes policies and procedures to be followed in the preparation of specifications and standards, is available to all agencies (Ref. 22).

Federal specifications are of two types—general and detailed. General specifications cover requirements common to different types, classes, grades, or styles of items or services. This avoids repetition of common requirements in each detailed item or process specification and permits changes to common requirements to be readily effected. A detailed specification may cover one or more types of items or services so as not to require preparation and reference of a general specification for the common requirements or, in contrast, may be incomplete without reference to a general specification. The style and format of a Federal specification is standardized to contain six sections whose titles are:

1. Scope and Classification
2. Applicable Documents
3. Requirements
4. Quality Assurance Provisions
5. Preparation for Delivery
6. Notes.

This style and format and the requirements for each section are essentially the same as required for military specifications and are discussed in par. 6-4.

An approved Federal specification is identified by a three-part number determined and assigned by the GSA. The first part consists of one or more capital Gothic letters—such as Q (which identifies coal end products) or QQ (which identifies metal). It is followed by a hyphen and a capital Gothic letter, which is the first letter in the name of the item specified. These are followed by a second hyphen and an Arabic numeral assigned to departments by the GSA. Detailed instructions are included in the *Federal Standardization Handbook* (Ref. 22). Fig. 6-2 illustrates the identification system (Ref. 22).

BB-N-411C
January 3, 1973
SUPERSEDING
FED. SPEC BB-N-411b
September 10, 1964

FEDERAL SPECIFICATION

NITROGEN, TECHNICAL

This specification was approved by the Commissioner, Federal Supply Services, General Services Administration, for use of all Federal Agencies.

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification covers gaseous and liquid nitrogen.

1.2 Classification.

1.2.1 Types, grades, and classes. The nitrogen shall be of the following types, grades, and classes, as specified (see 6.2):

Type I	-	Gaseous.
Type II	-	Liquid.
Grade A	-	99.95 percent pure.
Grade B	-	99.50 percent pure.
Grade C	-	99.50 percent pure, moisture content not specified (type I only).
Class 1	-	Oil free.
Class 2	-	Oil tolerant (Type I only) (see 6.3).

2. APPLICABLE DOCUMENTS

2.1 Specifications and standards. The following specifications and standards of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

Federal Specification

RR-C-901 - Cylinders, Compressed Gas: With Valve or Plug and Cap; ICC 3AA.

Federal Standard

FED. STD. No. 123 - Marking for Domestic Shipment (Civilian Agencies).

FSC 6830

Figure 6-2. Identification of Federal Specification

When a Federal specification or interim Federal specification establishes qualification examinations and tests, products may be tested for compliance with requirements of the specification in advance of and independently of any specific procurement action. This process identifies qualified products and provides for the establishment of a Federal Qualified Products Lists (QPL). The preparing activity responsible for a specification is administratively responsible for the qualification of applicable products for a QPL and for the continued maintenance of the QPL. Fig. 6-3 illustrates the procedure for the development of a QPL.

The limited scope of products covered by QPL's is illustrated by the fact that less than 1 percent of more than 5,000 Federal and interim Federal specifications incorporate QPL's as part of their requirements. Further, only 10 percent of the approximately 40,000 entries in the DODISS contain qualification requirements (Ref. 23).

Federal QPL's are paralleled by military QPL's, which are discussed in par. 6-4.

6-4 MILITARY STANDARDIZATION

The *Cataloging and Standardization Act* of 1952 requires the Secretary of Defense to "develop a single catalog system and related program of standardizing supplies for the Department of Defense". Further, the Secretary of Defense is required to maintain liaison with industry advisory groups to coordinate the development of the supply catalog and the standardization program with the best practices of industry; to obtain the fullest practicable cooperation and participation of industry in dev 'ng the supply catalog and the standardization program; to establish, publish, review, and revise, within the Department of Defense, military specifications, standards, and lists of qualified products; and to resolve differences between the military departments, bureaus, and services with respect to them (Ref. 1). The act also required the Administrator of General Services and the Secretary of Defense to coordinate the cataloging and standardization activities of the GSA and the DOD to avoid unnecessary duplication. Pursuant to the *Cataloging and Standardization Act*, DOD Directive 4120.3 established the Defense Standardization Program (DSP) (Ref. 24).

The principal objective of the DSP is to provide uniform definitions of the technical requirements for parts, equipment, and systems in which the various elements of the DOD have a common interest. The principal results of this program have been the development of nearly 40,000 specifications and standards defining the technical requirements of the DOD. This series of technical documents largely has replaced the individual specifications and standards formerly used by each of the military departments and provides industry with a great body of uniform technical requirements to be met by military suppliers. They are revised as necessary to reflect the most advanced techniques and hardware.

In addition to standards and specifications the program includes the effective management of drawings, handbooks, qualified products lists, and engineering records. The program covers the entire life cycle of military materiel from the generation of military operational requirements to the final disposal of items and related technical documentation. The intent is to minimize the variety of items, processes, and practices that are associated with design, development, production, and logistic support; including enhancing the interchangeability, reliability, and maintainability of military parts, equipment, and systems when essential to the improvement of the operational readiness of the military services.

Basic policies governing the Defense Standardization Program require that maximum use be made of available industry standards that are responsive to military requirements. In this way, duplication of effort in the development of needed standards between industry and the DOD is avoided.

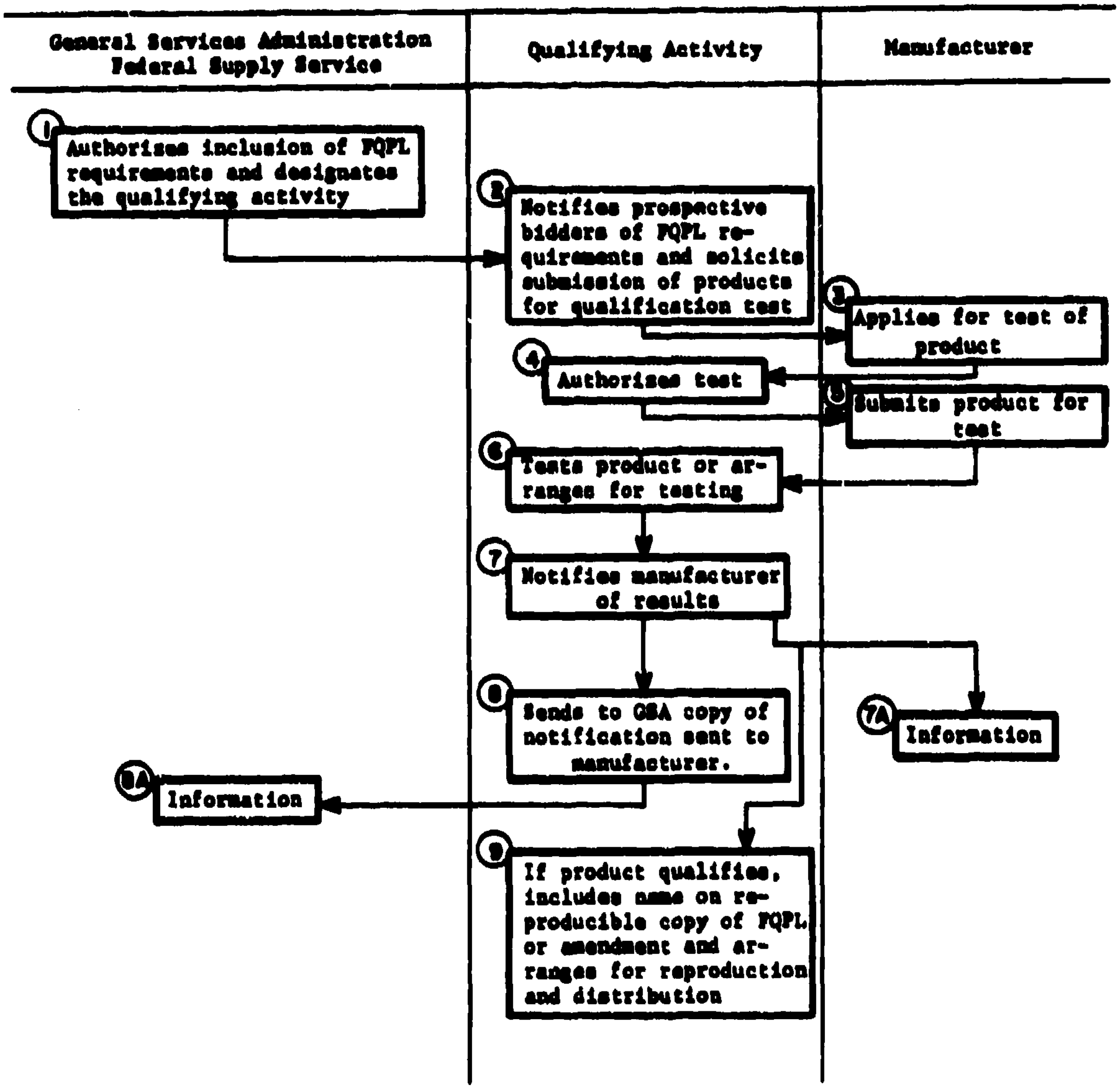


Figure 6-3. Flow Chart for Development of Federal Qualified Products Lists (Ref. 21)

The Defense Standardization Program is the largest and most comprehensive standardization program in the world—governmental or nongovernmental. The standards and specifications developed by the program are widely used within industry. In fact, many of its standards and specifications constitute the standard to which industry builds for commercial purposes. The procedures of the program have been copied widely by individual industrial firms and industry standardizing organizations as the basis for their own standardization programs (Ref. 5).

6-4.1 A RECENT HISTORY OF MILITARY STANDARDIZATION

The present DSP dates from the *Cataloging and Standardization Act* of 1952, and its administrative history is outlined in Fig. 6-4. Pursuant to this act, the Defense Supply Management Agency (DSMA) was created as an element of the DOD. In 1953, the

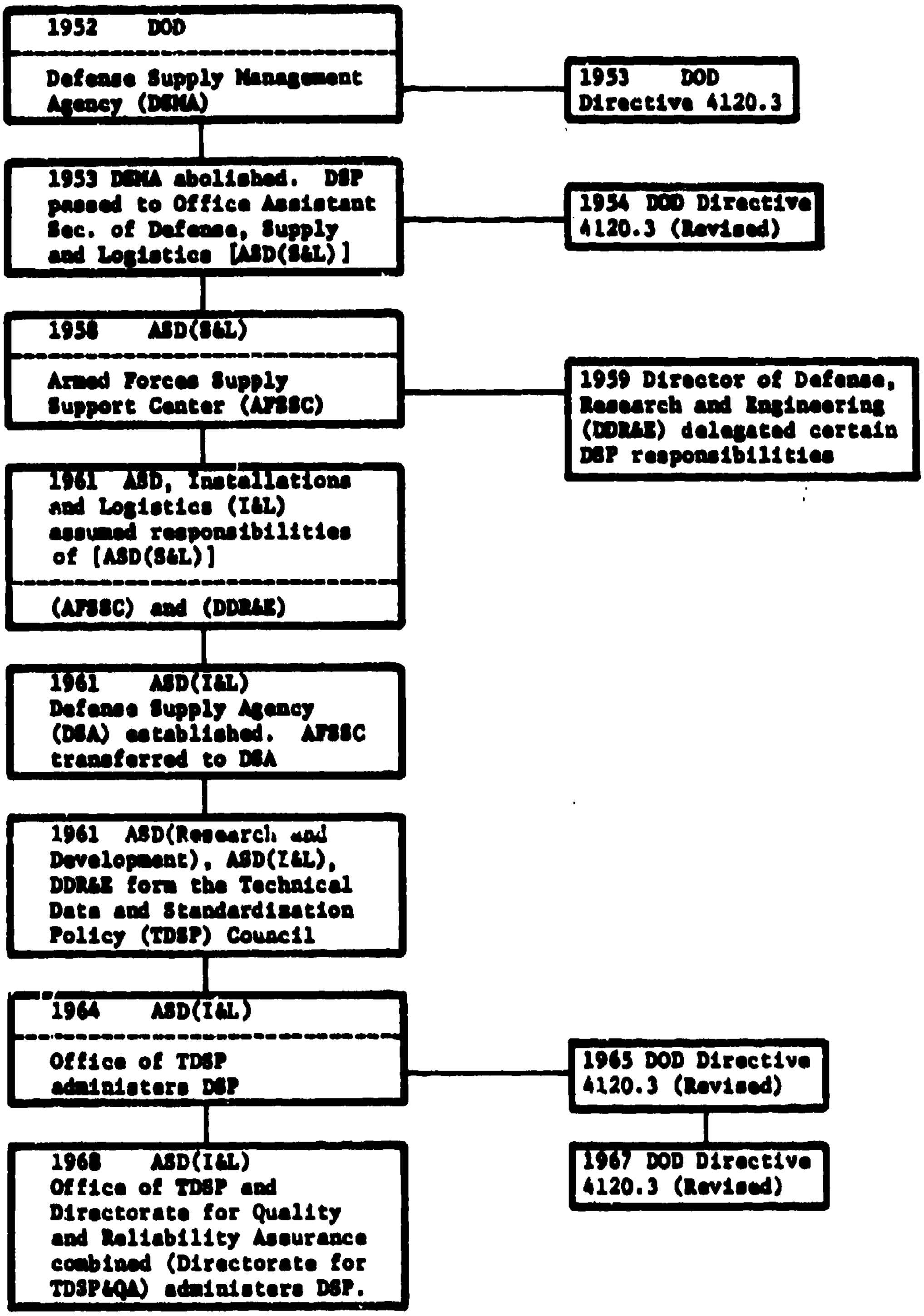


Figure 6-4. Administrative History of the DSP

director of DSMA issued DOD Directive 4120.3 (Ref. 24). Later in 1953, a reorganization of the DOD abolished the DSMA and created the Office of the Assistant Secretary of Defense for Supply and Logistics [ASD (S&L)]. This office became responsible for the administration of the DSP. In 1958, administration of the DSP was delegated to the newly established Armed Forces Supply Support Center (AFSSC) under the policy direction of the ASD(S&L). In 1959, the Director of Defense Research and Development (DDR&E) was given collateral responsibilities for certain phases of the program. The Assistant Secretary of Defense, Installations and Logistics [ASD(I&L)] was designated in 1961 and assumed the responsibilities previously delegated to ASD(S&L), which included responsibility for the DSP. The AFSSC continued to administer the program. Later in 1961, the AFSSC was transferred to the newly established Defense Supply Agency (DSA). The DSA's responsibilities included the administration of the DSP. Also in 1961, the Technical Data and Standardization Policy Council was established within the DOD. Council membership included the DDR&E and the ASD(I&L). The ASD(Research and Development) was also a member.

In 1964, the Office of Technical Data and Standardization Policy (TDSP) was established and assumed responsibility for administration of the DSP. The director of this office reported directly to the ASD(I&L). In 1968, the Office of TDSP was combined with the Directorate for Quality and Reliability Assurance to form the Directorate for Technical Data, Standardization Policy, and Quality Assurance. This Directorate continues to administer the DSP under the policy direction of the ASD(I&L) (Refs. 24,25).

6-4.2 DEFENSE STANDARDIZATION PROGRAM ORGANIZATION

The current organization of the DSP is illustrated in Fig. 6-5. As previously stated, the *Cataloging and Standardization Act* requires the Secretary of Defense to maintain a standardization program and to coordinate the program with the GSA Standardization Program. The DSP is implemented by the Directorate of Technical Data, Standardization Policy and Quality Assurance; Office of the ASD(I&L). At this organization level, the Directorate prepares and publishes DOD policies and procedures in consultation with the military departments and the Defense Supply Agency (DSA), establishes broad standardization goals, measures progress, prepares reports to the Secretary of Defense and Congress, recommends to the Secretary of Defense assignments of broad standardization responsibilities to the military departments and the DSA, and reconciles differences between military departments and the DSA.

At the headquarters level of each military department (Army, Navy, and Air Force), the Departmental Standardization Office (DepSO) administers the program within that military department. At the headquarters level of the DSA, a similar organization administers the standardization activities of the Defense Supply Centers. Each department level office monitors progress within its own department or agency and implements policies and procedures, reconciles interdepartmental differences, and participates in the development of DOD policies and procedures.

The DSA is directly responsible for providing supplies and services used in common by the military services. The objectives of DSA are (1) to provide effective logistic support to the operating forces of all military services in war and peace and to Federal civil agencies when requested; (2) to provide that support at the lowest feasible cost to the taxpayer; and (3) to provide contract administration services and support to the military departments, other DOD components, NASA, and other Government agencies upon request. DSA procures, stores, and distributes an immense variety of items commonly used by the Armed Forces and Federal civil agencies.

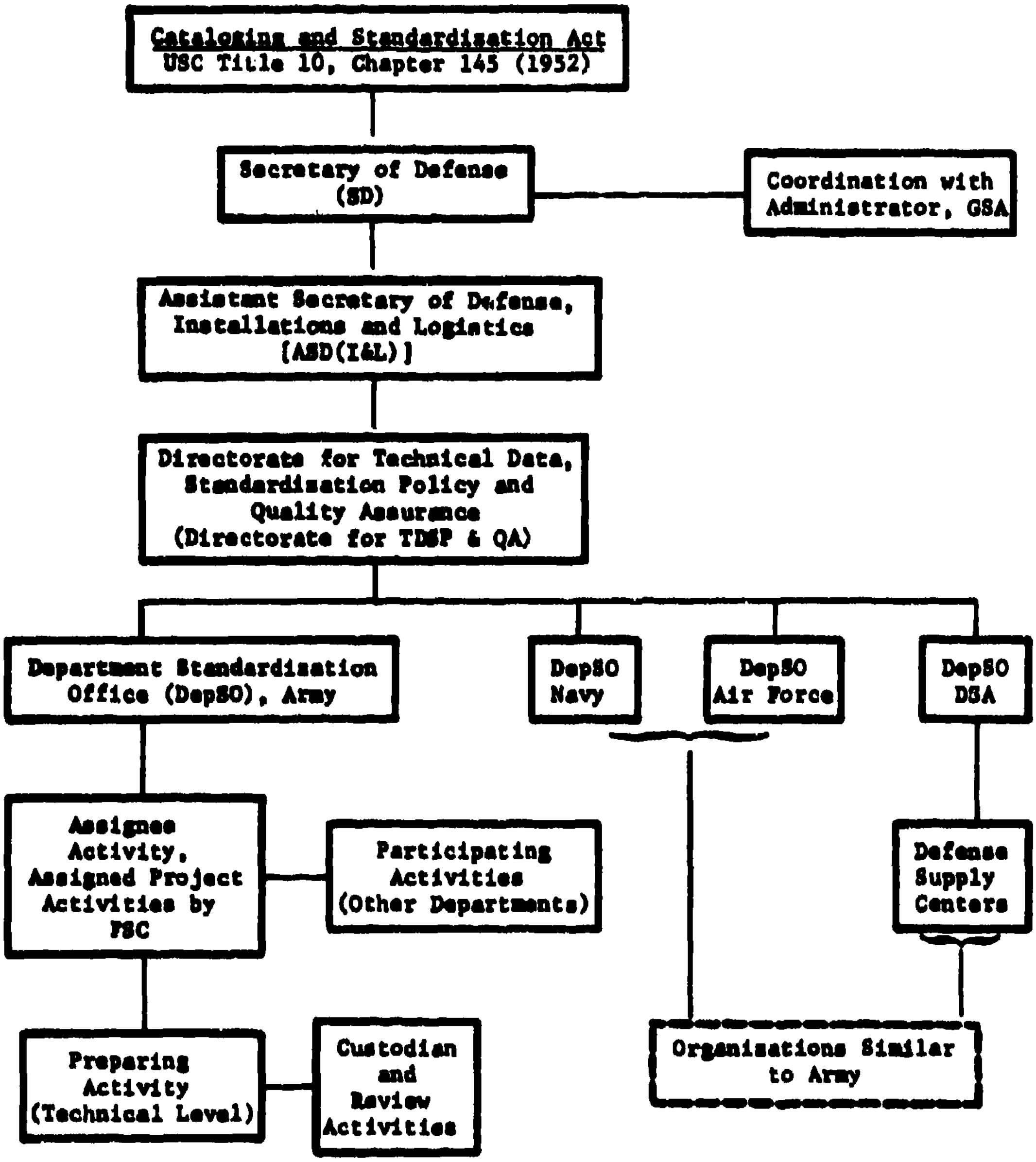


Figure 6-5. Organization of Defense Standardization Program

including clothing, medical items, repair parts for construction, electronic equipment, food, and fuels.

For each Federal Supply Class (FSC), DOD managerial responsiblity has been decentralized to an assigned department or agency, called the assignee. These assignee activities have been given DOD-wide responsibility to assure optimal standardization in assigned FSC's or areas in coordination with counterpart elements in other departments (referred to as participating activities), to assign projects to preparing activities based on interest and technical capability, and to monitor progress and report accomplishments.

The preparing activity is responsible for the preparation, issuance, and maintenance of assigned standards and specifications covering individual items, parts, systems, commodities, and practices. It is also responsible for effecting coordination with other military activities, civil agencies, and industry. Preparing activities are normally the subordinate commands and activities in the Army, Navy, Air Force, and Defense Supply Centers. The Laboratories and Arsenals of the Army are examples of engineering and development activities that are designated as preparing activities.

The custodial activity is one of the technical elements of the Army, Navy, and Air Force directed to effect departmental coordination, to review documents and studies submitted by preparing activities, and to submit coordinated department positions. The review activity is an interested military activity using (or planning to use) a document and asserting a justifiable requirement to review the document in draft form. The specific responsibilities of the ASD (I&L), the DepSO, participating departments, and the activities previously listed are detailed in the *Defense Standardization Manual* (Ref. 2).

6-4.3 DODISS

The Department of Defense *Index of Specifications and Standards* (DODISS) is published annually and kept current with supplements once every 2 months. DODISS is composed of two parts, issued separately, with data on unclassified Federal, military, and adopted industry Standards, Specifications, Handbooks, and related standardization documents. Part I, *Alphabetical Listing of Standardization Documents*, lists documents by titles. Additionally, it tabulates the document number, FSC, control symbols, preparing activities, custodians, and document dates. In Part II, *Numeric Listing of Standardization Documents*, the identical information is tabulated, but the documents are listed in numerical order. The Department of the Navy, DOD Single Stock Point for Standardization Documents, U.S. Navy Publications and Forms Center, Philadelphia, Pa. 19120, is responsible for indexing these standardization documents and is also a source for these documents.

A similar index is the Federal Supply Classification Listing of DOD Standardization documents. It contains all the listings of the DODISS arranged by FSC classes. In addition to the information in the DODISS, the FSC Listing identifies review and user activities and lists Federal documents for which no DOD interest has been registered. The FSC Listing can be advantageous in identifying standardization documents applicable to a given item. However, so many documents would have a MISC (miscellaneous) classification (including many environmental test documents) that it is not as helpful in locating documents as a key-word-in-context index such as is available for voluntary standards (Ref. 4). A key-word-in-context printing of the DODISS would be an extremely voluminous document.

A document related to the DODISS is the quarterly *Status of Standardization Projects* (SD-4). Through this medium the military and DSA DepSO's publicize the status of standardization projects within the DOD. This publication lists active projects and projects completed since the preceding report. Document projects (Military Specifications, Standards, etc.); engineering practice or item reduction studies; and the type of action (new standard, amendment, revision), are identified. Other standardization project information listed in the SD-4 document includes the preparing activity, initiation date, coordination date (if applicable), completion date, and a current status identification symbol.

6-4.4 MILITARY SPECIFICATIONS

Military Specifications are developed for materials or services that are intrinsically military in character. Their use is mandatory whenever applicable. If the material or services are required by more than one of the DOD departments, the covering specifications are coordinated by the involved DOD departments. The coordinating activity (usually the preparing activity) is responsible for coordinating specifications in accordance with procedures established in the *Defense Standardization Manual* (Ref. 2).

A limited coordinated Military Specification can be issued by one of the military departments to cover items peculiar to the needs of the department or to satisfy an immediate procurement need. Once the Specification is prepared and issued, it is mandatory for use by all procuring activities of the issuing department. This document, like the interim Federal Specification, is often the first formal document to describe an item or service that is later used by other activities. When coordinated by all military departments, the limited coordinated Military Specification becomes a fully coordinated Military Specification.

When the immediate procurement of an item with changed requirements does not allow time to complete coordination of a revision to a coordinated Military Specification, a "Used in Lieu of" revision to the existing specification may be issued, based upon the justified request of the requiring activity. A "Used in Lieu of" limited coordination specification bears the same title as the coordinated Military Specifications on which it is based (Ref. 16).

Military Specifications are classed broadly as either general or detail specifications. A General Specification covers requirements common to two or more types, classes, grades, or styles of products, services, or materials which avoids repetition of common requirements in related detail specifications and permits changes to common requirements to be readily effected. General Specifications also may be used to cover common requirements for weapon systems and subsystems. A Detail Specification covers all requirements for one or more types of items or services so as not to require preparation and reference to a General Specification for the common requirements. A Detail Specification and referenced General Specification (which contains the requirements common to the family of items) then constitute the total requirements (Ref. 26).

Both General and Detail Specifications may be further categorized as performance or design specifications. A performance specification expresses requirements in the form of output, function, or operation of a commodity; the details of design, fabrication, and internal workings are left to the manufacturer. It covers required performance rather than optimum performance and ordinarily is employed when information on design is not essential. The performance specification, however, also may contain design requirements. A design specification describes the exact features of design to be used in the manufacture of a product, including the physical features and limitations. It includes details of material, composition, physical and chemical requirements, weight, size, and dimensions. A design specification also is used when other than overall interchangeability is affected and when it is necessary to specify the details of design, such as the interchangeability of minor component parts (so that the components of one manufacturer's product will be interchangeable with those of another). The use of design specifications depends upon the extent to which the military departments feel that they must control the item in order to assure performance (Ref. 27).

Within the given categories, specifications may pertain to a complete system, a product such as subassemblies, or a basic raw material. They also may be classified as process specifications or development specifications. Complete descriptions of these categories and instructions for their preparation are readily available (Refs. 16,26).

Documents associated with Specifications include Amendments, Notices, Supplements, Qualified Products Lists, and Specification Sheets which are described in the paragraphs that follow.

6-4.4.1 Identification of Military Specification

Military Specifications are identified by a three-part symbol: the capital Gothic letters MIL; followed by a hyphen and a single Gothic letter (the first letter in the name of the item); followed by a second hyphen and an Arabic numeral that is within a block of numbers assigned to the DOD department responsible for the Specification. The date of approval for a Specification appears under the identification number located in the upper right corner of the front page.

When a Military Specification is revised, each revision is identified by adding a capital Gothic letter to the symbol. The first revision is identified by the letter A, and subsequent revisions are identified by other capital letters in alphabetical sequence (the letters I, O, Q, and S are not used). These procedures are illustrated in Fig 6-6. The figure identifies a fully coordinated Military Specification. The letter E included at the end of the symbol identifies it as the fifth revision of the original specification. Approval data and the symbol and approval date of the immediately preceding specification also are included.

Limited coordination Military Specifications are identified in the same manner as fully coordinated Military Specifications, except that the symbol designation of the preparing activity is added as a suffix to the Arabic number (Air Force limited coordination specifications bear the suffix USAF in all cases and are not shown by Air Force activity). Additionally, a statement following the title of the specification identifies the approving activity; e.g., MIL-T-5422 (AS) is a limited coordination testing specification approved by the Naval Air Systems Command, Department of the Navy. The suffix symbols are tabulated in several references, including the DODISS (Ref. 8).

A "Used in Lieu of" Specification is identified with the symbols that also identify the existing Specification. However, the specification number is prefixed with a "00", and the appropriate symbol designation of the preparing activity for the "Used in Lieu of" Specification and a revision indicator follow the specification number. The notation "Used in Lieu of" is displayed prominently in the space immediately preceding the supersession information. A preamble follows the title, such as is shown in Fig. 6-7.

The preceding examples apply to General Specifications. A Detail Specification is identified by the addition of a serial number to the General Specification symbol (less any revision number or suffix). The serial number follows a slash mark and indicates its position in the order of issue. For example, in MIL-B-18/25, the 25 indicates 24 previous issues. Revisions to Detail Specifications are indicated by a capital Gothic letter following the number, as in MIL-B-18/25A (Refs. 2,16).

Number allocations to the DOD Departments for assignment to Military Specifications are tabulated in Table 6-3.

6-4.4.2 Format of Military Specifications

The format of Military Specifications for most items, processes, and materials has been standardized to contain six numbered sections as follows:

1. Scope
2. Applicable Documents
3. Requirements
4. Quality Assurance Provisions
5. Preparation for Delivery
6. Notes.

MIL-E-5272C(ASG)
13 APRIL 1959

Superseding
MIL-E-005272B(USAF)
5 June 1957
USED IN LIEU OF
MIL-E-5272A
16 September 1952

MILITARY SPECIFICATION

ENVIRONMENTAL TESTING, AERONAUTICAL AND ASSOCIATED
EQUIPMENT, GENERAL SPECIFICATION FOR

This specification has been approved by the Department of the Air Force and by the Navy Bureau of Aeronautics.

1. SCOPE

1.1 General.- This specification establishes generally applicable procedures for testing aeronautical and associated equipment under simulated and accelerated climatic and environmental conditions. Procedures prescribed herein are to be utilized in subjecting equipment to simulated and accelerated environmental conditions in order to insure satisfactory operation and to reduce deterioration when the equipment is operated or stored in any global locality. In the case of any particular item of equipment, test procedures are to be followed to the extent specified in the applicable equipment specification.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids, form a part of this specification:

SPECIFICATIONS

Military

JAN-S-44	Shock-Testing-Mechanism for Electrical-Indicating Instruments (2-1/2 and 3-1/2 Inch, Round, Flush-Mounting, Panel-Type)
MIL-S-901	Shockproof Equipment; Class HI (High Impact), Shipboard Application, Tests for
MIL-S-4456	Shock, Variable Duration, Method and Apparatus for
MIL-G-5572	Gasoline, Aviation, Grades 80/87, 91/96, 100/130, 115/145
MIL-S-5705	Structural Criteria, Piloted Airplanes, Fuselage, Booms, Engine Mounts and Nacelles

Figure 6-6. Example of Front Page of a Fully Coordinated Military Specification (Ref. 2)

Example: MIL-G-001833A (SHIPS)
1 December 1951
USED IN LIEU OF
MIL-G-1833
27 December 1949

MILITARY SPECIFICATION
GUNS, LUBRICATING, PRESSURE, HAND-OPERATED
AND FITTINGS

This Limited Coordination Military specification has been prepared by the Bureau of Ships, based upon currently available technical information, but it has not been approved for promulgation as a revision of Military Specification MIL-G-1833. It is subject to modification. However, pending its promulgation as a coordinated military specification, it may be used in procurement.

Figure 6-7. Example of a Limited Coordination Military Specification (Ref. 2)

TABLE 6-3.
ALLOCATION OF NUMBERS FOR MILITARY SPECIFICATIONS (Ref. 2)

Army	10,000 through 14,999
	40,000 through 40,599
	43,000 through 53,999
	55,000 through 59,999
	60,000 through 70,326
	70,328 through 79,999
Navy	850 through 999
	21,000 through 21,259
	21,261 through 24,999
	81,000 through 82,999
Air Force	4,000 through 4,999
	8,788 through 8,999
	9,501 through 9,999
	25,000 through 27,000
	38,000 through 38,999
	83,000 through 83,999
USA	28,000 through 28,499
	30,500 through 31,499
	35,000 through 37,999
	39,000 through 39,499
	40,600 through 42,999
	54,000 through 54,999
	80,000 through 80,999

Additionally, appendixes and other concluding material may be included as required. Except for appendixes, if a section has no pertinent information, the following statement will appear below the section heading: "This section is not applicable to this specification". A description of the content, arrangement, paragraphing, etc., of each section can also be found in Refs. 1, 26.

6-4.4.3 Development and Coordination Procedures

Standardization document projects are assigned to preparing activities on the basis of an activities interest. If no draft of the standardization document is available (i.e., if it is a new document), the preparing activity will develop a draft of the proposed document from available data. The preparing activity is responsible for editorial correctness of the document and compliance with the provision of the *Defense Standardization Manual*. The preparing activity may utilize conferences, Federal standardization documents, and information available from related industries, for example. Draft copies are circulated to the assignee activity and all custodial, reviewing, and user activities for comment. (If the project involves an existing document, reviewing and user activities are recorded in the FSC Listing of DOD Standardization Documents.) Comments from all reviewing activities are submitted to the custodians who prepare verified departmental comments for submission to the preparing activity. Comments from the reviewing activities are designated as either "essential" or "suggested". Essential comments must be justified by the reviewing activity and reconciled by the preparing activity. Unresolved essential comments are referred to the assignee activity for reconciliation or referral to other command levels.

Concurrent with the circulation of a proposed document within DOD, draft copies are also circulated to a representative cross section of the affected segments of industry, to industry associations, and to national standardization organizations. Resulting review comments are evaluated and adopted to the maximum practicable extent.

In the interest of efficiency, the number of organizations and people participating and the time required for review and other coordination activities are kept to a minimum. The preparing activity processes standardization documents on behalf of all users and coordinates the document in the DOD only with designated review activities. Other activities waive coordination and rely upon the preparing activity and review activities to serve and protect their interests unless the risk involved with overlooking an essential requirement is unacceptable.

At the completion of the coordination cycle, the preparing activity will approve the document, date and number it, and arrange for its reproduction and distribution as a coordinated standardization document (Ref. 3).

6-4.4.4 Military Qualified Products Lists

When a Military Specification is based on performance requirements and sets forth qualification examinations, tests, and specific criteria for the retention of a qualified status, a Qualified Products List (QPL) may be established listing products that satisfy the requirements of the specification. The objective of establishing a QPL is to provide a means of relieving quality conformance inspection for long, complex, or extensive tests after each procurement action. QPL's association with a specification is the responsibility of the specification-preparing activity. The preparing activity is responsible for the inclusion of qualification criteria in a specification (with DepSO approval) and for the subsequent qualification procedures. Testing costs are borne by the supplier. When a QPL is completed, it is processed and distributed in the same manner as the basic Specification. Maintenance of a QPL through revisions, amendments, waivers, and cancellations remains the responsibility of the preparing activity. Specific procedures for developing QPL's are included in Ref. 2.

QPL's are identified by the symbol QPL followed by the number of the associated Specification and a serial number to identify the issue of the QPL; e.g., QPL-3125-1 identifies the initial issue of a list associated with Military Specification MIL-P-3125. Fig. 6-8 is an example of a QPL.

6-4.4.5 Other Associated Documents

Specification Sheets, Amendments, Notices, and Supplements are separately issued documents associated with Military Specifications. A Specification Sheet is a form of a Detail Specification that supplements the associated General Specification. It contains the data and describes the characteristics and performance requirements needed for application of the covered items in assemblies and for their procurement. It may cover a single item or a series of similar items which differ only in such respects as size, material, or parameter values. Specification Sheets are prepared when a family of items differing in some detail requires individual coverage. The associated General Specification covers all requirements, tests, and characteristics that are common to all items covered by the several Specification Sheets. Each specification sheet is identified by the heading "Military Specification Sheet" and by the same title, symbol, and number as the associated General Specification (it is identified as a Detail Specification (Ref. 2)).

Amendments to Specifications are issued to correct errors, to add or delete words to improve clarity, and to make minor changes in requirements. They are identified by the same heading, title, symbols, and numbers as the Specification with which they are associated. The word "Amendment" followed by a serial number and the date of approval appear with the symbol and numbers in the upper right corner. It is further identified by a preamble which follows the title. Amendments are cumulative; i.e., each successive Amendment is written so as to completely supersede all previous Amendments (Ref. 2).

Notices are intended to handle administrative details, such as cancellations, supersession data, changes in security classifications, and related matters. These, too, are clearly identified with the associated Specification, are numbered consecutively, and are written so as to supersede all previous Notices (Ref. 2).

A Supplement is a leaflet addition to a Specification issued to make special provisions for limited application and is clearly identified with the associated Specification (Ref. 2).

In addition, a Specification Change Notice (SCN) may be issued to correct a portion of a Specification that does not justify a complete revision. An SCN form is used as a cover sheet and letter of transmittal for the page changes associated with the SCN. SCN's are not cumulative insofar as transmittal of previous changes is concerned, and changes distributed with previous SCN's remain in effect unless changed by a SCN of later issue. The summary of current changes is a cumulative summary as of the date of approval of the latest SCN (Refs. 8,26).

6-4.4.6 Military Standards

As with voluntary consensus standards and Federal Standards, it is intended that Military Standards be active, working records of the decisions and recommendations of the best authorities on the subjects covered. Their primary use is to serve as tools for designers and engineers. It is also intended that Military Standards prescribe a level of quality and reliability commensurate with the needs of the military and that they be used with confidence in the development of designs and in manufacturing (Ref. 16).

6-4.4.6.1 *Book-form Military Standards.* Book-form Military Standards are used for the comprehensive presentation of engineering practices, including test methods, procedures, processes, codes, safety requirements, symbols, abbreviations, nomenclature, type designations, and characteristics for

DoD 4120.3-M

QPL-14-51
AMENDMENT-1
7 June 1971

QUALIFICATIONS VALIDATED FEBRUARY 1971

FSC 9330

QUALIFIED PRODUCTS LIST OF PRODUCTS QUALIFIED UNDER MILITARY SPECIFICATION

MIL-M-14

MOLDING PLASTICS AND MOLDED PLASTIC PARTS: THERMOSETTING

This list has been prepared for use by or for the Government in the procurement of products covered by the subject specification and such listing of a product is not intended to and does not connote endorsement of the product by the Department of Defense. All products listed herein have been qualified under the requirements for the product as specified in the latest effective issue of the applicable specification. This list is subject to change without notice; revision or amendment of this list will be issued as necessary. The listing of a product does not release the supplier from compliance with the specification requirements.

The activity responsible for this Qualified Products List is the Naval Ship Engineering Center

THIS AMENDMENT FORMS A PART OF QPL-14-51 DATED 5 February 1971

GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
Pages 2 and 5, Add the following products:			
CFG	Plenco 582 Black	Plastics Eng. Co. Rpt. USQ No. 10	Plastics Engineering Co. 1607 Geele Avenue Sheboygan, WI 53081 Plant: 2732 N. 15th St. Sheboygan, WI
CMG	Plenco 785 Brown	Plastics Eng. Co. Rpt. USQ No. 11	Plastics Engineering Co. 1607 Geele Avenue Sheboygan, WI 53081 Plant: 2732 N. 15th St. Sheboygan, WI
Page 7, Delete the following products:			
MAI-30	HAYSITE Grade No. 330 Premix	Hays Mfg. Co. Rpt. No. 23 dtd 3/4/65	Haysite Division Synthane-Taylor Corp. P.O. Box 6180 Erie, PA 16512 Plant: 5599 New Perry Hwy. Erie, PA
MAI-60	HAYSITE Grade No. 660 Premix	Hays Mfg. Co. Rpt. No. 22	Haysite Division Synthane-Taylor Corp. P.O. Box 6180 Erie, PA 16512 Plant: 5599 New Perry Hwy. Erie, PA

1 of 1

Figure 6-8. Sample of a Qualified Products List (Ref. 2) standard equipments, either singly or in families. They are also used to cover overall characteristics of a family of end-items or major components. Unlike Specifications, Standards are not procurement documents. They become a procurement consideration through the medium of Specifications. Standards insure that designers and manufacturers apply standard engineering criteria and use standardized components whenever practicable. The use of applicable Military Standards is mandatory in the DOD.

Military Standards are developed through basically the same procedures as are Military Specifications. They may be fully coordinated or limited coordination standards. During development, they are identified as Proposed Standards and may be modified through the issuance of revisions, notices, and change notices (Refs. 2,8). Military Standards are not amended.

A book-form Military Standard is identified by the heading "Military Standard" and a three-part symbol composed of the letters MIL-STD- followed by an Arabic numeral. This symbol is located in the upper right corner of the self-cover. The approval date appears below this symbol, as illustrated in the following example:

Example: MIL-STD-210
1 June 1953

Revisions and supersessions data are incorporated in the symbol in the same manner as for a Military Specification. Revisions are identified by a capital letter immediately following the document symbol; e.g., MIL-STD-210A is the first revision of MIL-STD-210. Subsequent revisions are identified in alphabetical sequence. Supersession data are included immediately below the symbol and date, separated by a horizontal line. Fig. 6-9 illustrates a Military Standard self-cover sheet.

Number allocations to the DOD Departments for assignment to book-form Military Standards are listed in Table 6-4.

The content of a book-form Standard is governed by its purpose and the specific

TABLE 6-4.
NUMBER ALLOCATIONS FOR ASSIGNMENT TO BOOK-FORM MILITARY STANDARDS (Ref. 2)

Department	MIL-STD Numbers
Army	317 through 400
	604 through 699
	901 through 930
	1,155 through 1,299
	1,400 through 1,499
Navy	700 through 799
	1,300 through 1,399 (Except 1,321)
Air Force	800 through 899
DSA	931 through 1,154

MIL-STD-202D
14 April 1969

SUPERSEDING
MIL-STD-202C
12 SEPTEMBER 1963

MILITARY STANDARD

TEST METHODS FOR ELECTRONIC AND ELECTRICAL COMPONENT PARTS

MISC

Figure 6-9. Self-cover Sheet of a Military Standard requirements involved. Although there are numerous variations, a general outline of the content follows (Ref. 2).

A. Self-cover

B. Promulgation sheet

C. Foreword

D. Contents

E. Text and illustrations

1. Scope

2. Referenced documents

3. Definitions

4. General requirements

5. Detail requirements

F. Notices

G. Custodian, preparing activities, other interest designations

H. Appendixes

I. Index

J. Analysis sheet (DD Form 1426)

In addition to the heading and identification symbols, the self-cover sheet includes the title and the FSC designation. Since the use of Military Standards is mandatory, it is very important that the titles of Standards be complete and precise. Otherwise, applicable standards can be easily overlooked. A clear, concise statement of scope is also essential since it defines the extent of the technical contents of the Standard.

6-4.4.6.2 *Sheet-form (MS) Standards.* Sheet-form or MS Standards are issued to cover component parts—such as fasteners and electronic components—as distinguished from equipments. They provide an identifying standard part number and depict physical and design features of items. MS Standards may be limited or fully coordinated Standards and may be revised to reflect Specification changes. They are identified by the symbol MS followed by an Arabic numeral. The numbers allocated to the DOD departments for assignment to MS Standards are tabulated in Table 6-5. Fig. 6-10 illustrates the basic format of an MS Standard.

6-4.5 MILITARY HANDBOOKS

Military Standardization Handbooks are used for the presentation of general information, technical data, and reference material that will enhance the DSP. They are identified by a self-cover sheet that includes the identifier MIL-HDBK- followed by an Arabic numeral and an approval date in the upper right corner. The words "Military Standardization Handbook", followed by a title, are centered on the self-cover, and an FSC designation appears in the lower right corner. Revision symbols, supersession data, and other such data conform to the instructions for military book-form standards. The text, style, and illustrations also conform to book-form standards (Ref. 2).

6-4.6 ADOPTION OF INDUSTRY STANDARDIZATION DOCUMENTS

It is a policy of the DSP to adopt suitable industry standardization documents for military use whenever a satisfactory industry document exists but no satisfactory military document exists. An industry document also may be developed for DOD adoption if industry is willing to update an existing document or develop a new document in time to meet the needs of the military. If an industry document is to be developed or adopted in lieu of preparing a military or Federal series document, it is required, in part, that they fully satisfy the needs of the military and be available in sufficient quantity to satisfy DOD-generated demands.

With respect to the development or

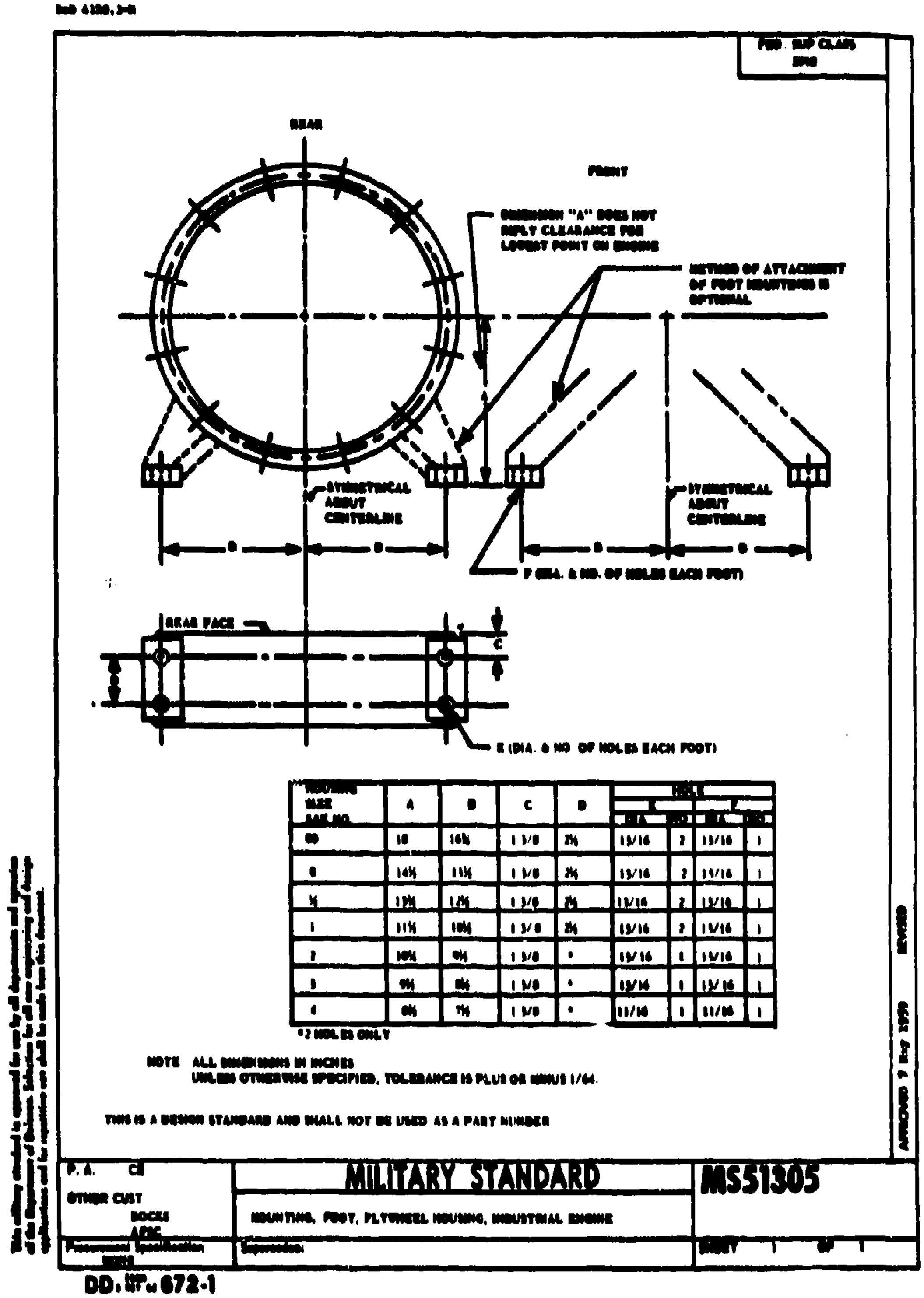


Figure 6-10. Basic Format of Sheet-form (MS) Military Standard (Ref. 2)

TABLE 6-5.
NUMBER ALLOCATIONS FOR ASSIGNMENT TO SHEET-FORM (MS) MILITARY STANDARDS
(Ref. 2)

Department	MS numbers
Army	3,200 through 3,210
	10,000 through 13,999
	35,000 through 48,999
	51,000 through 63,199
	66,600 through 66,740
	70,000 through 90,000
	500,000 through 599,999
Navy	3,100 through 3,199
	3,211 through 3,510
	14,000 through 19,999
	90,294 through 90,528
	91,621 through 91,676
Air Force	8,000 through 8,004
	9,000 through 9,999
	20,026 through 34,999
	100,000 through 499,999
DSA	49,000 through 50,000
	63,200 through 66,599
	66,741 through 69,999
	90,530 through 90,700
	90,707 through 90,900
	90,908 through 90,999
	91,076 through 91,082
	91,269 through 91,309
	91,522 through 91,583
	91,907 through 99,999

adoption of industry standardization documents for DOD use, an assigned activity is responsible for selecting existing documents having a potential for DOD use and establishing projects for obtaining the requisite coordination of the document within DOD, obtaining additional industry coordination, if required, and arranging for final DOD approval and listing in the DODISS. If an industry document is to be developed, an assigned activity is responsible for assuring DOD participation. Each industry document adopted for use within the DOD will be identified in the DODISS by an industry group symbol, number, title, date of the DOD-adopted issue, and the military coordinating activity within DOD. Each listed industry document will be identified as either coordinated or limited coordination in the same form as that being used for identifying Standards and Specifications as either coordinated or limited coordination. The military coordinating activity will endeavor through participation with industry groups to have each adopted industry document kept current and suitable for military use.

An industry document adopted outright is the subject of an acceptance notice which, with a copy of the document, is submitted for indexing and inclusion in the DODISS. It is identified by the title, "Acceptance Notice", and in DODISS by the industry-assigned number. Fig. 6-11 is an example of an Acceptance Notice for a coordinated industry document adopted by DOD.

Other industry documents are adopted for DOD use only in part. Excerpts of industry documents may be included in military standardization documents under certain circumstances, or an industry document may be referenced in a military or Federal document. Details of policies and procedures to be followed are included in the *DSP Manual* (Ref. 2).

Standardization documents of certain industry groups have been cleared for adoption by DOD in accordance with the procedures of the *DSP Manual*. (Ref. 2).

6-4.7 ORDER OF PRECEDENCE

MIL-STD-143, which gives the order of precedence for the selection of standardization Specifications, lists the order of precedence that follows for the selection of Standards and Specifications within the Federal Government, including the DOD. The selection of a Standard or Specification of lower precedence is to be made only when the Standards and Specifications from groups above it do not provide items technically or economically suitable for the application. The selection of a document within any one grouping of Standards and Specifications shall be a suitable Standard, if any, over a suitable Specification (Ref. 28).

1. Coordinated Federal Standards and Specifications

2. Coordinated Military Standards and Specifications

3. Industry standards and specifications; e.g., those promulgated by nationally recognized associations, committees, and technical societies having coordinated status established under DOD policies and procedures

4. Limited coordination Military and interim Federal Standards and Specifications issued by the Government command or agency concerned

5. Industry standards and specifications having limited coordination status established by the Government command or agency concerned under DOD policies and procedures

6. Limited coordination Military and interim Federal Standards and Specifications issued by other Government commands or agencies

7. Industry standards and specifications promulgated by nationally recognized industry associations, committees, and technical societies that are not listed in the DODISS

8. Government Standards and Specifications other than those of the Military and Federal series, and not listed in DODISS; e.g., D-23 Specifications (Ref. 21).

6-5 ENVIRONMENTAL STANDARDIZATION DOCUMENTS

Standards and specifications define the characteristics of virtually all military materiel including their compatibility with the environment to be encountered during their life cycle. Of the life cycle phases, the operational or use phase is primary in that all other phases exist for this phase alone. In a broad sense, standards and specifications applicable to every phase relate to the operational environment. An operational environment is envisioned in the concept formulation phase, for example, and materiel and processes are specified in other phases with the operational environment in mind. Environmental criteria usually are specified

ASA X3.5-1966
10 January 1967
USED INSTEAD OF
MIL-STD-682A
21 May 1962

ACCEPTANCE NOTICE

The above Industry Standardization Document was adopted on 10 January 1967 and is approved for use by the DoD. The indicated industry groups have furnished the clearances required by existing regulations. Copies of the document are stocked by DoD Single Stock Point, U S Naval Publications and Forms Center, Philadelphia, Pennsylvania, for issue to DoD activities only.

Title of Document: Flowchart Symbols for Information Processing

Date of Specific Issue Adopted: 8 June 1966

Releasing Industry Group: United States of America Standards Institute

Custodians:

Army - EL

Navy - SH

Air Force - 26

Review Activity:

Navy - SH

Military Coordinating Activity

Army - EL

Project Number 7440-0007

Figure 6-11. Acceptance Notice for a Coordinated Industry Standardization Document Adopted by DOD (Ref. 2) in the contract definition phase, and environmental tests are conducted in both the development and production phases. The environmental tests specified are to demonstrate that the item will function as it is designed to function and under the conditions expected during its lifetime.

Environmental criteria exist in most equipment specifications. A complete equipment specification comprises so many detailed specifications that many include general environmental standards and specifications by reference only. These general environmental documents are discussed in detail in this paragraph. Environmental standards and specifications have several advantages over equipment standards and specifications that contain environmental criteria. It is extremely difficult to insure that the latest information is reflected in every applicable specification as compared to a general environmental standardization document. Furthermore, if individually prepared, different environmental requirements may be specified for otherwise identical equipment, significantly increasing costs.

Environmental standardization documents and environmental criteria in equipment specifications are, in general, out of date and based upon uncertain assumptions that are documented poorly if documented at all. Considerable efforts are being invested in updating environmental data and environmental standardization documents (Refs. 29,30). Table 6-6 indicates the types of environmental tests found in a variety of Military Standards.

6-5.1 MIL-STD-210, CLIMATIC EXTREMES FOR MILITARY EQUIPMENT

MIL-STD-210, *Climatic Extremes for Military Equipment*, evolved from the structural and operational failure of combat and support equipment during World War II because of exposure to environmental extremes (Ref. 31). In response to this experience, a U S Army Quartermaster Report was published in 1951 which provided low-risk, surface level land and sea extremes. This report served as the basis for the original MIL-STD-210 which was published and made mandatory for DOD use in June 1953. The A revision, published in August 1957, includes limited upper air data. MIL-STD-210 is the basic document describing military environmental extremes. It is a unique document, unlike any others to be discussed.

MIL-STD-210 lists the probable extreme climatic conditions of the natural environment to which military equipment may be exposed. Probable extremes are defined as values determined by scientific judgment not to be surpassed in more than 10 percent of the days during the most extreme month (3 days). This is a calculated risk policy adopted in view of the increased cost and complexity of designing military equipment for the absolute extreme conditions that might occur anywhere in the world. The environmental factors considered in this standard are thermal stress, humidity, precipitation, wind, penetration and abrasion, and atmospheric pressure. Seven spheres of operations are delineated as follows (Ref. 31):

1. Operation, ground, worldwide
2. Operation, ground, arctic winter
3. Operation, ground, moist tropics
4. Operation, ground, hot desert
5. Operation, shipboard, worldwide
6. Operation, airborne, worldwide
7. Worldwide short-term storage and transit.

MIL-STD-210A currently is being revised. A revision, the B revision, has been undertaken in 1972-73 and, when published, will supersede revision A. This revision effort

TABLE 6-8.
TYPES OF ENVIRONMENTAL TESTS IN VARIOUS STANDARDS

	Vibration	Temperature	Humidity	Shock	Temperature/ Altitude	Altitude
MIL-STD-810	X	X	X	X	X	X
STANAG 3518	X	X	X	X	X	X
MIL-E-4158	X	X	X	X		X
MIL-E-5272	X	X	X	X	X	X
MIL-E-5400	X	X	X	X	X	X
MIL-T-5422	X	X	X	X	X	X
MIL-E-16400	X	X	X	X		X
MIL-T-21200	X		X	X	X	X
MIL-STD-202	X	X	X	X	X	X

was brought about by a vastly improved climatological data base, maturing concepts in the application of climatic information in design, and dissatisfaction with wording in the current issue.

An introductory paragraph to revision A reads, in part, as follows: "This standard indicates the probable extreme climatic conditions of the natural environment to which military equipment may be exposed and is intended to establish uniform limits not to be exceeded in normal design requirements." With this wording in the Introduction, the standard can be interpreted as a restriction for establishing design extremes not to be exceeded rather than a requirement that these extremes be the goals for military equipment, as was the original purpose of the drafters of the first edition. Preliminary drafts of the B revision indicate that the "purpose" will be reworded to read, in part, as follows (Ref. 32):

> "To establish mandatory requirements to be used as a basis for design of military materiel which must withstand and operate in the world-wide climatic extremes of the natural environment. These requirements are not necessarily testing criteria, but will serve as a basis for testing. This document does not apply in the design of materiel to be used only in specific locations.
>
> "When these requirements are impractical for a specific item of materiel, an exception or deviation must be identified and justified. This justification will include engineering studies showing savings involved in the acceptance of alternative, limiting extremes, and environmental studies showing the risk incurred by the acceptance of these alternatives."

The proposed B revision contains other fundamental and noteworthy changes in philosophy and content from the A revision. Major changes are discussed in the paragraphs that follow.

Extremes for only the unmodified, natural environment are included in the B revision. Revision A includes a set of extremes for short-term storage and transit that is now considered unrealistic and that significantly increases the difficulty and cost of equipment design.

Storage and transit extremes are too dependent upon physical properties of the equipment and conditions of exposure to be specified quantitatively in any standard. It is unrealistic to hope to specify the infinite number of intermediate, induced conditions that can occur in storage.

Extremes are separated into three parts: overland, maritime (over sea and coast), and upper air. Only one set of extremes for each part will be presented as opposed to regional breakdowns; e.g., arctic winter, hot desert, etc. These extremes are representative of the severest geographic areas but not of anomalous locations within those areas. Extreme values for several environmental factors deemed important in the design of some equipments are not included because of a lack of data. These are to be included in subsequent revisions as needs arise and data become available.

The two types of mandatory extremes used in the B revision are operating and withstanding, rather than operations and short-term storage in transit as currently used in the A version. Moreover, the risk policy is changed from extremes that are equaled or surpassed on 10 percent of the days (3 days) to 1 percent of the hours (7.4 hr) in the most severe month for most of the climatic elements (some exceptions have been recommended).

Extremes that have a near zero chance of being equaled or surpassed are to be provided as design goals for equipment when operational failure due to an extreme environment would endanger life. Furthermore, a set of less severe values with a greater likelihood of occurrence than the mandatory limits may be included in the B revision to provide guidance in requesting waivers.

Climatic extremes given individually in revision A frequently have been used jointly in equipment testing to provide so-called accelerated or aggravated tests. This practice frequently leads to conditions that involves many cycles of the simulated natural extremes, but imposed in much shorter time than would be encountered in nature. Accelerated tests provide some indication of the long-term tolerance of a piece of equipment; however, they do not include highly controlled correlations determined in the laboratory. However, aggravated tests utilizing extremes far beyond those occurring in nature should be used only when the results of the tests can be correlated to degradation in the natural environment from past investigations for the specific class of items being tested (Ref. 32).

6-5.2 MIL-STD-810, ENVIRONMENTAL TEST METHODS

MIL-STD-810, *Environmental Test Methods*, establishes uniform environmental test methods for determining the resistance of equipment to the effects of natural and induced environments peculiar to military operations (Ref. 33). It evolved from an obvious need to upgrade existing environmental test procedures and criteria and to establish a single standard environmental test document.

Numerous standardization documents were reviewed during its preparation and three, in particular, are reflected in MIL-STD-810. These are MIL-T-5422F(AS), *Testing, Environmental, Airborne, Electronic, and Associated Equipment;* MIL-E-5272C(ASG), *Environmental Testing, Aeronautical and Associated Equipment, General Specification for;* and MIL-E-4970, *Environmental Testing, Ground Support Equipment* (Refs. 34-36). MIL-E-4970 was cancelled subsequent to the publication of the B revision of MIL-STD-810, and both MIL-E-5272 and MIL-T-5422 are inactive for new designs that should use MIL-STD-810. MIL-STD-810 includes 19 environmental test methods applicable to most military materiel and recommends a test sequence to be followed for each category. Specific items of materiel referenced in the standard are all ground equipment for both sheltered and unsheltered use; aircraft and missile support equipment for outdoor use; electrical, electronic, and communications equipment in both sheltered and unsheltered environments; and equipment installed in aircraft, helicopters, and air and ground launched vehicles. Additionally, guidance in testing satellites and space vehicles is included. The test methods included in MIL-STD-810 are tabulated in Table 6-7 (Refs. 33,37).

Revision C of MIL-STD-810 is currently in preparation which will significantly alter its format and its technical procedures. The present version will evolve into two separate documents with revision C. MIL-STD-810 will be issued as an upgraded environmental test methods document, and a new standard (proposed MIL-STD-811) will be issued as a test requirements document. This practice is in common use; e.g., MIL-E-5400 is an environmental requirements document and MIL-T-5422 is a related environmental testing document (Refs. 38,34). The environmental requirements document will include a description of the environmental conditions under which the equipment will be used, including the environmental extremes to be encountered during its life cycle. The requirements document will delineate between operating and withstanding environments and specify required environmental tests. The test methods document will include improved and upgraded test methods that are more readily adaptable to specific equipment requirements, an objective partially achieved in revision B. Additionally, detailed failure criteria that include failure mode descriptions and exact retest procedures have been proposed for the MIL-STD-810C/811 documents.

TABLE 6-7.
ENVIRONMENTAL TEST METHODS IN MIL-STD-810

Test Method	Environmental factor
500	Altitude
501	High temperature
502	Low temperature
503	Temperature-shock
504	Temperature-altitude
505	Sunshine
506	Rain
507	Humidity
508	Fungus
509	Salt fog
510	Dust
511	Explosive atmosphere
512	Leakage (immersion)
513	Acceleration
514	Vibration
515	Acoustical noise
516	Shock
517	Space simulation
518	Temperature-humidity-altitude
519	Gunfire vibration, aircraft

A difficulty frequently encountered in revising or consolidating environmental standardization documents is a lack of information concerning the origin of requirements and test limits. The MIL-STD-810 review committee has recommended that the background to all new requirements and test methods be documented, referenced in the Standard, and kept on file by the committee. This recommendation is not intended to prevent the inclusion of new concepts that are based on engineering judgment. In many cases engineering judgment is the only basis for including new concepts. The rationale for such inclusions should be documented, however, to enhance future revision efforts (Ref. 30).

6-5.3 MIL-STD-202, TEST METHODS FOR ELECTRONIC AND ELECTRICAL COMPONENT PARTS

MIL-STD-202 "establishes uniform methods for testing electronic and electrical component parts, including basic environmental tests to determine resistance to deleterious effects of natural elements and conditions" (Ref. 39). It is a basic environmental standardization document comparable to MIL-STD-810; however, it is specifically applicable to component parts, whereas MIL-STD-810 is applicable to materiel.

The test methods included in MIL-STD-202 are classified as environmental tests, physical characteristics tests, and electrical characteristics tests. Many of the physical characteristics tests are actually induced environmental tests and are tabulated along with the environmental tests in Table 6-8.

6-5.4 OTHER ASSOCIATED DOCUMENTS

MIL-T-5422F(AS), *Testing, Environmental, Airborne Electronic and Associated Equipment*, is a limited coordination Military Specification approved by the Naval Air Systems Command (Ref. 34). It contains procedures for the environmental testing of the subject equipment. This test method specification is inactive for new designs and MIL-STD-810 should be used instead. However, much materiel in the military inventory was qualified through the testing procedures in MIL-T-5422 and replacement parts will continue to be qualified by this document until this materiel is replaced. The environmental tests specified in this Specification are largely reflected and upgraded in MIL-STD-810 (Ref. 33).

MIL-E-5272C(ASG), *Environmental, Testing, Aeronautical and Associated Equipment, General Specification For*, is another limited coordination specification (Ref. 35). It is inactive for new design, but is still used in the procurement of replacement parts for the maintenance of military materiel. For new designs, MIL-STD-810 must be used in lieu of MIL-E-5272. Test methods comparable to those of MIL-E-5272 are included in MIL-STD-810 (Ref. 33).

MIL-STD-446, *Environmental Requirements for Electronic Parts*, "establishes uniform levels of environment and conditions that electronic parts will be exposed to

TABLE 6-8.
ENVIRONMENTAL TEST METHODS IN MIL-STD-202

Test method	Environmental factor
101	Salt spray (corrosion)
102	Temperature cycling
103	Humidity
104	Immersion
105	Barometric pressure (reduced)
106	Moisture resistance
107	Thermal shock
109	Explosion
110	Sand and dust
111	Flammability
112	Seal
201, 204, 214	Vibration
202, 205, 207, 213	Shock
212	Acceleration

in military service" (Ref. 40). It establishes environmental goals to be met in developing parts to meet military needs. It does not include test methods but rather references test methods from other documents.

A particularly useful feature of MIL-STD-446 is an appendix that provides guidance for determining the environmental requirements levels of component parts that are compatible with the parts application in military equipment. Seven categories of application are defined, and environmental factors characteristic of each category are tabulated. Table II of that appendix is included herein as Table 6-9.

These and many other standardization documents that relate to the environment are categorized and tabulated in Table 6-10. The Criteria, Terminology, and Test Method documents are limited in number, and their tabulations in the table are reasonably complete. Equipment specifications that contain environmental criteria are numerous, so that the tabulation of such specifications should be considered only as a sample.

6-6 STANDARDIZED ENVIRONMENTAL TESTS

Environmental tests are conducted to determine the effects of the environment on materiel. In keeping with the objectives of the Defense Standardization Program (DSP), many environmental tests have been standardized in military and other standards and specifications. These standardized tests are intended to reflect the natural and induced environments to which military materiel will be exposed. They are helpful at each of the life cycle phases and are mandatory upon the DOD departments.

Although numerous equipment specifications include environmental criteria, there are relatively few environmental test standards and specifications. As the DSP continues to evolve, it is likely that many will be cancelled in lieu of improved, more applicable documents. For example, MIL-T-5422 and MIL-E-5272 are reflected largely in MIL-STD-810 and are inactive for new designs.

Table 6-11 tabulates environmental factors for which standardized test procedures have been prepared. Applicable standards and specifications are included for each factor along with a brief statement of the test conditions. A brief discussion of each of these standardized environmental tests follows.

6-6.1 ALTITUDE (LOW PRESSURE)

Altitude or low pressure tests are conducted to determine the deleterious effects of low pressure on unpressurized aerospace and ground equipment. Ground equipment may be exposed to low pressure while being air transported or when operated at elevated ground sites. Unpressurized aerospace equipment is required to perform satisfactorily under all low pressure mission conditions. Low pressure problems evolved as aircraft began flying at altitudes higher than a few thousand feet above sea level. They vary in severity from the mild problems encountered by aircraft flying in the atmosphere of the earth to the severe ones encountered by space vehicles in the near-perfect vacuum of outer space (Ref. 33).

Low pressure test requirements for ground support in aerospace equipment are discussed in MIL-E-5272. A temperature of −54°C is specified, but various altitudes to 100,000 ft are given. MIL-T-5422 contains a temperature-altitude, mission-profile-type test with a choice of temperatures ranging from +260°C to −62°C and altitudes to 80,000 ft. In neither of these specifications is any mention made of dewpoint control. The low pressure test of MIL-STD-810 standardizes the wide spread of altitude and temperature requirements in existing equipment specifications and reconciles the differences in MIL-E-5272 and MIL-T-5422.

With the advent of space vehicles, no set limit short of a perfect vacuum can be

TABLE 6-9.
GROUP ARRANGEMENT OF ENVIRONMENTAL INTENSITIES (Ref. 40)

Environments	Application groups						
	Group I Ground level building, sheltered	Group II Ground level semisheltered in black boxes exposed to natural climatic environments	Group III Ground level unsheltered and exposed to natural and induced environment	Group IV Ground level semisheltered in black boxes exposed to increased natural and induced environment	Group V Altitude to 70,000 ft and nuclear radiation	Group VI Altitude to 50,000 ft, ballistic missiles and nuclear detonations	Group VII Altitude beyond 150,000 ft, outer space
Low temperature storage, hr at °C temp.	All groups, 48 hr at -65°C						
High temp. operation, hr at °C temp.	25 K†, 85°C	25 K, 85°C	10 K, 125°C	10 K, 150°C	1 K, 200°C	1 K, 200°C	1 K, 200°C
Temp. change, no. of cycles & temp. range	25, -65° to +85°C	50, -65° to +85°C	50, -65° to +85°C	100, -65° to +150°C	100, -65° to +150°C	250, -65° to +200°C	250, -65° to 200°C
*Pressure, atmospheric, hr & in. Hg	50 K, 28.58	50 K, 28.58	50 K, 28.58	100 K, 28.58	30 K, [illegible].31	30 K, 0.0402	30 K, 3.316 × 10^{-8}
*Pressure change, 1 in. Hg min^{-1}, or ft min^{-1}	NA	NA	NA	NA	1,000 ft min^{-1}	1,000 ft min^{-1}	1,000 ft min^{-1}
Humidity, hr & % RH	NA	Groups II through VII, 10 cycles (24 hr each) 98 % RH at -10° and +65°C					
Salt spray, hr & % solution	NA	Groups II through VII, 96 hr, 5 % salt solution					
Fungus, days, % solution & temp.	NA	Groups II through VII, 28 days, 95 % viable organisms at 29°C					
Sand & dust, velocity at 2 gr ft^{-3} density	NA	Groups II through VI, 2,500 ft min^{-1}					NA
Vibration, hr & frequency	6, 10-55 Hz	6, 10-55 Hz	6, 10-55 Hz	9, 10-500 Hz	12, 10-2,000 Hz	12, 10-2,000 Hz	12, 10-2,000 Hz
Shock, no. of blows & G	18, 50 G	18, 50 G	18, 100 G	18, 500 G	18, 1,500 G	18, 1,500 G	18, 1,500 G
Acoustical noise, hr & dB	All groups, 0.5 hr at 140-dB level						
Acceleration, min & G	30, 17 G	30, 17 G	30, 17 G	30, 100 G	30, 100 G	1, 10,000 G	1, 10,000 G
Ozone, hr & concentration	All groups, 3 hr, 0.010 to 0.150 % by volume						
Fire atmosphere, seconds resistance	All groups, 15 s resistance						
Explosive atmosphere, 12 to 1 vapor ratio	All groups, resistant to 10 K ft altitude and 26.7°C						

*Not applicable to shipboard applications which is sea level pressure
†K = 1,000

TABLE 6-10.
ENVIRONMENTAL STANDARDIZATION DOCUMENTS (Ref. 30)

Category/Document	Title
Environmental criteria	
1. MIL-STD-210	Climatic Extremes for Military Equipment
Environmental terminology	
1. MIL-STD-1165	Glossary of Environmental Terms (Terrestrial)
Environmental test methods	
1. MIL-STD-810	Environmental Test Methods
2. MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
3. MIL-STD-446	Environmental Requirements for Electronic Parts
4. MIL-T-5422	Testing, Environmental, Aircraft Electronic and Associated Equipment (Inactive for New Designs--use MIL-STD-810)
5. MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment, General Specification for (Inactive for New Designs--use MIL-STD-810)
Equipment documents, including environmental criteria	
1. MIL-T-8679	Test Requirements, Ground, Helicopter
2. MIL-T-7743	Testing, Store Suspension Equipment, General Specification for
3. MIL-T-8207	Test Procedure for Aircraft Pressurized Compartment
4. MIL-T-25920	Test, Ground and Flight, Aircraft Gas Turbine Propulsion System Installation
5. MIL-STD-108	Definition of Basic Requirement for Enclosure for Electric and Electronic Equipment
6. MIL-T-5920	Test, Aircraft Armament Installations and Accessories

TABLE 6-10 (Continued).
ENVIRONMENTAL STANDARDIZATION DOCUMENTS (Ref. 30)

Category/Document	Title
7. MIL-T-21200	Test Equipment for Use with Electronic and Fire Control Systems, General Specification for
8. MIL-STD-331	Fuze and Fuze Components Environmental and Performance Test for
9. MIL-STD-167	Mechanical Vibrations of Shipboard Equipment
10. MIL-STD-258	Test and Inspection of Trucks, Forklift, Self-side Loading, Gasoline
11. MIL-STD-259	Test and Inspection of Tractor, Wheeled, Warehouse, Gasoline and Electric
12. MIL-STD-261	Test and Inspection of Crane Truck, Warehouse, Gasoline, Pneumatic Rubber Tires
13. MIL-STD-262	Test and Inspection of Crane Truck, Warehouse, Electric, Solid Rubber Tires
14. MIL-STD-265	Test and Inspection of Truck, Fixed
15. MIL-STD-266	Test and Inspection of Truck, Fixed Platform, Powered Electric Pneumatic Rubber Tires
16. MIL-STD-267	Test and Inspection of Truck, Straddle-carry, Gasoline, Pneumatic Rubber Tires
17. MIL-STD-268	Test and Inspection of Truck, Lift, Fork
18. MIL-STD-735	Test Methods and Test Equipment for Thermometers used in Machinery and Piping Systems
19. MIL-STD-788	Test Requirements for Replenishment-at-sea
20. MIL-STD-858	Testing Standard for Personnel Parachutes
21. MIL-STD-872	Test Requirements and Procedures For Aircraft Emergency Ground and Ditch Escape Provisions
22. MIL-STD-888	Testing Program for Emergency Escape Capsule Recovery Systems
23. MIL-STD-448	Test Methods For Construction and Industrial Machinery

TABLE 6-10 (Continued).
ENVIRONMENTAL STANDARDIZATION DOCUMENTS (Ref. 30)

Category/Document	Title
24. FED-STD-191	Textile Test Methods
25. MIL-W-5522	Test Procedure for Aircraft Hydraulic and Pneumatic Systems
26. MIL-T-6780	Test Procedure in Electrical Installation Aircraft
27. MIL-T-152	Treatment, Moisture- and Fungus-Resistant, of Communication, Electronic, and Associated Electrical Equipment

specified for installed equipment operation. In consideration of this fact. Method 500, Procedure 2 of MIL-STD-810 simply states that the chamber internal pressure shall be reduced to the lowest pressure condition for which the test item is designed to operate while maintaining the specified temperature.

Currently, the Standards and Specifications pertinent for low pressure or altitude tests are MIL-STD-810, Methods 500 and 504; MIL-E-5272, Section 4.14; and MIL-T-5422, Section 1.4. The temperature-altitude test of MIL-T-5422 has been incorporated into the temperature-altitude test, Method 504, of MIL-STD-810. The requirement for conducting a corona or electric arc survey with the test item operating as pressure is increased is unique to MIL-STD-810. This survey is not included in MIL-E-5272 or MIL-T-5422.

These standards and specifications, in some instances, control both temperature and pressure. Low pressure can be included as part of any combined environmental tests; however, since the purpose of these tests is to attain the specified vacuum, other environments are either ignored or uncontrolled.

6-6.2 HIGH TEMPERATURE

The high temperature test is conducted to determine the resistance of aerospace and ground equipment to elevated temperatures that may be encountered during service life, either in storage with or without protective packaging or under service conditions. Many types of equipment are affected by high temperature, but not all in the same way. The high temperature test is recommended for all classes of aerospace and ground equipment. In the absence of well-defined system criteria regarding compartment temperatures, intended heat exchangers, ram air available for cooling, etc., general test procedures can give only general guidance and test levels for performing the average test. Test Method 504 of MIL-STD-810 recognizes the ever-increasing severity of equipment operating temperatures. Five equipment classes are identified in this standard, and tests are indicated that range from 55° to 260°C (131° to 500°F).

6-6.3 LOW TEMPERATURE

Low temperature testing is conducted to determine the effects of low temperature on aerospace and ground equipment. Low

TABLE 6-11.
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
1. Altitude (low pressure)	A. MIL-STD-810	
	1. Method 500 Procedure I	a. For ground equipment transport survival, high elevation, operating b. 50,000 ft, 1 hr, nonoperating c. 10,000 ft, operating
	2. Method 500 Procedure II	a. For airborne equipment, excluding space vehicles b. Specified low pressure, -54°C, 1 hr c. Test for arcing, corona during pressure changes
	3. Method 504	a. Altitude-temperature profile, to 8,000 ft, -62° to +260°C
	B. MIL-E-5272(ASG)	
	1. Procedure 4.14.1	a. Time-temperature-altitude profile requires several hours. b. To 50,000 ft, -54°C, operating if required by specifications c. To 40,000 ft, +30°C, cycle on-off d. To 50,000 ft, +35°C, operating e. Rates of pressure change limited
	2. Procedure 4.14.2	a. Specifies test chamber equivalent to MIL-C-7951 b. Test to applicable equipment specifications
	C. MIL-T-5422(AS)	
	1. Procedure 4.1	a. Composite test procedure including temperature b. Equipment categorized as to class, altitude range, mode c. Altitude-temperature-time profiles specified
	D. MIL-STD-202	
	1. Method 105	a. Test to 656,000 ft
	E. MIL-STD-446	a. Refers to MIL-STD-202 b. Sea level for shipboard equipment c. To 10,000 ft for ground equipment d. 100,000 to 250,000 ft; worst-case for corona and arc-over e. 875,000 ft for space effects

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
2. High temperature	A. MIL-STD-810	
	1. Method 501	a. Test to 71°C or to highest specified ambient temperature; maintain operating until stabilization reached. b. Temperature cycle operating to 68°C
	B. MIL-E-5272(ASG)	
	1. Procedure 4.1.2	a. Operating, 71°C, 48 hr
	C. MIL-T-5422(AS)	
	1. Procedure 4.1	a. Combined with altitude
	D. MIL-STD-446	a. Temperature-exposure time schedule
3. Low temperature	A. MIL-STD-810	
	1. Method 502	a. Test nonoperating to time-temperature in equipment specifications b. Test operating to equipment specifications low until temperature stabilization
	B. MIL-E-5272(ASG)	
	1. Procedure 4.2.1	a. Test operating to -54°C until temperature stabilization
	2. Procedure 4.2.2	a. Nonoperating to -62°C, 72 hr
	C. MIL-STD-446	a. References MIL-STD-202, Thermal Shock b. -65°C, 48 hr
4. Temperature Shock	A. MIL-STD-810	
	1. Method 503	a. Nonoperating, repeated cycle between +71° and -54°C ambient within 5 min. Maintain each extreme 4 hr.
	B. MIL-E-5272(ASG)	
	1. Procedure 4.3.1	a. Nonoperating, repeated cycle between +85° and -40°C ambient within 5 min
	C. MIL-T-5422(AS)	
	1. Procedure 4.9.3	a. Nonoperating, repeated cycle between +71° and -54°C

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
	D. MIL-STD-202	
	1. Method 107	a. Repeated cycle between specified temperature extremes within 2 min
	E. MIL-STD-446	a. Refers to MIL-STD-202, Method 107 b. Repeated cycles between specified maximum and minimum temperatures at 1 deg s^{-1} minimum
5. Sunshine	A. MIL-STD-810	
	1. Method 505	a. Specifies attributes of test facility b. Profile of radiant energy, ambient air temperature as functions of time specified
	B. MIL-E-5272(ASG)	
	1. Procedure 4.9.1	a. Radiant energy 100-140 W ft^{-2}; 50-84 W ft^{-2} below 7800 Å, 4-8 W ft^{-2} below 3800 Å b. 48-hr test, chamber temperature at 45°C
6. Rain	A. MIL-STD-810	
	1. Method 506	a. Specifies attributes of test facility b. Specifies schedule of rain rate (in./hr) and horizontal wind velocity
	B. MIL-E-5272(ASG)	
	1. Procedure 4.10.2	a. Specifies test chamber equal to MIL-C-8811 (obsolete) b. Droplet diameter greater than 1.5 mm c. Water supply between 11° and 20°C d. Rainfall to 45 deg from vertical e. Expose each of four sides for 30 min each f. Rain rate 4 in. hr^{-1}

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
7. Humidity	A. MIL-STD-810	
	1. Method 507 Procedure I	a. Specifies attributes of test facility
	2. Method 507 Procedure II	a. Specifies profile of humidity and temperature b. Includes operating test
	3. Method 507 Procedure III	a. Similar to Procedure II, for sealed equipment (not hermetically sealed).
	4. Method 507 Procedure IV	a. Specifies profile of humidity and temperature b. RH to 95%, temperature cycled to 60°C
	5. Method 507 Procedure V	a. Specifies profile of humidity and temperature
	B. MIL-T-5272(AGS)	
	1. Procedure 4.4.1	a. Specifies profile of humidity and temperature b. RH to 95%, temperature to 71°C
	2. Procedure 4.4.3	a. RH 95%, temperature 49°C, 360 hr
	C. MIL-E-5422(AS)	
	1. Procedure 4.4.3	a. Same as MIL-STD-810, Method 507, Procedure I
	D. MIL-STD-202	
	1. Method 103B	a. RH 90-95%, temperature 40°C b. Includes provisions for voltage excitation
	E. MIL-STD-446	a. Refers to MIL-STD-202, Method 103

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
8. Fungus	A. MIL-STD-810	
	1. Method 508	a. Specifies attributes of facilities and materials, i.e., mineral salts, reagents, water b. Specifies preparation of inoculum, identifies sources c. Test item placed in preconditioned facility, inoculated incubated (28 days), inspected
	B. MIL-E-5272(ASG)	
	1. Procedure 4.8	a. Specifies attributes of facilities and materials (chamber equal to MIL-C-9452 (obsolete) b. Specifies preparation of inoculum, identifies sources c. Test item inoculated, incubated (28 days), inspected
	C. MIL-T-5422(ASG)	
	1. Procedure 4.8	a. Specifies attributes of facilities and materials b. Specifies preparation of inoculum, identifies sources c. Test item inoculated, incubated (28 days), inspected.
	D. MIL-STD-446	a. Refers to MIL-STD-810, Method 508
9. Salt fog	A. MIL-STD-810	
	1. Method 509	a. An accelerated test b. Lists deficiencies and limitations c. Specifies facility attributes, preparation of salt solution (5 + 1%) d. Exposure to salt fog for 48 hr
	B. MIL-E-5272(ASG)	
	1. Procedure 4.6	a. References FED-STD-151, Method 811 b. Test periods of 50, 100, and 168 hr
	C. MIL-T-5422(AS)	
	1. Procedure 4.5	a. Similar to MIL-STD-810, Method 509

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
	D. MIL-STD-202	
	1. Method 101	a. Specifies test facility and materials b. 5% and 20% salt solutions, test periods of 48 and 96 hr
	E. MIL-STD-446	a. Refers to MIL-STD-202
	F. FED-STD-151	
	1. Method 811	a. Includes 5% and 20% solutions b. Same as ASTM-B-117 and ANSI Z118.1, 1966
10. Sand and dust	A. MIL-STD-810	
	1. Method 510	a. Specifies test facility attributes, sand and dust requirements; identifies sources b. Nonoperating; temp. 23°C (6 hr), 63°C (6 hr), RH < 22%, concentration 0.1 to 0.5 g ft^{-3}, wind velocity 1,500-2,000 ft min^{-1} c. Stop dust feed, reduce wind velocity, 100 to 500 ft min^{-1}, 6 hr
	B. MIL-E-5272(ASG)	
	1. Procedure 4.11	a. Specifies test facility equal to MIL-C-9436, sand and dust requirements; identifies sources b. Nonoperating; temp. 25°C (6 hr), 71°C (6 hr), RH 30%, concentration 0.1 to 0.5 g ft^{-3}, wind velocity 100 to 500 ft min^{-1}, 2,000 to 3,000 ft min^{-1} if specified
	C. MIL-T-5422(AS)	
	1. Procedure 4.7	a. Similar to MIL-STD-810 and MIL-E-5272
	D. MIL-STD-202	
	1. Method 110	a Same as MIL-E-5272
	E. MIL-STD-446	a. Refers to MIL-STD-202 b. Temp. 25°C (3 hr), concentration 0.1 to 0.25 g ft^{-3}, wind velocity 2,500 ft min^{-1} $\approx$ 28.4 mph

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Results
11. Explosive atmosphere	A. MIL-STD-810	
	1. Method 511 Procedure I	a. Specifies explosion-proof chamber equal to MIL-C-9435 b. Specifies gasoline grade 100/130 conforming to MIL-G-5572 c. Altitudes to 50,000 ft (10,000 ft for ground equipment), temperature to 71°C d. Test: Set altitude 10,000 ft above test altitude. Inject fuel (13:1 air: fuel ratio), reduce altitude 5,000 ft, operate test item, reduce altitude 10,000 ft e. If no explosion, proof test fuel by positive ignition
	2. Method 511, Procedure II	a. For explosion and flame arresting cases b. Apparatus and fuel as for Procedure I c. Test: Ignite fuel mixture inside test case d. Proof test fuel mixture external to test case by positive ignition
	3. Method 511 Procedure III	a. For shipboard equipment cases b. Test to MIL-E-2036
	B. MIL-E-5272(ASG)	
	1. Procedure 4.13	a. Same as MIL-STD-810, Procedures I and II
	C. MIL-T-5422(AS)	
	1. Procedure 4.6	a. Same as MIL-STD-810, Procedures I and II
	D. MIL-STD-202	
	1. Method 109A	a. Same as MIL-STD-810, Procedure I (taken from MIL-F-5272)
	E. MIL-STD-446	a. Refers to MIL-STD-202 b. Air/Fuel ratio, 13:1, 10,000 ft, 27°C

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Results
12. Leakage (Immersion)	A. MIL-STD-810	
	1. Method 512 Procedure I	a. Gross leak test b. Immerse 27°C test item in 18°C water for 2 hr c. Open, examine for leakage
	2. Method 512 Procedure II	a. Test for hermetic seals b. Immerse 23°C test item in 128°C oil (specified) for 60 s c. Observe leak as bubble stream
	B. MIL-E-5272(ASG)	
	1. Procedure 4.12	a. Immerse test item in suitable liquid (boiled ethylene glycol or water), reduce pressure above liquid b. Observe leak as bubble stream
	C. MIL-STD-202	
	1. Method 104A	a. Repeated cycles of immersion in hot and cold water (or salt solution) b. Test by measuring attributes
13. Acceleration	A. MIL-STD-810	
	1. Method 513	a. Centrifuge or track and rocket sled facility required
	2. Method 513 Procedure I	a. Structural test b. Specifies G-test levels when G-rating and orientation of test item known c. Specifies G-test level for categories of equipment when G-rating and orientation unknown d. Test period 1 min
	3. Method 513 Procedure II	a. Operating test b. Similar to Procedure I with lower G-levels specified

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Results
	B. MIL-E-5272(ASG)	
	1. Procedure 4.16.1	a. Centrifuge, operating, to equipment specifications b. Rotate 90 deg while maintaining acceleration
	2. Procedure 4.16.3	a. Centrifuge, 14 G and 6 G if orientation known b. Centrifuge, orthogonal 14 G if orientation unknown
	C. MIL-STD-202	a. Centrifuge, acceleration, and acceleration rates as per equipment specifications b. Gradient not to exceed 15% specified G-level
	D. MIL-STD-446	a. Refers to MIL-STD-202 b. Specifies worst-case mounting, test acceleration, and durations
14. Vibration	A. MIL-STD-810	
	1. Method 514	a. Test procedures for nine categories of equipment, including airborne, ground, shipboard b. Test profiles according to equipment location in aircraft, use conditions, mounting conditions. c. Resonance search and dwell tests d. Random vibration profile
	B. MIL-E-5272(ASG)	
	1. Procedure 4.7.2	a. For equipment mounted on reciprocating aircraft engines (excluding alternators and generators) b. Test profile for resonance search c. Test at resonances
	2. Procedure 4.7.4	a. For reciprocating engine aircraft b. Vibration error test for panel-mounted instruments c. Circular vibration mode, 0.009 to 0.011 in, 5-50 Hz
	3. Procedure 4.7.5	a. For reciprocating engine aircraft b. Vibration failure test for panel-mounted instruments c. Circular vibration mode, 0.018 to 0.020 in, 5-50 Hz, cycle each hour for 5 hr

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Results
	4. Procedure 4.7.7	a. Engine-mounted alternators and generators, reciprocating engine aircraft b. Resonance search, fundamental bending mode, 10-G peak, 100-500 Hz
	5. Procedure 4.7.8	a. Vibration endurance test for reciprocating engine-mounted alternators and generators b. Circular vibration mode, 15-G peak, 90-200 Hz, 24 hr.
	6. Procedure 4.7.12	a. For equipment mounted on gas-turbine engines, on structures of reciprocating engine, turbojet- or turbopropeller- driven aircraft, and on missiles powered by turbojet engines b. Tests include temperature extremes
	7. Procedure 4.7.13	a. For subassemblies for installation on resiliently mounted assemblies b. Resonance search c. 5-500 Hz
	8. Procedure 4.7.14	a. For equipment located in vicinity of exhaust cone (245°C) of turbojet engine or rocket engine. b. Test profile, 20-2,000 Hz
	C. MIL-T-5422(AS)	
	1. Procedure 4.2.2.1	a. Equipment normally mounted (vibration isolator, if any, in place) b. Resonance search c. Profile specified for resonance dwell tests
	2. Procedure 4.2.2.2	a. For vibration-isolated equipment, isolators removed b. Resonance search c. Profile specified for resonance dwell tests
	3. Procedure 4.2.3	a. Used in lieu of procedures 4.2.2.1 and 4.2.2.2, if specifically approved b. Profiles specified for: 1. Operating tests, normally mounted 2. Endurance tests, normally mounted 3. Operating tests, external isolator removed

TABLE C-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Results
	4. Procedure 4.2.4	a. For aircraft ground equipment b. Resonance search c. Profile specified for resonance dwell tests
	C. MIL-STD-202	
	1. Method 201A	a. Sinusoidal vibration, 0.03-in. peak. cycle 10 to 55 to 10 Hz in 1 min, 2 hr in each of 3 directions b. Test mode under electrical hood, if applicable
	2. Method 204B	a. High frequency method b. Lesser of 0.03-in. or 10-G peak, 10-500 Hz each axis, 3 hr logarithmic cycle c. Lesser of 0.03-in. or 15-G peak, 10-2,000 Hz each axis, 4 hr logarithmic cycle d. Method 201 followed by constant 10-G peak, 55-2,000 Hz, single sweep with dwell at resonances e. Lesser of 0.03-in. or 20-G peak, 10-2,000 Hz each axis, 3 hr logarithmic cycle f. Lesser of 0.03-in. or 50-G peak, 10-2,000 Hz each axis, 4 hr logarithmic cycle
	3. Method 214	a. Random vibration test profile, rms G to 44.8 and 5[illegible].1
15. Acoustical noise	A. MIL-STD-810	
	1. Method 515	a. Noise environment categorized, sound pressure levels and frequency specified for each category b. Sound pressure levels to 165 dB (referenced to 2×10^{-4} dyn cm^{-2}), frequencies to 11,200 Hz
	B. MIL-STD-5422(AS)	a. Specifies measurement of acoustical noise for human operator protection
	C. MIL-STD-446	a. References MIL-STD-810

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
16. Shock	A. MIL-STD-810	
	1. Method 516	a. Specifies instrumentation and calibration procedure b. Specifies shock pulse shape, amplitude, time duration c. Drop test for equipment packaged for transit d. Test for equipment mounting survival e. High-intensity test for high acceleration, short time duration shocks f. Bench drop test (servicing) g. Rail impact test h. Specifies MIL-S-901 for high impact, ballistic, and shipboard equipment shock tests
	B. MIL-E-5272(ASG)	
	1. Procedure 4.15.3	a. Specifies shock testing machine MIL-S-901 and applicable equipment shock specifications
	2. Procedure 4.15.4	a. Specifies equipment equivalent to JAN-S-44 (obsolete) and applicable equipment shock specifications b. Shock levels specified for use in lieu of equipment specifications
	3. Procedure 4.15.5	a. Specifies shock testing machine MIL-S-4456 (obsolete) b. Shock conditions specified
	4. Procedure 4.15.6	a. Crash safety tests (or equipment mounting survival), 30 G on attachment joints
	C. MIL-T-5422(AS)	
	1. Procedure 4.3.2.1	a. Specifies shock-pulse shape, amplitude, duration
	2. Procedure 4.3.2.2	a. Crash safety test (or equipment mounting survival), 30 G on attachment joints

TABLE 6-11 (Continued).
ENVIRONMENTAL FACTORS AND APPLICABLE STANDARDS AND SPECIFICATIONS

Environmental factor	Applicable standards and specifications	Remarks
	D. MIL-STD-202	
	1. Method 202	a. Superseded by Method 213 (31 Dec 1969) b. Includes detailed specifications for test apparatus c. Drop test specified
	2. Method 203	a. Specifications for random drop test apparatus and procedure
	3. Method 205	a. Superseded by Method 213 (31 Dec 1969) b. Includes detailed specifications for test apparatus c. Drop test specified
	4. Method 213	a. Shock waveforms, calibration procedures, instrumentation, and test procedures specified
17. Space simulation	A. MIL-STD-810	
	1. Method 517.1	a. Specifies apparatus: thermal-vacuum chamber, solar simulator, heat flux simulator b. Recommends pressure levels for simulating various effects c. Tabulates radiation characteristics of planets and solar electromagnetic energy distribution d. Provides guidance for planning and conduction of space simulation tests
18. Combination of temperature, altitude and humidity	A. MIL-STD-810	
	1. Method 518	a. Test profile for cycling with pressure, temperature, and humidity controlled

temperature is encountered from ground level to all altitudes. As a result of the low temperature testing experience gained in the past, and based upon criteria established in MIL-STD-210, the following conditions are established as standard:

(1) −62°C (−80°F) for transportation and storage

(2) −54°C (−65°F) for worldwide operations

(3) −40°C (−40°F) for operation in continental United States

(4) +2°C (+35°F) for equipment operated in temperature controlled areas.

The low temperature testing specified in MIL-STD-810 provides the lowest natural temperature conditions that aerospace and ground equipment can be expected to experience except for possible extreme conditions in the Antarctic or operations involving cryogenic fluids. MIL-E-810 is basically a combination of MIL-E-4970, which it supersedes, and MIL-E-5272C. It takes into consideration the lowest temperature under which the test item is designed to operate. MIL-STD-810 requires the minimum exposure of not less than 48 hr to a temperature of −62°C (−80°F). It is reasoned that, for all practical purposes, most test items would have reached stabilization after 48 hr and that little could be gained by exposure for an additional 24 hr. However, experience has shown that some massive test items actually do require up to 72 hr to reach a practical degree of stabilization. Also, congealing of oils and greases is a progressive action extending over hours or days. Differential contraction and other low temperature effects cannot be complete until stabilization at a low temperature is complete. The exposure time of a low temperature test must be sufficiently long to insure that the effects that will occur during operational use will also occur during the test. Investigation of changes in organic materials (such as lubricants, plastic, and rubber) and test experience have indicated that 72 hr is usually a correct time duration (Ref. 32).

The rapidly expanding use of cryogenic fluids has opened a whole new area of low temperature operations. Cryogenic engineering has developed as a specialized field of knowledge. Items such as pumps, valves, storage vessels, and connecting pipes are designed and used according to cryogenic practices. These items are tested by installing them in cryogenic systems. Test Method 517 of MIL-STD-810 requires a test chamber wall temperature of −195°C (−320°F). This is the only current, general environmental test procedure that requires use of cryogenic temperatures.

6-6.4 TEMPERATURE SHOCK

The temperature shock test is conducted to determine the effects on aerospace and ground equipment of sudden changes in temperature of the surrounding atmosphere. Cracking or rupture of material due to sudden dimensional changes—by expansion or contraction—are the principal difficulties to be anticipated. This could occur in service to aerospace equipment during rapid altitude changes and whenever ground equipment is moved from heated storage buildings to low temperature or outdoor areas or vice versa. An item of equipment may be exposed to the heat of the desert and tropics on the ground and to the low temperature of high altitude a few minutes later. It is possible, for example, for an item of equipment to be subjected to a maximum ambient temperature traverse of 125 deg C (225 deg F) within a few minutes. This rapid change of ambient temperature in an item of equipment, known as temperature shock, may cause malfunctions.

The temperature extremes specified for thermal shock tests are not intended to be in agreement with temperature extremes specified for high and low temperature tests. The extremes specified for thermal shock tests are intended to provide for a thermal traverse of 125 deg C within a few minutes (Ref. 37).

6-6.5 TEMPERATURE-ALTITUDE (CYCLING)

The temperature-altitude test applies to aerospace equipment and is conducted to determine the ability of such equipment to operate satisfactorily under simultaneously applied varying conditions of low pressure, high and low temperature, and high relative humidity. The temperature-altitude test and low temperature solar energy test of MIL-STD-810 are the only tests in present environmental test standards and specifications that attempt to accomplish a combined or mission profile type test. The test combines over a specified time period, high humidity, temperature extremes, low pressure, and equipment on off-duty cycles. Only the absence of the temperature shock, mechanical shock, vibration, acceleration, and explosive atmosphere in environments prevents this procedure from being a total mission profile test.

This test differs from the low pressure (altitude) tests discussed in par. 6-6.1 by the addition of humidity as an environmental factor. With the introduction of humidity, the formation and melting of frost during cycling from low to high temperatures is an added factor.

6-6.6 SUNSHINE (SOLAR RADIATION)

The sunshine test is conducted to determine the deleterious effects of radiant energy on aerospace and ground equipment. The sunshine test is applicable to any item of equipment that may be exposed to sunshine during service at the surface of the earth or in the lower atmosphere (below 100,000 ft). For the purposes of this test, only the terrestrial portion of the solar spectrum is considered. The effects of solar radiant energy may be divided into two general classifications—heat effects and photochemical effects. Heat effects on exposed equipment can raise the internal temperature of the equipment substantially above the ambient temperature. The photochemical effects of sunshine may cause fading of colors, deterioration of paints, plastics, fabrics, and natural rubber.

The solar spectrum and energy distribution within the spectrum have been measured scientifically and accurately. It is difficult, however, for state-of-the-art energy sources to match perfectly this spectrum and energy distribution. The present test simulates the radiant heat effects of natural sunshine.

In a sunshine test, the heat effect is due to radiation. It is directional and produces temperature gradients through the test item. The temperature will vary from a low, equal to ambient air temperature, to a high, many degrees above ambient.

Although the sunshine test rarely is performed in combination with other environmental tests, the following relationships can exist:

(1) *Sunshine and fungus.* Because of the resulting heat from solar radiation, this combination probably produces the same combined effects as high temperature and fungus.

(2) *Sunshine and sand and dust.* It is suspected that this combination will produce high temperatures.

(3) *Sunshine and vibration.* Under vibration conditions, solar radiation deteriorates plastics, elastomers, oils, etc., at a higher rate. The sunshine tests are applicable to equipment that may be exposed to solar radiation during service or unsheltered storage at the surface of the earth or in the lower atmosphere (Ref. 37).

6-6.7 RAIN

The rain test is conducted to determine the efficiency of protective covers or cases designed to protect equipment from the elements. This test is applicable to all items of unsheltered ground equipment and may apply in certain special cases to sheltered and vehicle-installed equipment. The simulated rain, as used in this test, is not wind driven and, therefore, is unsatisfactory as a rain-erosion test. Rain-erosion testing of items such as radomes and nose cones requires special test procedures.

The rain test has not been impeded through a lack of knowledge of the environment, effects, and measurements, but rather in the lack of development of a facility capable of simulating natural rainfall. A satisfactory facility has now been developed and is described in MIL-C-8811, *Chamber, Rain Testing* (Refs. 37,41).

Rain, as a source of moisture or humidity, will promote the growth of fungus. In general, rain as an environmental factor is seldom considered as having a definite relationship to the other environmental tests.

6-6.8 HUMIDITY

The humidity test is conducted to determine the resistance of equipment, components, and systems to the effects of exposure to warm, humid atmospheres such as encountered in tropical areas. The descent of aircraft from the cold, upper atmosphere to the surface of the earth also causes moisture problems even in temperate climates.

Present day standards and specifications for humidity tests have evolved through a long history of comparison studies. These are accelerated environmental tests, accomplished by the continuous exposure of the test item to high relative humidity at elevated temperatures. These conditions impose a vapor pressure on the equipment under test that constitutes the major force behind moisture migration and penetration.

It is reasonable to expect that a test item that corrodes when subjected to one of these humidity tests would sooner or later corrode in a natural tropical environment. The same item also would probably corrode after repeated exposure to water condensation upon return of an aircraft from the cold regions of the atmosphere to a warm, humid landing area. Experience has shown that the humidity test is one of the more difficult environmental tests for an item of equipment to pass (Ref. 37).

Humidity combined with high temperature and sand and dust will also promote the growth of fungus. Humidity is a requirement of fungus and the salt fog test. Corrosion of structural metallic parts resulting from humidity will accelerate failure when the test item is subjected to vibration and mechanical shock (Ref. 37).

6-6.9 FUNGI

The fungi test is conducted to determine the resistance of equipment to fungi and to determine if such equipment is affected adversely by fungi. The test involves exposure of components, equipment, and materials to fungi in an environment highly conducive to fungous growth.

The fungi test procedures in current use are the result of both experiment and experience. Fungi are living organisms whose growth rate can be accelerated only slightly and whose sensitivity to various environmental factors cannot be controlled directly. This places certain limits on test conditions that cannot be changed arbitrarily. The temperature and relative humidity used for the test provide optimal or near optimal growth conditions for the fungi specified. Experience has shown that the specified length of time is necessary for valid test results. In most cases the cost of continuing a test for 28 days is low compared to the cost of failure of the item in the operational environment. After a period of time, the action of moisture and bacteria may cause conditions that will support fungous growth where it would not have occurred before. The fungi test merely indicates that an item can resist fungous growth for a time equal to the duration of this test. The test item may or may not remain free of fungous growth for longer periods of time in actual service. However, some indication of fungous resistance is highly desirable for military hardware.

Although materials that support fungous growth are known and can be avoided in the construction of equipment, the equipment should still be subjected to a fungi test to assure that no fungi-supporting material has been inadvertently used. Subjection of equipment or systems to a fungi test also will help demonstrate the general suitability of the test item for use in tropical areas.

Recent reports have indicated that bacterial and fungous growth still occurs in fuel tanks. Fungi testing of all parts and components used in fuel systems would help solve this problem.

Conspicuously missing from the present fungi test criteria is a clear definition of what constitutes failure. This is not easy to determine because of the complicating corrosive effects of high humidity.

The fungi test can also be considered a humidity test for many items. However, the constant temperature and relative humidity conditions of the fungi test do not provide the breathing of equipment which occurs during a humidity test in which the temperature is cycled. Another difference between the fungi test and the humidity test is that temperatures of up to 160°F are used in the humidity test compared to a temperature of 86°F used in the fungi test. It might be found that 28 days of low altitude temperature cycles around 86°F would provide corrosion as great as that produced during the 10 days of the present humidity test.

Typical materials that will support and are damaged by fungi are cotton; wood; linen; cellulose nitrate; regenerated cellulose; leather; paper and cardboard; cork; hair and felt; natural rubber; plastic materials containing linen, cotton, or wood flour as a filler; plastic films containing fungi-susceptible plasticizers, and elastomers containing fungi-susceptible catalysts, plasticizers, or fillers (Refs. 33,37).

6-6.10 SALT FOG

The salt fog test is conducted to determine the resistance of equipment to the effects of a salt atmosphere. Damage to be expected from exposure to salt fog is primarily corrosion of metals, although in some instances salt deposits may result in clogging or binding of moving parts. In order to accelerate this test and thereby reduce testing time, the specified concentration of moisture and salt is greater than is found in service. The test is applicable to any equipment exposed to salt fog in storage or service conditions. Military operations have revealed serious damage to metallic components and equipment from salt fog.

The salt fog test is the oldest of the environmental tests dating back to 1914. It has a long history of development directed toward standardizing test conditions to obtain better correlation among different laboratories conducting these tests. In addition to being the oldest environmental test, it is probably the most controversial. The salt fog test currently in use reproduces the natural forces of saline deterioration in kind if not in degree, and the usefulness of the test for evaluation of equipment is dependent to a considerable degree upon the skill and knowledge of the evaluator.

The question of correlation of laboratory tests with natural environments is raised constantly. The prospect of devising a uniform laboratory procedure that would exactly simulate a complex variable such as worldwide natural marine atmosphere is remote. An incalculable amount of time and money already has been spent for this purpose.

Experience has shown that a direct relationship seldom exists between resistance to salt spray corrosion and resistance to corrosion in other media. However, some idea of the relative service life and behavior of different samples of the same or closely related metals or of protective coating-base metal combinations in marine and exposed seacoast environments can be gained by means of a salt spray test. It is especially helpful as a screening test for revealing inferior coatings.

6-6.11 SAND AND DUST

The sand and dust test is used during the development, test, and evaluation of equipment to ascertain its ability to resist the effects of sharp-edged, fine sand and dust particles which may penetrate into cracks, crevices, bearings, and joints and cause a variety of damage fouling of moving parts, making relays inoperative, and acting as a nucleus for the collection of water vapor. It is applicable to all mechanical, electrical, electronic, electrochemical, and electromechanical devices for which exposure to the effects of dry sand- and dust-laden atmosphere is anticipated. Because of the abrasive character of sand and dust, items of hardware having moving parts are particularly vulnerable. Aircraft engines are particularly vulnerable to sand and dust entering through unprotected air intakes (Ref. 37).

6-6.12 EXPLOSIVE ATMOSPHERE

The explosive atmosphere test is conducted to determine the ability of equipment to operate in the presence of an explosive atmosphere without creating an explosion or to contain an explosion occurring inside the equipment. Equipments that are to operate in potentially explosive atmospheres are operated in the presence of the optimum fuel-air mixture that requires the least amount of energy for ignition. The igniting energy may be produced electrically, thermally, or chemically. These items, therefore, are tested by operating them in ignitable fuel-air mixtures in a test chamber to insure that the item will not ignite the optimum fuel-air mixtures.

Explosive atmosphere tests have evolved from extensive research and experimentation. These results are reflected in the requirement for the use of aviation gasoline and the slowly varying altitudes, both above and below the test altitude.

The explosive atmosphere tests are intended primarily for use with flight vehicles. Ground equipment used in or near vehicles also are tested in accordance with this procedure, except that the specified altitude survey need be conducted only to 10,000 ft (Ref. 37).

6-6.13 IMMERSION (LEAKAGE)

The immersion test determines the ability of an equipment to be immersed in fluid without leakage of the fluid into the enclosure. It is conducted to determine the integrity of hermetic and gasket seals and is applicable to all equipment incorporating such features.

The validity of any immersion or leakage test as an environmental test has been questioned. It is argued that the immersion test must be made by the equipment manufacturer as a part of his production line quality control and should be specified in detailed equipment specifications (Ref. 37).

6-6.14 ACCELERATION

The acceleration test determines structural soundness and satisfactory performance of equipment in an environment of steady-state acceleration other than gravity.

The acceleration test contained in MIL-STD-810 for equipment encompasses the general requirements of preceding acceleration tests; e.g., MIL-E-5272, such as test time duration, minimum size of centrifuge, axes, and directions of mounting the test item. Determination of test levels was based on the assumption that in most cases the thrust and thus the acceleration is one of the initial parameters determined or specified in the planning or development of a weapon system or aerospace vehicle. These determinations usually are reached long before the development of supporting hardware. Therefore, when the design factors are specified for the supporting equipment, the location and G-levels anticipated would be known. The multipliers given are based on actual data gained from past experiences. The envelopes given represent the approximate severity of the upper quartile of data considered and do not cover extreme or unusual environmental conditions. It is emphasized that these data are not definitive or mandatory. The envelopes are presented as suggested G-level estimates that are considered reasonable in the absence of known data.

Acceleration is closely related to any other environment that can change stress levels or induce motion into the test item. Further, sustained acceleration usually intensifies–or even accelerates–effects of other environments such as vibration, noise, and shock. Temperature gradients and extremes also should be considered as a related environment. Any environment that can affect the stress-resisting ability of the test item–such as abrasion, salt fog, particle impacts, and sputtering–should not be ignored. These related environments should be considered seriously for inclusion as applicable in any test involving sustained acceleration. It is only through such a combined test that a true assessment can be made of an equipment as related to its intended mission (Ref. 37).

6-6.15 VIBRATION

The vibration test is conducted to determine that the equipment is constructed to withstand expected dynamic vibrational stresses and that performance degradations or malfunctions will not be produced by the simulated service vibration environment. Vibration effects are difficult to anticipate because of the problem in analyzing attenuation or amplification of applied loads. Anything that can conceivably shake or jar loose is suspect.

Applicable standards and specifications address themselves to vibration problems. Vibrational characteristics of reciprocating and jet engines differ significantly, for example, as do the characteristics likely for naval requirements and ground support equipment. The latest environmental test standard, MIL-STD-810, attempts to reconcile the differences among earlier specifications (Ref. 33). MIL-STD-810 also includes new criteria for ground- and air-launched missiles and space vehicles which, prior to its publication, had not been considered.

Certain newly developed vibration criteria are unique to MIL-STD-810. For example, a set of vibration test curves is offered which varies in severity, depending upon the location of the equipment within the vehicle. Also included is a new requirement that the test item demonstrate proper operation during vibration cycling and resonance dwell–ground-launched missiles excepted. Air-launched missiles are considered for the first time in the vibration test. During the first test phase, the missile is exposed to a vibration test such as that imposed on the equipment located within the aircraft. This is justified by the fact that the missile is attached directly to the aircraft and is essentially a piece of aircraft hardware until it is launched.

The vibration test curves of MIL-STD-810, intended for testing aircraft hardware, are similar to the curves of previous specifications. The frequency range of applied vibration is still 5 to 500 Hz for all test curves except for equipment to be mounted directly onto an aircraft engine. The 500-Hz frequency limit has been retained because the vast majority of measured data recorded at various equipment locations throughout modern aircraft have indicated insignificant amplitudes at higher frequencies. The test curve required for engine-mounted hardware extends to 2,000 Hz because significant amplitudes have been recorded on some new higher thrust engines within this extended frequency range. The test curves for equipment to be installed on helicopters were basically unchanged from earlier specifications (MIL-T-5422). Data recorded aboard recently developed helicopters did not indicate a need for change (Ref. 33).

6-6.16 ACOUSTICAL NOISE

The acoustical noise test is conducted to determine the effects on equipment of sound fields that are characteristic of aircraft, missiles, and other such producers of high sound levels. In general, equipments located in areas where noise levels are 130 dB overall or less will not require testing in noise environments. The acoustic noise test is not intended to be a substitute for the conventional sinusoidal or random vibration test when specified in equipment specifications. A reverberation-type test chamber is required—one that is suitably formed and proportioned to produce as closely as possible a diffuse sound field, the sound energy density of which is very nearly uniform throughout the enclosure—along with acoustical generation, reproduction, and measuring equipment suitable to accomplish these tests.

American National Standard S1.1., *Acoustical Terminology* (including mechanical shock and vibration) includes a comprehensive list of standard terminology pertinent to acoustical noise tests (Ref. 42).

Equipments that are sensitive to vibration are usually sensitive to sound field exposure. For this reason, a suitable vibration test is often a good indicator of acoustic sensitivity. However, it is possible that high frequency resonances of some responding equipment elements may be overlooked during the vibration test due to the high frequency limitation of the shaker and vibration attenuation of the test jig in the equipment under test. Further, vibration isolators can be used to protect equipment from vibration transmitted through the vehicle structure to the various equipments. An intense sound field, such as that generated by jet and rocket engines, can excite the structures on which an equipment is mounted or can result in air-induced vibration that impinges directly on the surface of the equipment.

Analysis of acoustic noise fields reveals frequencies of at least 3,000 Hz and greater. For bulky test loads, the generation of these high frequencies often exceeds the simulation capability of vibration shakers. The energy developed at these high frequencies can have destructive effects on small or miniaturized devices containing components with high, natural frequencies and low internal damping. Examples of such microphonic devices are electron tube elements, piezoelectric crystals, semiconductor devices, and miniaturized relay parts.

Acoustic tests can be especially valuable in the higher frequency regions; i.e., above 500 Hz. When the test item is mounted directly to a shaker table, energy will be introduced only through the test item mounting lugs. It cannot be assured that the high frequency input at the mounting lugs will be transmitted without attenuation to small parts within the test item that may be susceptible to high frequency excitation. A high frequency sound source, on the other hand, may impress the vibration field directly on the part.

Equipments with properties that are insensitive to acoustical noise are those having small surface areas, high mass-to-volume ratios and high internal damping. Examples are:

(1) High density modules, particularly the solid or encapsulated types

(2) Modules or packages with solid-state elements mounted on small, constrained, or damped printed-circuit boards or matrices

(3) Large masses—such as valves, hydraulic servo controls, and auxiliary power unit pumps

(4) Equipments surrounded by heavy metallic castings, particularly those that are

potted or encased within the casting by attenuating media.

Equipments with sensitive properties are those normally classified as being microphonic and those having large compliant areas of exposure, low mass-to-area ratios, and low internal damping. Examples are:

(1) Equipment with high frequency resonances, such as electron tubes, waveguides, klystrons, piezoelectric components, and relays attached to thin plate surfaces

(2) Equipments containing or consisting of exposed diaphragmatic elements such as pressure-sensitive transducers, valves, switches, relays, and flat, spiral antenna units (Ref. 32).

6-6.17 SHOCK

The shock test is conducted to determine that structural integrity and performance of equipment are satisfactory with respect to the mechanical shock environment expected in handling, transportation, and service use.

The service and transportation environment consists of a great variety of mechanical shocks, many of which can be severe enough to damage equipment. Rough handling shocks caused by production line handling, transportation handling, warehouse handling, and handling by service and maintenance personnel are a serious problem. Rough landing and crash landing impacts in aircraft provide two different conditions to be safeguarded against. Staging shocks caused by explosive separation in space vehicles provide a wide range of input shocks plus many other types of shocks. MIL-STD-810 includes three major departures from previous military specifications. The most important departure was the removal of requirements for use of specific shock machines. Instead of specifying the machine, a waveform is specified. As a result, a large variety of shock machines capable of producing the specified shocks have evolved. Some of these machines are great improvements over those previously specified in military specifications.

Another important departure from previous specifications is in the specification of certain characteristics of the measuring system, including frequency response. This is an important advance in specifying shock tests because it recognizes the important role that instrumentation plays in shaping the recorded pulse. These requirements are meant to provide a maximum fidelity record of the shock motion. This eliminates past practice of shaping the output signal to resemble a half-sine wave with a low pass or bandpass filter. Another important departure from previous specifications is the introduction of the high intensity 100-ms terminal peak, sawtooth shock test.

6-6.18 SPACE SIMULATION

Space simulation tests are intended for the evaluation of space vehicle components, space vehicle subsystems, and complete space vehicles, including installed equipment. These tests are conducted to determine whether space vehicles such as satellites, spacecraft, space stations, and associated equipment can withstand the deleterious effects of very low pressure, low temperatures, and solar radiation. One of the major problems encountered in space simulation is to provide in one facility all of the environments to be encountered by space vehicles from launch to landing. Some environments of space, such as weightlessness and micrometeoroid hits will be extremely difficult, if not impossible, to obtain in an earth-bound laboratory.

Test Method 517.1 of MIL-STD-810 is the only military standard intended for general usage to contain a test procedure for some of the space environments. It is intended only for general guidance and for a means of focusing attention on the problems that should be considered.

6-6.19 SUMMARY

The environmental tests included in present standards and specifications do not comprise all of the required testing of a complete system to the gamut of terrestrial and space environments. Tests involving weather—e.g., wind, snow, hail, sleet, and lightning—are not included in such standards and specifications. Such tests are accomplished through actual flight testing and exposure at outdoor sites or in all-weather, climatic facilities. The environmental tests discussed in standards and specifications are treated, for the most part, as individual stresses. With the exception of the temperature-altitude test and the low pressure, solar energy test, procedures as now organized do not intentionally combine two or more environmental factors for the purpose of determining mutually debilitating effects.

REFERENCES

1. *Cataloging and Standardization Act*, United States Code, Title 10, Chapter 145, Sections 2451-6, 1952.
2. *Defense Standardization Manual*, 4120.3-M, *Standardization Policies, Procedures and Instructions*, Dept. of Defense, Washington, D.C., January 1972.
3. *Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, Pa. (published annually).
4. W. J. Slattery, Ed., *An Index of US Voluntary Engineering Standards*, NBS Special Publication 329, National Bureau of Standards, Washington, D.C., March 1971.
5. J. E. Hartman, *Directory of the United States Standardization Activities*, NBS Misc. Publication No. 288, National Bureau of Standards, Washington, D.C., August 1, 1967.
6. E. J. Struglia, *Standards and Specifications Information Sources*, Gale Research Company, Detroit, Mich., 1965.
7. *Index of Federal Specifications and Standards*, General Services Administration, Federal Supply Service, Washington, D.C. (published annually).
8. *Index of Specifications and Standards* (DODISS), Dept. of Defense, Washington, D.C. (published annually).
9. *Catalog*, American National Standards Institute, N.Y. (published annually).
10. D. L. Peyton, "ANSI: Consensus Agency for Voluntary Standards", Defense Management Journal, 9, No. 2 (April 1973) pp. 41-5.
11. W. L. Fleischmann, "Specifications...Their Preparation and Use. A Challenge to the Engineering Profession", *Metal Progress*, September 1967.
12. J. B. Rather, "General Relationship of Technical and Professional Societies and Trade Associations in the Standardization Field", Materials, Research, and Standards, 5, No. 6 (1965).
13. *Encyclopedia of Associations*, Vol. 1, *National Organizations in the United States*, 7th Edition, Gale Research Co., Detroit, Mich., 1972.
14. *Federal Register*, May 28, 1970.
15. *Voluntary Product Standard:* PS-0-70, *Editorial Format for Voluntary Product Standards*, Office of Engineering Stan-

dards Services, National Bureau of Standards, Washington, D.C., March 1971.

16. *Fundamentals of Specifications*, USALMC-ST-38-50A, US Army Logistics Management Center, Fort Lee, Va., 1967 (AD-495 090).

17. O. Sturen, "Towards International Standardization", National Bureau of Standards Technical News Bulletin, 56, No. 10 (October 1972).

18. W. A. McAdams, *International Standards: The Impact on US Business*, American National Standards Institute, N.Y., April 1972.

19. *The ABC's of International Standardization*, The American National Standards Institute, N.Y., April 1972.

20. Newsweek, LXXXI, No. 1 (January 1, 1973), p. 25 (quoting Ulrich de Maiziere, Generalinspektor der Bundeswerks, West Germany).

21. *Federal Property and Administrative Services Act*, United States Code, Title 40, Chap. 10, Sect. 471-524, 1949.

22. *Federal Standardization Handbook, Federal Property Management*, FPMR Regulations 101-129, General Services Administration, Washington, D.C., 1965.

23. *Guide to Specifications and Standards of the Federal Government*, General Services Administration, Washington, D.C., June 1969.

24. *Defense Standardization Program*, DOD Directive, 4120.3, Washington, D.C., January 13, 1967.

25. R. A. Elwell, *An Introduction to Defense Standardization*, Tech. Report 71-28-QAO, US Army Natick Laboratories, Natick, Mass., December 1970 (AD-717 559).

26. MIL-STD-490, *Specification Practices*.

27. *Formulation of Specifications*, USALMC-ST38-51, US Army Logistics Management Center, Ft. Lee, Va., October 1963 (AD-495 089).

28. MIL-STD-143, *Standards and Specifications, Order of Precedence for the Selection of*.

29. H. C. Schafer, "Some Thoughts on RDT&E Environmental Theory Related to Propulsion Systems", *Proceedings*, Institute of Environmental Sciences, Mt. Prospect, Ill., 1970.

30. D. Earls, "Progress Report on New Developments in MIL-STD-810", *Proceedings*, Institute of Environmental Sciences, Mt. Prospect, Ill., May 1972, pp. 158-161.

31. MIL-STD-210, *Climatic Extremes for Military Equipment*.

32. R. V. Cormier and N. Sissenwine, "Climatic Extremes for Military Equipment: MIL-STD-210B", *Proceedings*, Institute of Environmental Sciences, Mt. Prospect, Ill., May 1972.

33. MIL-STD-810, *Environmental Test Methods*.

34. MIL-T-5422, *Testing, Environmental, Airborne, Electronic, and Associated Equipment*.

35. MIL-E-5272, *Environmental Testing, Aeronautical and Associated Equipment, General Specification for*.

36. MIL-E-4970, *Environmental Testing, Ground Support Equipment*.

37. V. J. Junker, *The Evaluation of USAF Environmental Testing, AFFDL-TR-65-197, Air Force Flight Dynamics Lab*, Wright-Patterson Air Force Base, Ohio, October 1965 (AD-625 543).

38. MIL-E-5400, *Electronic Equipment, Airborne, General Specification for.*

39. MIL-STD-202, *Test Methods for Electronic and Electrical Component Parts.*

40. MIL-STD-446, *Environmental Requirements for Electronic Parts.*

41. MIL-C-8811, *Chamber, Rain Testing.*

42. *Acoustical Terminology*, S1.1, American National Standards Institute, N.Y., 1960.

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